FARM-LEVEL CONSTRAINTS TO HIGH RICE YIELDS IN ASIA: 1974-77

International Rice Research Institute

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FARM-LEVEL CONSTRAINTS TO HIGH RICE YIELDS IN ASIA: 1974-77

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The responsibility for this publication rests with the International Rice Research Institute.

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Foreword

Convincing evidence shows that the yields of Asian rice farmers would be substantially higher if they took full advantage of the new rice technology. But even in areas where modern varieties are used, farmers' yields are frequently lower than they could be. The constraints studies reported in this volume have attempted to determine why rice farmers are continuing to produce less than the known potential.

A network of cooperating researchers from Thailand, Indonesia, Sri Lanka, Bangladesh, Taiwan, and IRRI was organized in late 1974 to jointly plan and conduct coordinated studies of the constraints that keep rice yields on farmers' fields low. The papers in this volume, originally presented at a workshop in April 1978, form a comprehensive report of the results of the network's studies.

The lead paper by Randolph Barker reviews the constraints problem as conceptualized by various researchers and recounts the rationale underlying the formulation of the project methodology. The second paper, by the IRRI researchers, discusses the methodology evolved over the life of the project. The subsequent papers report the results obtained in specific locations. The final paper summarizes the results of the entire network.

Some of the research results for 1975 and 1976 are reported in greater detail in an earlier interim report, but all of the important earlier findings are contained in this volume. In addition to the interim report and the present volume, the methodology used in the project has also been summarized in an IRRI publication, *A Handbook on the Methodology for an Integrated Experiment-Suvey on Rice Yield Constraints.*

Researchers studying the same problems in South America, India, Pakistan, and Malaysia have adopted the approach and some of the methodology used here. Scientists conducting research on other crops have also found the methodology to be of value.

Network cooperators in a number of Asian countries continue to use the research pattern developed in this study. The International Rice Research Institute is pleased to have the opportunity to participate in the network.

The four IRRI researchers with major leadership responsibility for the project during its initial phase were Randolph Barker, agricultural economist; Kwanchai A. Gomez, statistician; Surajit K. De Datta, agronomist; and Robert W. Herdt, agricultural economist.

The International Development Research Centre (IDRC) of Canada provided funds to initiate the network activities and support part of the research. Each collaborating research institution also provided significant resources for the project.

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Adoption and Production Impact of New Rice Technology – The Yield Constraints Problem

Randolph Barker

Dr. Robert F. Chandler recently wrote, "On retiring from IRRI in 1972, the only real disappointment I felt was that somehow we did not understand sufficiently why the Asian farmer who had adopted the new varieties was not doing better. Somehow, I felt that the rice scientists who had obtained yields of 5 to 10 metric tons per hectare on the IRRI farm still could not explain why so many Filipino farmers (for example) obtained, on the average, less than one metric ton per hectare increase in yield after shifting from the traditional to the high-yielding varieties. All of us were a bit mystified as to why not more than 25% of the rice land in the less developed Asian countries was planted to the new varieties" (Chandler 1975, p. 15).

Through the research conducted by the International Agroeconomic Network (IRAEN) over the past 4 years, much of which is presented in this volume, we have come to understand more clearly the yield constraints problem described by Chandler. This paper discusses the background and nature of the constraints problem in its broadest context. The objectives are:

1. to review the changes taking place in adoption of new rice technology, production, and yield;

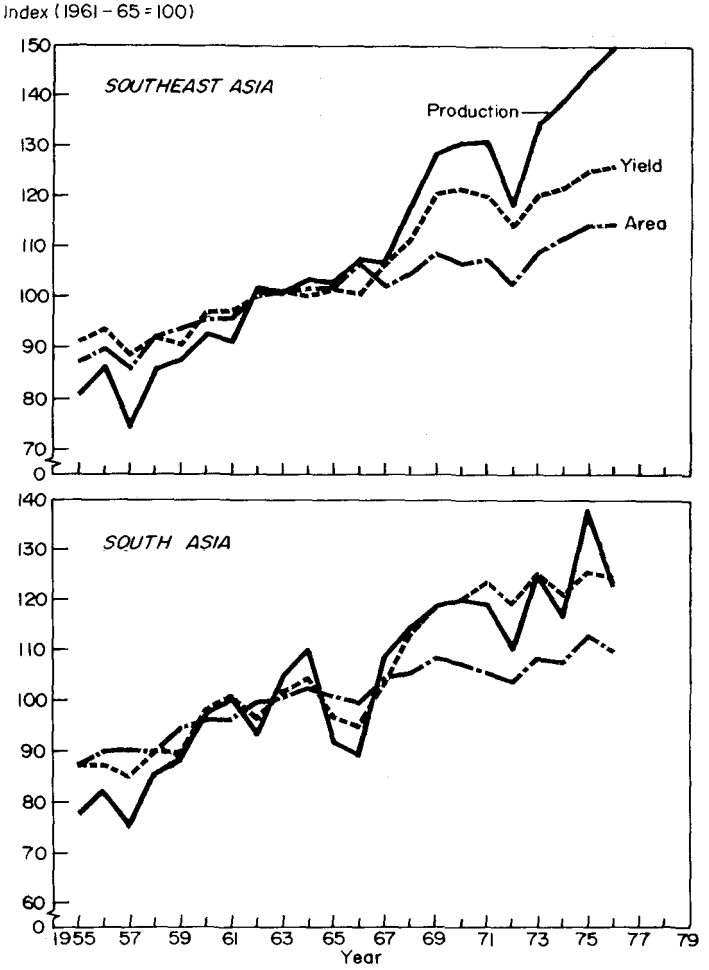
2. to discuss the concept of yield potential and *yield gap;*

3. to define the yield constraints problem;

4. to suggest why a new approach is needed for an understanding of the nature of the problem.

THE IMPACT OF NEW TECHNOLOGY

Rice production in Asia has always expanded by applying labor and traditional cultural practices over a larger area. As long as land was available, this process provided the means for



1. Trends in regional production (rough rice), area and yield, 1955–1976.

supplying food to an expanding population. In fact, in the later part of the 19th century, the opening up of new lands in three major river deltas - the Irrawaddy, the Chao Phraya, and the Mekong - had led to a sizable surplus for export. There continued to be an adequate supply of new rice land to develop into rice paddies until a decade or more after World War II. But, by the 1960s, a turning point was being reached with the expanding population encountering a land constraint.

The development of the new short-statured fertilizer-responsive varieties of rice in the 1960s provided the vehicle for the introduction of modern inputs and the subsequent shift to

dependence on yield increase rather than area expansion as the major source of increased production (Fig. 1). The gross cropped area continued to expand with the expansion of irrigation and the area double cropped, but with a few exceptions, the area of rice land in South and Southeast Asia has expanded very little over the past decade. In most of the countries fertilizer, new varieties, and irrigation became the major sources of growth in production. For those contries whose production grew more than 2% per annum, only in Thailand did new land area continue to be the major source of output growth (Table 1).

The modern varieties released in the mid-1960s had spread to a little over a quarter of the rice-growing area in South and Southeast Asia by 1975. It was soon apparent that the varieties did best in areas with good water control. Among countries, rate of adoption, percent of area irrigated, fertilizer per hectare, and percent increase in yield over the decade from the early 1960s to the early 1970s tended to be closely associated (Table 2).

The national level statistics, however, obscure much of the variation. A survey of farms in 36 predominantly irrigated villages in 14 locations in Asia for the 1971-72 crop year (IRRI 1978) shows a general positive correlation between yield and nitrogen input (Fig. 2). Yields in excess of 4 tons were confined largely to those areas where modern varieties were planted and 90 kg/ha of nitrogen or more were applied. However, there were also many villages where 100% of the sample farmers had adopted the modern varieties but were applying very low levels of nitrogen (Fig. 3). These findings tend to corroborate Chandler's observation that the average yields of many Asian farmers who had adopted the modern varieties were well below the 5 to 10 tons per hectare obtained at IRRI and at many other experiment stations.

MAXIMUM POSSIBLE YIELDS AT EXPERIMENT STATIONS

The maximum possible yield of a variety is sometimes defined as the highest yield a variety has attained at any experiment station or during any season at one station. The maximum yield recorded at IRRI is 11 t/ha. The maximum recorded yield obtained in South and Southeast Asia is 13 t/ha in Pakistan. This information has very limited applicability to the problem of increasing rice production on farms.

A second definition is the average yield of a variety or set of varieties when grown by the best available methods and with maximum inputs in trials on experiment stations in a given

Table 1. Estimated proportion of growth in rice output attributed to components of area and yield for selected Asian countries, mid–1960s to early 1970s*.

Country	Period	Annual rate of production growth (%)	Percentage points (%) attributed to Area		Yield	
			Irrigated	Unirrigated	Fertilizer[a]	Residual[b]
Pakistan	1965–73	7.9	1.4	0	1.7	4.8
Malaysia	1965–73	5.7	3.7	0.1	1.4	0.5
Sri Lanka	1965–72	5.6	0.5	0.1	3.5	1.5
Indonesia	1965–72	4.8	2.2	-0.3	1.1	1.8
Philippines	1965–73	3.4	1.2	-0.3	1.5	1.0
India	1965–70	3.2	0.6	0.2	1.5	0.9
Thailand	1965–72	2.1	0.2	1.7	0.3	-0.1

* Production, total area, and yield data are from U.S. Dept. of Agriculture (USDA), except for Indonesia and Thailand, which use national sources. Irrigation data are from national sources. Fertilizer data are estimated from FAO *Annual Fertilizer Review,* national sources, and special studies. For a more detailed explanation of sources of irrigation and fertilizer data, see Palacpac, World Rice Statistics (IRRI Agricultural Economics Dept., April 1977).

[a] Calculated on the basis of 10 kg yield for every 1 kg of fertilizer.

[b] Includes the contribution to yield of improved quality of land attributable to higher proportion of irrigated area.

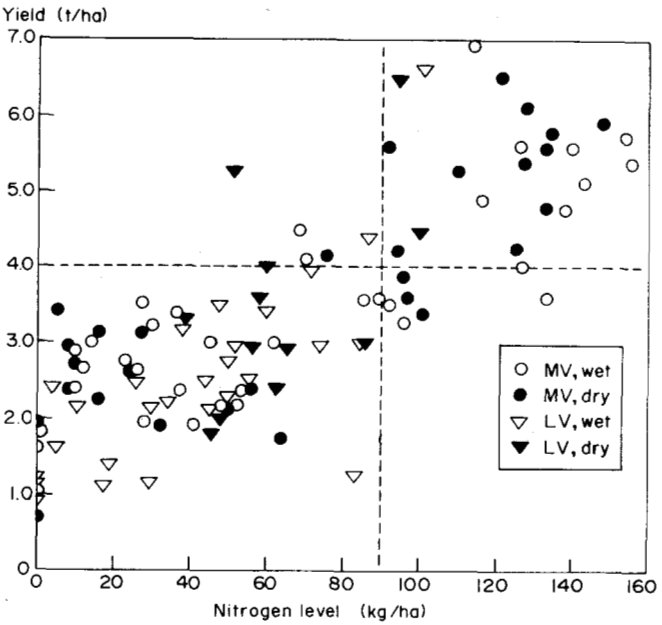
Table 2. Percent of area in modern varieties, percent area irrigated, kg NPK/ha of rice, and rice yield increase, 1961–65 to 1971–75, selected countries of Asia.

Country	Area in MV 1974–75 (%)	Area irrigated mid–1970s (%)	Fertilizer applied to rice 1973–74 (NPK/ha)	Increased yield 1961–65 to 1971–75 (%)
Pakistan	40	100	25	62
Sri Lanka	55	50	113	43
Philippines	62	43	23	27
Indonesia	40	39	33	24
Malaysia	36	63	83	19
India	30	39	23	15
Vietnam	31	13	-	11
Thailand	7	24	7	9
Burma	7	16	6	6
Nepal	19	17	-	2
Bangladesh	15	11	5	2
South and SE Asia	26	32	20	15

season but over a number of years. At IRRI, maximum yield was determined on the basis of 154 fertilizer trials conducted by the Agronomy Department between 1966 and 1972 (IRRI 1974). A mean maximum yield of 4.8 t/ha was obtained in the wet season with 75 kg of N/ha and mean maximum yield of 6.6 t/ha was obtained in the dry season with 112 kg of N/ha.

The International Rice Yield Nurseries (IRYN) report yield data from locations throughout Asia for a series of test lines and varieties. The top 5 medium maturity lines grown in the wet season at each of 14 stations were averaged over a 3–year period 1975–1977 (Table 3). The two top–yieldingsites, Coimbatore and Hyderabad, are not typical monsoon rice–growingareas, the dry climate permitting extremely high yields in some years. Omitting these two sites, the average of the remaining 21 is 4.7 t/ha.

Data obtained from fertilizer response studies at several experiment stations provide much the same picture for the wet season (Table 4). From these data it can be observed that maximum yield tends to be obtained on the Indian sites at nitrogen levels considerably higher than for other locations. Maximum yield averages 5.7 t/ha for the dry season sites (Table 5) compared with 4.9 t/ha for the wet season sites. Another set of data from experiments tends to confirm the generally higher maximum yield level in the dry season (Table 6).

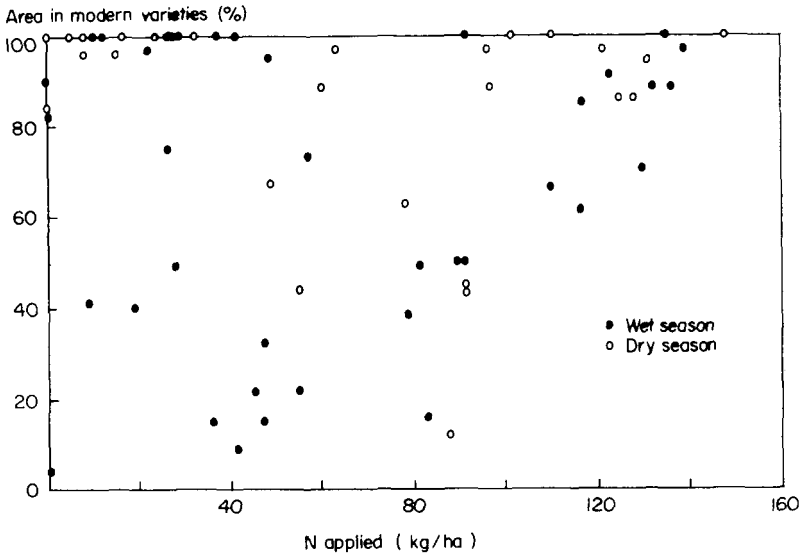


2. Relationship between average farm yield of rice and nitrogen applied per hectare by village, by season, and by varietal type, 36 villages in Asia, 1971-72 wet and dry seasons. MV = modern varieties; LV = local varieties (IRRI 1978).

However, none of the above data provide a basis for judging that the yield potential is higher in one location or in one country than another. A wide range of factors, including the variability in the management of the experiments, could contribute to the differences observed in Tables 3 and 6. However, evidence points to a maximum wet season yield of about 4.5 to 5.5 t/ha and a maximum dry season yield of 5.5 to 6.5 t/ha, with yields in excess of this being exceptional.

YIELD GAP

It is difficult to identify the potential yield under experiment station conditions, but there is much more confusion when one talks about the yield gap. This confusion stems from the fact that there is not a single yield gap but a whole range of yield gaps or differences between actual and potential yields. The problem is one of definition rather than measurement. It is, therefore, useful to trace out the various concepts and definitions of yield gap used in the literature.



3. Relationship between percent area planted to modern varieties and nitrogen applied per hectare by village, wet and dry seasons, selected areas of Asia, 1971–72 (IRRI 1978).

Table 3. Average of top 5 lines by location, International Rice Yield Nursery, Medium (IRYN – M), 1975 – 77wet season. IRRI, 1975 – 77 .

Location	Yield (t/ha)
Coimbatore, T.N., India[a]	7.1
Hyderabad , A.P., India	6.8
Suphan Buri, Thailand	5.8
Pantnagar , U.P., India[a]	5.5
Bogor, Indonesia	5.2
Los Baños, Philippines	5.2
Patna, Bihar, India[a]	5.1
Comilla, Bangladesh	4.6
Yezin, Burma	4.6
Chinsura, W. Bengal, India	4.5
Joydebpur , Bangladesh	4.4
Faizabad, U.P., India[a]	4.3
Parawampur, Nepal	4.0
Cuttack, Orissa, India	3.4

[a]2 years only.

Table 4. Maximum yield and nitrogen input at maximum yield for selected modern varieties of rice at selected experiment stations in Asia, 1967-75 wet season (Barker 1978).

Location	Variety	Period	Maximum yield (t/ha)	Nitrogen of maximum yield (kg/ha)
		India		
Maruteru, A.P.	IR8/Jaya[a]	1967-68, 1970-72	4.1	119
Pantnagar, U.P.	IR8/Jaya	1967-68, 1971-73	7.0	143
Faizabad, U.P.	IR8/Jaya	1967-70	5.3	206
Cuttack, Orissa	IR8/Jaya	1967-69, 1971-72	4.6	143
Coimbatore, T.N.	IR8/Jaya	1967-73	6.2	227
		Indonesia		
Pusakanegara, W. Java	PB5 (IR5)	1969-71	6.0	140
		Philippines		
Maligaya, Central Luzon	IR20	1968-75	4.8	91
Visayas	IR20	1968-75	5.6	87
		Thailand		
Suphan Buri	RD1	1969-70, 1974	4.0	98

[a]In India, data used for 1967-68 are for IR8; data for 1969–73 are for Jaya. Because of the close similarity in their basic characteristics, IR8 and Jaya are considered as one variety.

Table 5. Maximum yield and nitrogen input at maximum yield for selected modern varieties of rice at selected experiment stations in Asia, 1967-75 dry season (Barker 1978).

Location	Variety	Period	Maximum yield (t/ha)	Nitrogen at maximum yield (kg/ha)
		India		
Maruteru, A.P.	IR8/Jaya [a]	1968 – 70, 1972 – 73	5.8	163
Cuttack, Orissa	IR8/Jaya	1968 – 69, 1971	8.5	208
Coimbatore, T.N.	IR8/Jaya	1967 – 68, 1972 – 73	6.8	285
		Philippines		
Maligaya, Central Luzon	IR8	1968 – 75	6.4	143
Visayas	IR8	1970 – 75	5.2	151
		Thailand		
Suphan Buri	RD1	1970 – 71, 1974	5.6	119

[a] Data used for 1967 – 68 are for IR8; data for 1969 – 73 are for Jaya. Because of the close similarity in their basic characteristics, IR8 and Jaya are considered as one variety.

A systematic study of the relationships between yields on farms and at experiment stations was undertaken for Australia by Davidson and Martin (1965). For a number of crops, including rice, they discovered that the gap between farm yields and experimental yields varied according to the growing season. In good years the yield at the experiment station increased more rapidly than the yield of farms in the same district. They concluded that this was because farmers were limited in their input investment by the desire to maximize profit, while the experimenter, with little, if any, cost restraint, attempted to maximize yield.

It is common to find the yield gap defined as the difference between the highest yield on a farm or at an experiment station

Table 6. Average maximum rice yields recorded at experiment stations.

Country	Wet season		Dry season	
	Experiments (no.)	Yield (t/ha)	Experiments (no.)	Yield (t/ha)
India (ICAR)	27	5.4	12	6.8
Bangladesh (BRRI)	na	4.9	na	6.6
Indonesia (CRIA)	10	4.8	12	5.9
Philippines (BPI–IRRI)	64	4.6	54	5.9
Vietnam (IRRI)	9	4.1	12	5.8
Sri Lanka (Dept. of Agric.)	32	5.3	24	5.7
Thailand (Dept. of Agric.)	80	3.7	80	4.4

and the national average yield. This kind of comparison is frequently used in the press, since it leads to newsworthy (but scientifically worthless) statements such as the following:

> "Miracle rice which can produce up to 10 times as much as the old varieties, have (sic) given India a new hope of banishing forever the shadow of famine." (Manila Times, 8 October 1967, cited by Castillo 1967).

A slightly different version of this approach has recently been utilized in India (Mukherji 1977). The *gap* was defined as the ratio between the potential yield as found in the national demonstrations in a given state and the average state yield. Ratios were calculated using data from the 1975–76 Kharif season (Table 7). The conclusion drawn by Mukherji is that when the gap ratio is low (i.e., the state average yield approaches the yield of the demonstration plots), farmers' technical competence is high and *vice versa*. However, it could be argued that the high ratio found in states like Bihar and Orissa reflects the fact that demonstration plots are normally located in irrigated areas, while most of the rice in these states is grown under rainfed conditions.

A number of scientists from different countries of South and Southeast Asia were recently asked to estimate the following for the different water control environments, in their countries: the present yield level, the present potential yield level, and the potential yield level in another ten years. The gap between the present and potential yield levels is shown for each environment by averaging the results of questionnaires submitted

Table 7. Estimate of the gap analysis value or ratio of national demonstration plot yield to the average state yield. India, 1975–76 Kharif (wet) season (Mukherji 1977),

State	Gap analysis ratio	Range of gap on farmers' technical knowledge
Pondicherry	1.53	10.0–19.9%
Tammu and Kashmir	1.58	
Punjab	1.77	
Tamil Nadu	1.84	
Goa	1.86	
Maharastra	1.92	
Rajasthan	1.96	
Karnataka	2.15	20.0–29.9%
Himachal Pradesh	2.16	
Andhra Pradesh	2.56	
Haryana	2.57	
West Bengal	2.97	
Madhya Pradesh	3.05	30.0 — 39.9%
Gujarat	3.20	
Uttar Pradesh	3.80	
Bihar	5.48	50.0% and above
Orissa	6.07	

by 8 country delegations (Table 8). The scientists as a group estimate that, even after 10 years, the yield potential for irrigated rice areas in their country will be lower than the present yield potential at the experiment station. These estimates suggest the existence of a gap between the yields that can be achieved at the experiment station and in the farmers' fields.

A number of studies have not only defined *gap* but have attempted to explain the factors accounting for the gap. Herdt and Wickham (1975) defined gap as the difference between the yield potential at the experiment station during the dry season in a good year and the average national yield. For the Philippines they estimated the high experiment station yield to be 8 t/ha as compared with a national yield average of 1.8 t/ha. Using data from a number

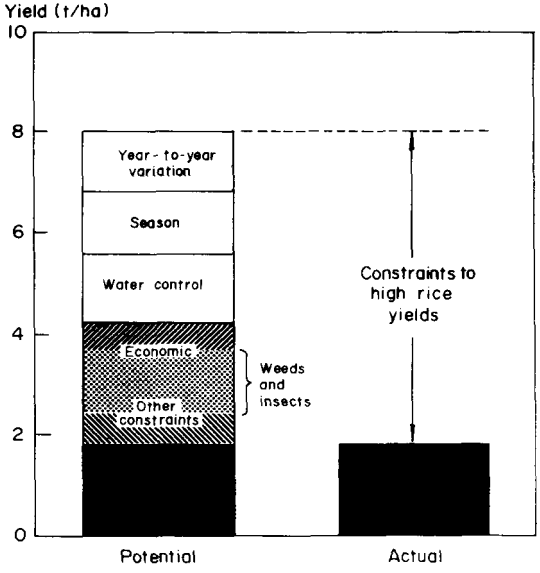
Table 8. Average of responses on present and potential yield based on the judgment of rice scientists from 8 country delegations[a] attending the International Rice Research Conference. Philippines, April 1977.

Water environment	Present yield (t/ha) (1)	Present potential yield (t/ha) (2)	Future potential yield[b] (t/ha) (3)	Present gap (2) – (1)	Future gap (3) (1)
Irrigated – wet	2.6	3.6	4.3	1.0	1.7
Irrigated – dry	3.1	4.2	4.9	1.1	1.8
Shallow RF	1.7	2.3	3.0	0.6	1.3
Intermediate RF	1.5	2.0	2.5	0.5	1.0
Semi – deep RF	1.2	1.6	2.2	0.4	1.0
Deepwater	1.0	1.5	2.0	0.5	1.0
Upland	1.1	1.7	2.3	0.6	1.2

[a] Includes Bangladesh, Burma, India, Indonesia, Nepal, Philippines, Sri Lanka, and Thailand.
[b] After 10 years.

of sources, they partitioned the gap into year – to – year yield variation, seasonal effects (dry vs wet), water control, economic constraints, and a residual including lack of available inputs and nonadoption of technology (Fig. 4). Approximately 40% of the yield gap was estimated to be the result of socioeconomic factors described in the latter two categories, while 60% was the result of environmental factors and lack of water control.

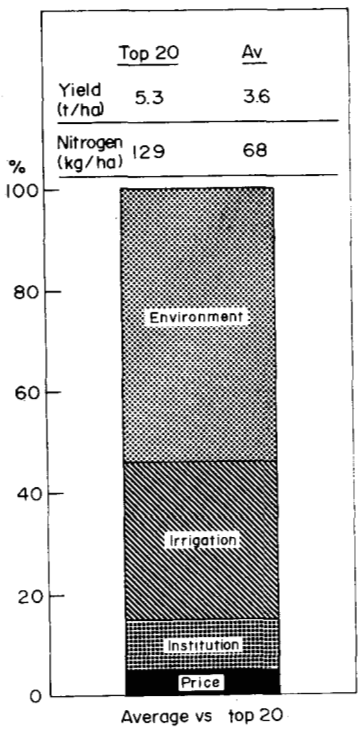
There is a reasonably close association between the level of nitrogen input and yield. For any given year, the level of nitrogen input may provide a good projection of anticipated yield, whereas the actual yield may vary considerably at a site, depending on weather conditions and other factors. Barker and Anden (1975), in a study of changes in rice farming, identified the gap in nitrogen input between the high and the average of sites, based on observations from 36 irrigated Asian rice villages (36 observations for the wet season and 29 for the dry season). Their analysis suggests that environment (solar energy and rainfall) and irrigation accounted for the major differences in nitrogen use between the top 20 and the average of 65 sites (Fig. 5). All but 4 villages were irrigated. However, there was enormous variability in the quality of irrigation, and it is not surprising that farmers with good water control should be expected to use more fertilizer.



4. A preliminary identification of factors constraining rice yields in the Philippines (Herdt and Wickham 1975).

Parthasarathy and Prasad (1977) analyzed the differences in the rate of growth of the yield of rice in 583 districts in India. *Top* districts with more than 2% growth rates were compared with districts showing *negative* growth rates. They also concluded that this *gap* in performance was associated with a difference in environmental factors. They noted a high correlation between environment, infrastructure development, level of input use, and development of institutions on the one hand and growth rates on the other. No causal relationships could be established with their data, but they concluded that there was a need to study the sequence of the growth process.

The All India Coordinated Rice Improvement Project (AICRIP 1974) ran a set of management minikit experiments in Andhra Pradesh. They hypothesized that the yield gap was caused by variability in cultural practices - land preparation, depth of transplanting seedlings, and weeding. Simulating farmers practices (suboptimal), they showed that by changing from suboptimal to optimal practices, yields could be increased by over 700 kg/ha at the same level of nitrogen and by 250 kg/ha or more even when the nitrogen level was cut in half (Table 9). In concept and procedure, the AICRIP work was somewhat similar to IRAEN. However, there was no assurance that the AICRIP suboptimal practices used in



5. Factors explaining differences in level of nitrogen inputs between average and 20 highest users of nitrogen (Barker and Anden 1975).

the experiments accurately simulated the farmers' practices, and therefore no assurance that the gap being measured was in fact the gap between actual and potential yield.

The discussions in this section illustrate that there are many ways of defining a gap. However, there are two common conceptualizations. One is to compare a *potential* yield from experiment station or demonstration plots with the present yield (Mukjerji 1977, Herdt and Wickham 1975). The other is to compare the yield of the best farms, best villages, or best districts with the average or the poorest (Barker and Anden 1975, Parthasarathy and Prasad 1977). Although the size of the gap will vary tremendously according to the definition of the gap, as well as to actual measurement of yield, it seems reasonable to expect that environment will be an important factor contributing to the gap in both of the above conceptualizations. This is mentioned because of its policy implications. The physical environment can be altered, but usually

Table 9. Profitability of increased fertilizer compared with improved management, mini-kit data. West Godavari, Kharif 1973. (All India Coordinated Rice Improvement Project, Hyderabad).

Management [a]	N level (kg/ha)	Added yield (kg/ha)	Added cost (Rp/ha)	Additional income (RP/ha)
		Java, Delta (18 locations)		
Good	0	-	-	-
Suboptimal	60	126	238	-62
Good	30	387	346	196
Good	60	873	761	461
		Java, Upland (14 locations)		
Good	0	-	-	-
Suboptimal	80	311	417	17
Good	40	712	598	398
Good	80	1269	1088	688

[a] Land preparation, depth of transplanting seedling, weeding.

at high cost; therefore the implications of the environmental constraints are important for policy making.

Some of the gap analyses described above indicate why some farmers in better environments get higher yields and are more receptive to the use of the modern rice technology than others. But they do not explain whether or how the farmer in the context of his own environment and resource constraints can profitably achieve a higher yield. It is this issue which I would judge to be the focal point of Chandler's query.

THE YIELD CONSTRAINTS ISSUE IN BROAD PERSPECTIVE

Constraints to high yield can be classified into two categories: those that affect the yield potential of the crop under the farmer's environment; and those that affect the farmer's ability and willingness to achieve the yield potential on his own farm. The first category of constraints is related directly to the development of new technology and, hence, the organization of research. The second is concerned on the one hand with the

realization of the production potential, given the existing technology and physical environment, and on the other with the degree of equity among farmers and landless workers in access to resources and inputs. These include such issues as diffusion of knowledge among farmers, input and credit availability, and landownership patterns.

The increasing population pressure on the land encourages the use of yield-increasing modern technology. But the growing number of landless workers creates a problem with respect to both production and employment. From the production perspective, the issue is one of avoiding the increasing fragmentation of land-holdings, leading to inefficient use of the limited land resources.

The introduction of a new technology creates a yield gap and what economists sometimes refer to as *economic slack* (Evenson 1976). Economic slack is the difference between the present product of a sector and the product that could be realized if all resources were optimally utilized. Research activities produce technology that increases economic slack. It is reduced by such factors as expansion of extension activities and improvement in rural infrastructure, the incentive for such changes coming from access to more productive technology. However, such changes do not occur immediately, and it is the delay in or constraints to the process of change that materialize in a gap between the actual and potential yield in the farmer's field.

The agricultural production process can be viewed as containing three subsystems: farmer-producer, input delivery, government regulating and facilitating (Gaikwad et al 1977). The farmer produces the crop and bears the risks and uncertainties of production. Increasingly, governments control the supply of inputs, including seeds and credit. Government also has the responsibility of providing the wide range of incentives and services - research, extension, irrigation development and water management, price supports, and input subsidies. The shift toward modernization of agriculture seems to have left most governments much more in control of the rate and process by which economic slack both is created and reduced. Strategies range from short-term *crash* programs to long-term investments in rural infrastructure and institutional changes such as land reform and agricultural research. Research that can precisely define the causes of low farm yield can be useful to the appropriate agency - research, extension, input delivery - in establishing its priorities.

The gap between the actual and potential yield in farmers' fields, and the factors that explain this gap form the central focus of IRAEN research. The physical environment - soil, climate, water control - and the institutional environment - farm size, tenure status - are taken as given in the research that has been

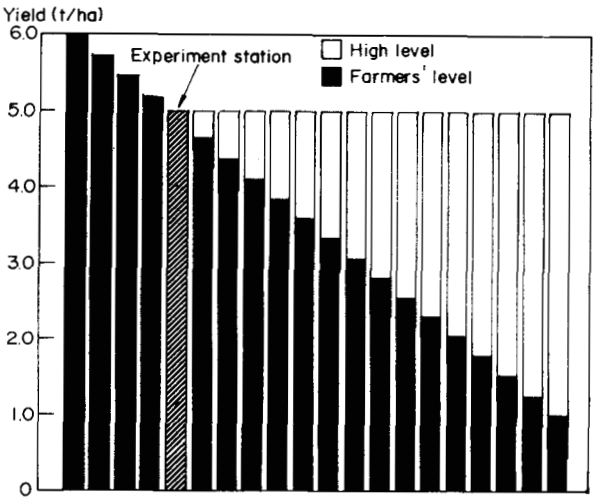
conducted to the present. Also, omitted from consideration is the alternative of increasing total farm production through cropping intensification. Thus, IRAEN is concerned only with a limited aspect of the broad issue of production and yield constraints. Yet it is this core of the constraints problem over which farmers and government agencies are able to exercise some control. At the same time, by identifying the yield potential in the farmer's environment, this research can provide feedback to researchers on the efficiency of their technology under farm field conditions.

To define the focus of IRAEN research on constraints to high yield, two hypothetical situations are depicted in Figure 6. In Case I (the top of the graph), the yield potential has been shown to be 5 t/ha under experiment station management and that the same potential exists for all farms depicted. But there are some farmers who obtain very low yields compared with their own farm potential, and there are a few with very good management whose yields exceed the experiment stations'. It would appear in this situation that the dominant constraints to high yield are socioeconomic in origin. One of these constraints is the economizing behavior of the farmer, which causes him to maximize profits rather than yield. Because there is little likelihood of removing this constraint, it is appropriate to consider the *economically recoverable yield gap* as the relevant portion of the gap that can be reduced. When this economically recoverable gap has been removed, economic slack has been eliminated.

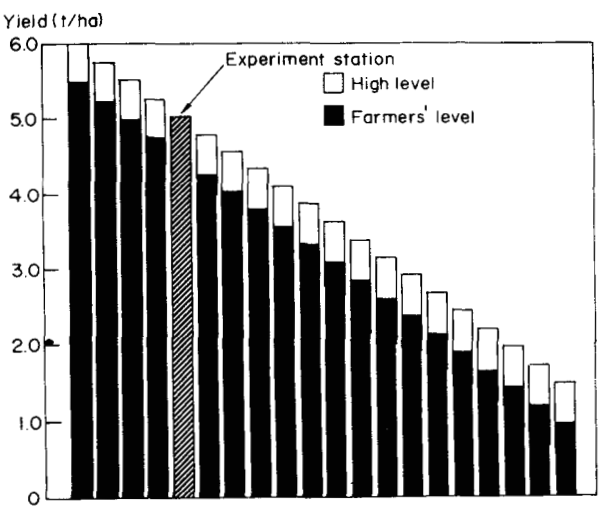
Other socioeconomic constraints may include inadequate supply of inputs or credit, unfavorable prices faced by some farmers, lack of knowledge, or even differences in the farmers' responses to risk or preference for leisure.

Case II shows a situation in which the high potential yields occur at the experiment station and on a few farms, some of which may be located in an even more favorable rice-growing environment than that at the experiment station. But there is a wide variability in the potential yield among farms. (In the constraints research in the Philippines, it has been fairly common to find that the yields obtained at high levels of inputs from experimental plots in farmers' fields have varied widely, the yield of the low site being half that of the yield of the high site). The small gap of 0.5 t/ha that does exist in each case is assumed not to be economically recoverable. For this situation we can conclude that farmers are in fact responsive to the technology, but that the potential yields are much higher on some farms than on others.

Biological scientists are often inclined to feel that Case I is the prevalent situation, that the fault somehow lies with the farmer or the institutional system and not the technology.



Case I. Dominant socioeconomic constraints.



Case II. Dominant environmental constraints.

6. Two hypothetical situations for high level and farmers' levels of yields on a group of farms. Experiment station yield is 5 t/ha.

Social Scientists, on the other hand, are often quick to suggest that the technology developed under experiment station conditions is not *appropriate* for the farmer's environment. Thus, a plant breeder in India will make a case that Orissa farmers simply are not as progressive as the farmers in Andhra Pradesh, where the new rice technology is more widely utilized. But it is reasonable to respond by asking whether the Orissa environment is as suitable for the new technology as the Andhra Pradesh environment.

Many who area convinced that Case I is the prevailing situation argue that the solution to the problem lies in an expanded extension effort. However, there are others who argue that variance in response among farmers is the result of institutional constraints that affect some farmers (e.g., small farmers or tenants) more seriously than others. A recurring theme of the Asian Development Bank's Second Asian Agricultural Survey is that institutional constraints, not lack of technology, is the major factor slowing the rate of agricultural and economic development.

The problem in fact is that different constraints may prevail in different situations and at different times. It is, therefore, impossible to identify the dominant constraints without careful research. The success of this research depends upon the development of an appropriate research methodology.

THE METHODOLOGY ISSUE

At. the first meeting of the International Rice Agroeconanic Network (IRAEN) held in April 1974, there was general agreement that a better understanding of why farmers' yields are low despite the adoption of improved varieties is needed. However, there was considerable controversy about the appropriate methodology for identifying and measuring constraints to high yields in farmers' fields. This section attempts to trace out some of the origins of this controversy and the compromises that had to be reached by the various disciplines involved: compromises that eventually led to the development of the methodology on constraints to high yields adopted by IRAEN.

Economics provides us with a theory of efficient resource use based upon the concept of the production function. Figure 7 portrays the gap between potential yield and actual yield. This gap can be further partitioned into three segments. The first segment due to *profit seeking behavior* reflects the difference between maximum yield and yield at maximum profit. Farrell (1957) was among the first to distinguish between *price,* or *allocative inefficiency* -- the failure to maximize profit, and *technical inefficiency* -- the failure to produce on the most efficient

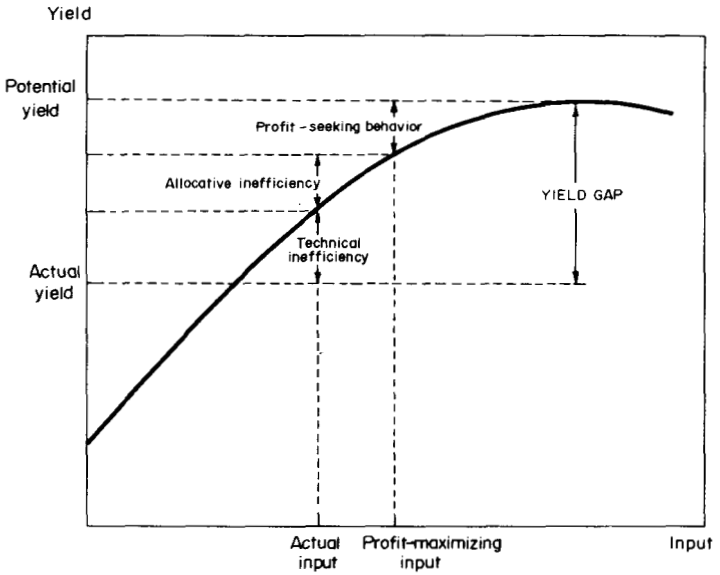
production function. He defined *technical efficiency* as the measure of a farm's "success in producing maximum output from a given set of inputs." There has been considerable work in recent years to define the concept of technical inefficiency and to separate the effects of technical and allocative inefficiency (e.g., Timmer 1970, Lau and Yotopoulos 1971). It is also possible to introduce into this framework the concept of external constraints like inadequate supply of fertilizer.

This approach, however, had two major obstacles. First, the traditional methodological procedure used by the economists consisted of fitting a production function to data of questionable accuracy obtained through traditional farm survey techniques. It is difficult or impossible to separate technical from allocative efficiency with such data. Second, technical inefficiency can result from factors that are within the management capacity of the farmers, and those factors, both physical and social, over which the farmer has no control. The problem lies in being able to identify the cause of technical inefficiency in order to be able to suggest the appropriate solution.

In 1973 the IRRI Statistics Department had begun to develop and test a procedure for quantifying the factors limiting rice yields in farmers' fields (Gomez et al 1973). The procedure involved identifying the gap between farmers' yield and potential yield in farmers' fields and quantifying the contribution of *management* factors to the yield gap. Management factors were considered to be those factors over which the farmer had some control, such as the level of inputs or the cultural practices used. The partitioning of the gap between high level and farmers' level was accomplished qby calculation of the main effects in the experiments.

The economists at the first workshop objected to the selection of only two management levels - the farmers' level and the *maximum potential* yield - on the grounds that it did not permit the determination of the point of maximum profit by marginal analysis. The yield gap could not be partitioned in the manner described in Figure 7. However, there were two strong advantages to this approach. First, the experiments to be conducted in farmers' fields could be kept fairly simple with 2^n treatments, n being the number of management factors. Second, given the exploratory nature of the work, it was important initially to identify the magnitude of the yield gap and the contribution of management factors to the yield gap. This would at least point out the general nature of the constraints and indicate the direction for subsequent research.

To provide a basis for estimating an economic optimum, it was also agreed that *management package* experiments would be conducted. A management package methodology had been developed



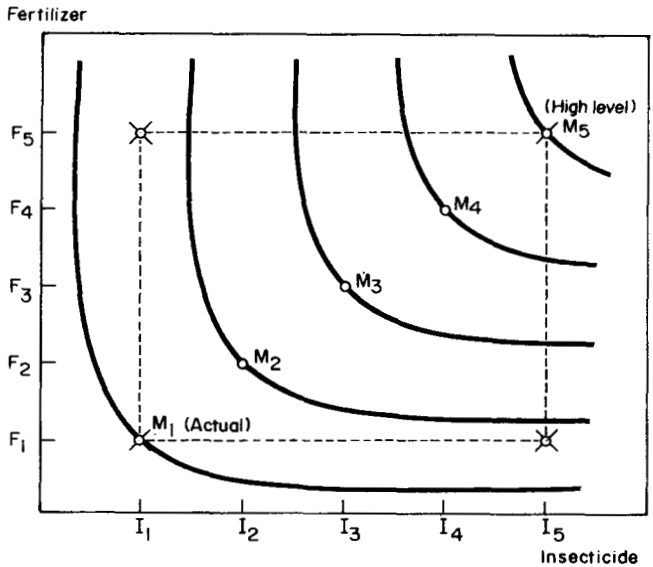
7. Three economic components of the yield gap.

by the IRRI Agronomy Department (De Datta et al 1976). These management packages would contain intermediate levels of inputs in fixed combinations approximately along the optimum expansion path. The relationship between the management package treatments and the factorial treatments is illustrated in Figure 8.

There was much discussion at the workshop about how the *farmers' actual yield* input level, the *maximum potential yield* input level, and the intermediate management package level should be defined and specified. A first approximation was reached (Table 10).

It was envisioned that once the management factors contributing to the yield gap had been identified, follow-up farm surveys would make it possible to pinpoint the socioeconomic factors that might prevent the farmers from using a higher level of those specific inputs found to have the potential to increase yields.

The strength of the compromise in methodological approach from the outset has rested with the power of the experiments conducted in farmers' fields to provide an accurate measurement of the yield gap and the cultural practices or input factors contributing to the gap. Despite the difficulties of conducting controlled experiments in farmers' fields, the rewards have come from placing the scientist in the farmers' field, thus bridging a



8. Treatments $M_2 - M_5$ as points in the expansion path and Xs marking treatments in the factorial.

communication gap. Subsequent refinement of the experimental approach has been largely with the objective of simplifying the experimental design to enlarge the number of experiments possible and to gain a more representative coverage of the study area.

Identifying the socioeconomic factors explaining farmer behavior is a more difficult task. No agreement on methodological procedure was reached at the initial workshop, although there was general recognition that analysis of experimental data, combined with survey results, would provide more meaningful answers than the traditional survey approach. Analysis of the experimental results had made it possible to identify the economically recoverable yield gap and to measure the probability of achieving higher profits from site to site and from year to year. Beyond this point, the identification of socioeconomic factors accounting for the yield gap still remains more of an art than a science.

CONCLUSIONS

Introduction of the new technology has raised the yield potential under experiment station conditions to at least 4.5 t/ha in the wet season and 5.5 t/ha in the dry season throughout most of South and Southeast Asia. It is clear that, even in the irrigated areas, farm yields are well below this potential.

Table 10. Level of inputs to be used in initial IRAEN design, based on first workshop, April 1974.

Input level of variable factors[a]	Factorial	Management package	Input level of fixed factors[b]
"Actual yield" input level	x	x	Farmers' level
Somewhat higher		x	Maximum yield level
Intermediate level		x	Intermediate level
Agronomic optimum		x	Farmers' level
Maximum "potential yield" input level	x	x	Maximum yield level

[a]Variable factors might include fertilizer, weed control, insect control, land preparation, seed, and variety.

[b]Fixed factors included water control, agroclimatic zone, socioeconomic environment.

Many studies have identified a gap between the actual or the average yield performance and the potential as measured by experiment station results or by the performance of the best farms, villages, or districts. But they fail to explain whether or how the farmers, within the contexts of their own environments and resource constraints, can profitably achieve higher yields.

There is a wide range of constraints to high yield, including those factors that affect the yield potential of the crop under the farmers' environment and those that affect the ability and willingness of the farmer to achieve the potential yield on his own farm. The research of IRAEN falls into the second category, dealing as it does with the gap between actual and potential yield in farmers' fields. The focus of this research is further narrowed by the decision to accept the physical environment and the institutional setting as it exists in order to focus on that

core of the constraints problem over which farmers and government agencies can exercise the most control - the management of inputs and cultural practices.

The first task of IRAEN research has been to determine the size and extent of the gap between actual and potential yield in the farmers' fields. Does the technology really offer the potential for increasing yields? Is the farmer already using the new technology to best advantage? The answers to these questions have important implications for research.

Identifying the yield gap and partitioning the factors explaining the yield gap required a new methodological approach. The production function analysis of economics based upon unreliable data obtained from traditional survey techniques was simply not adequate. The methodology developed by IRAEN has the capacity to accurately determine the yield gap, the cultural practices or input factors contributing to the yield gap, and the economically recoverable portion of the yield gap.

REFERENCES CITED

Asian Developnent Bank. 1978. Asian Agricultural Survey 1976. Manila, Philippines.

All–IndiaCoordinated Rice Improvement Project (AICRIP). 1974. Mimeographed report. Hyderabad, India.

Barker, R. 1978. Yield and fertilizer input in International Rice Research Institute. Interpretive analysis of selected papers from Changes in Rice Farming in Selected Areas of Asia. Los Baños, Philippines.

Barker, R., and T. Anden. 1975. Factors influencing the use of modern rice technology in the study areas. In International Rice Research Institute. Changes in Rice Farming in Selected Areas of Asia. Los Baños, Philippines.

Castillo, G. T. December 1967. "Miracle rice" as produced by the press. Paper prepared for the International Seminar on Communications Media and National Development, University of the Philippines, Quezon City, Philippines. (mimeo)

Chandler, R. F., Jr. Case history of IRRI's research management during the period 1960 to 1972. Asian Vegetable Research and Developnent Center. Republic of China.

Davidson, B. R., and B. R. Martin. December 1965. The relationship between yields on farms and in experiments. Australian Journal of Ag. Economics. Vol. 9, No. 2, pp. 129 – 140.

De Datta, S. K. , W. N. Obcemea, W. P. Abilay, M. T. Villa, B. S. Cia, and A. K. Chaterjee. 1976. Identifying farm yield constraints in tropical rice using a management package concept. Paper presented at the 7th Annual Meeting of the Crop Science Society of the Philippines, Davao City, Philippines.

Evenson, R. E. September 1976. Agricultural Research and Extension in Asia: A survey report for asian agricultural survey 1976. Asian Developnent Bank. (mimeo.)

Farrell, M. J. 1957. The measurement of productive efficiency. Journal of Royal Statistical Society. 120. Series A (General) Part III. pp. 263 – 281.

Gaikwad, V. R., G. M. Desai, P. Mampilly, and V. S. Vyas. June 1977. Development of Intensive Agriculture, Lessons from IADP. Indian Institute of Management, Ahmedabad, India.

Gomez, K. A., D. Torres, and E. Go. November 1973. Quantification of factors limiting rice yields in farmers' fields. Paper presented at the IRRI Saturday Seminar, International Rice Research Institute. Los Baños, Philippines. (mimeo.)

Herdt, R. W., and T. Wickham. 1975. Exploring the gap between potential and actual rice yields in the Philippines. Food Research Institute Studies, Vol. XIV, No. 2 pp. 163 – 181.

International Rice Agroeconomic Network. May 1974. Summary of the First Workshop, April 26 – 27, 1974. IRRI, Los Baños, Philippines. (mimeo.)

International Rice Research Institute (IRRI). 1974. Annual report for 1973. Los Baños, Philippines.

International Rice Research Institute (IRRI). 1976. Preliminary report of the Third International Rice Yield Nursery - Medium (IRYN – M). Los Baños, Philippines.

International Rice Research Institute (IRRI). 1977. Final report of the Fourth International Rice Yield Nursery - Medium (IRYN – M-1976). Los Baños, Philippines.

International Rice Research Institute (IRRI). March 1978. Preliminary report of the Fifth International Rice Yield Nursery - Medium (IRYN – M-1977). Los Baños, Philippines.

Lau, L. J., and P. A. Yotopaulos. 1971. A test for relative efficiency and application to Indian agriculture. American Economic Review, Vol. 61, No. 1, pp. 94-108.

Mukherji, D. K. July 1977. Gap analysis - an effective production increase concept in rice. Summary of lecture delivered at the State Level Training Meeting on Rice held at Purulia, Department of Agriculture, West Bengal, India. (mimeo.)

Parthasarathy, G., and D. S. Prasad. 1977. Spatial variations in rates of growth of productivity in rice: an analysis of 'top' and 'bottom' districts. Department of Cooperative and Applied Economics, Andhra Pradesh University, Waltair, A.P. India. (mimeo.)

Timmer, C. P. 1970. On measuring technical efficiency. Food Research Institute Studies in Agricultural Economics, Trade and Development. Vol. 9, No. 2. pp. 99-171.

A Methodology for Identifying Constraints to High Rice Yields on Farmers' Fields

Kwanchai A. Gomez, Robert W. Herdt, Randolph Barker,
and Surajit K. De Datta

This paper outlines the objectives, methodology, and procedures followed in the International Rice Agroeconomic Network (IRAEN), an international and interdisciplinary research project established in 1974 to coordinate research work undertaken at IRRI and in several Asian countries for the study of factors preventing rice farmers from getting higher yields. The procedures described here have evolved from a 5-year experience based on studies undertaken by IRRI and by national research teams participating in the IRAEN project. For more detailed discussion see *A Handbook on the Methodology for an Integrated Experiment-Survey on Rice Yield constraints* (De Datta et al 1978).

THE PROBLEM

During the decade following World War II, a growing gap between population growth and food production became apparent in many parts of the world. Numerous efforts were made to increase food production by encouraging farmers in the developing countries to adopt scientific farming techniques, efforts largely frustrated by a lack of technology adapted to tropical farming conditions. When agricultural technology from the temperate areas was tried, even under experimental conditions, crop yields were not substantially increased.

During the 1950s, the conviction grew that the lack of tropical farming technology could be solved by concerted scientific research sharply focused on a single crop. IRRI was a result of that conviction, and IRRI's overriding objective during its early years was the development of a technology that would give high rice yields in the tropics. That objective was achieved by 1966, and by 1969 rice varieties with yield potential two or three times those of previously available varieties were being grown by farmers throughout Asia.

It was estimated that 30% of tropical Asia's rice land was planted to modern rice varieties by 1978, and in some countries the proportion reached over 50%. But still, the average farm yields

of the modern varieties are far below the level demonstrated to be possible on experiment stations. Instead of reaching the experimental levels of 6–8 t/ha, good farmers get 3–4 t/ha, and many farmers get as little as 2 t/ha.

In this situation two questions arise:

1. Why are some farmers still not growing the modern varieties, while many others have accepted them?

2. Why are many farmers unable to achieve the full potential yields of the new technology?

The first question has received considerable attention from many workers and is becoming increasingly well understood. The second question has received very little attention, and we still have a poor grasp of the factors responsible for low yields of the new varieties under farm conditions. Of course, if the rice plants are provided with all their biological needs, and if they are adequately protected from damage, they will give high yields. But those conditions, which can be met on experiment stations, are apparently more difficult to meet on the farms.

The factors preventing farmers from applying all the necessary inputs may be physical, economic, or social. The physical conditio] prevailing on some farms may prevent the farmer, or anyone else, from exploiting the full potential of the modern rice technology. Perhaps under the prevailing water availability, or given the farmer's soil, or with the prevailing climate, the modern technology may not give higher yields than the farmer's own technology.

In some cases high yields may be physically possible but unprofitable In still other cases social or institutional problems may exist that cannot be controlled, or that require inputs that are not available to farmers. Lack of credit may prevent farmers from using available inputs, or certain aspects of the technology may not be understood by farmers. Thus, there may be a combination of reasons, some physical, some economic, and some social, that explain why farmers are not getting the high yields that should be possible with the new varieties.

It thus becomes important to identify the limiting factors at the farm level and to determine how those factors can be overcome. Study by a combination of disciplines is required. Participants in an April 1974 IRRI workshop strongly supported the idea of a coordinated agronomic–economic project to identify yield constraint under a range of environmental conditions.

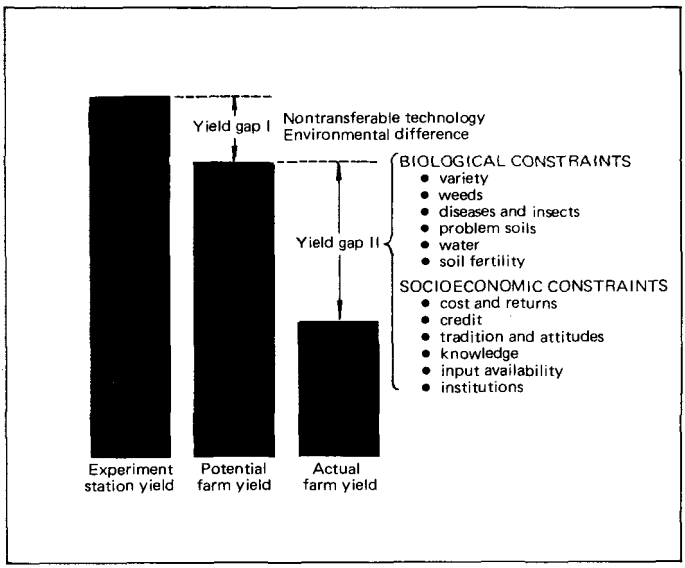
GENERAL APPROACH AND BASIC CONCEPT

The approach used is an integrated experiment – survey, involving the conduct of both controlled agronomic experiments on farmers' fields and farm surveys. A research team is usually composed of agronomists, agricultural economists, and at times, statisticians.

The conceptual model on which the approach is based is illustrated in Figure 1 (Gomez 1977). The model breaks the difference between the actual farm yield and the experiment station yield (the yield gap) into two distinct parts by introducing an intermediate yield level representing the potential farm yield or yield obtained in farmers' fields using the modern technology. The first part, yield gap I, is the difference between experiment station yield and potential farm yield. It exists mainly because of environmental differences between experiment stations and the actual rice farms. The technology that gives high yields on experiment stations may not give nearly as high yields in the less favorable environments that exist in much of the rice – growingareas of Asia. There may also be some components of the technology that are not transferable from the experiment station to the farmers' fields. The primary objective of the IRAEN project is not to examine yield gap I (although its size can be assessed). Its main focus of research is on yield gap II -- the difference between the potential farm yield and the actual farm yield. This gap exists because farmers use inputs or cultural practices that result in lower yields than those possible on *their* farms. It is possible to explain the gap in two ways. One is to identify *what* biological or physical inputs or cultural practices account for the gap. The other is to identify *why* farmers are not using the inputs or cultural practices that would result in higher yields on their own farms.

The biological explanation of yield gap II shows that farmers' yields would be higher if they would use the highest – yielding variety, apply maximum-yield levels of fertilizer and insecticide, correct existing soil problems, and use the best cultural practices. The most critical factors differ from one region to another, but before any remedy can be taken (e.g., recommending a package of improved practices) the biological nature of the gap must be understood. Experiments on farmers' fields are essential to obtain this information.

The socioeconomic constraints explain why farmers do not use the practices and inputs necessary to obtain maximum yields. The reasons may include economic calculations of costs and returns, lack of knowledge of how to use the technology, lack of credit, poorly operated irrigation systems (nonavailability of inputs) or traditional beliefs. The importance of these factors will differ from area to area, but understanding them will help in designing



1. The concept of yield gaps between an experiment station rice yield, the potential farm yield, and the actual farm yield (Gomez 1977).

programs to provide the missing biological components to overcome the yield gap. Farm surveys provide the main research inputs for this aspect.

The general objective of the methodology - to identify the factors that explain the difference between actual and potential rice yields in the study area - includes the following specific objectives:

- to measure yield gap II or the difference between the actual farm yield and the potential farm yield (i.e., the yield obtained in the farmers' own environments but with improved technology);
- to identify major production techniques or factors responsible for the existence of yield gap II and to determine their contributions;
- to determine the extent to which use of each production factor can be profitably increased;
- to identify the social and institutional factors that prevent farmers from using technology that gives higher and more profitable yields;

- to determine the extent to which it is possible to remove the physical, socioeconomic, and institutional factors constraining yields.

EXPERIMENTS

Field experiments are conducted on farmers' fields. Procedures for selection of experimental farms are described under the SURVEYS section.

The primary objective of the field experiments is to accurately estimate the potential farm yield, the actual farm yield, and the intermediate yield levels representing varying combinations of input use. Two types of treatments are usually tested in each experiment: the factorial component and the management-package component.

Factorial component treatments

The major objectives for testing the factorial component are (a) to measure the size of yield gap II by determining the potential farm yield and the actual farm yield and (b) to separate and measure contributions of individual production factors to yield gap II by a systematic addition or withdrawal of one or more production inputs.

The concept of "test factors". The accuracy of the estimate of the yield gap[1] is greatly dependent upon the choice of the production inputs to be tested (test factors). Normally, as the number of test factors increases, the more accurate the estimate of potential farm yield becomes and, consequently, the better the estimate of yield gap. However, the more test factors there are, the more complex the experiment becomes. The size of the experiment should be kept as small as possible, not only to facilitate actual tests in farmers' fields but also because the small size would allow the evident possible representation of farm conditions in the study area. A proper choice of test factors is therefore essential. Only the most important production inputs hypothesized by the researchers to be the major causes of low yields in farmers' fields in the study area should be included. Such information is generally obtained from the results of the preliminary survey described in the SURVEYS Section.

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[1]In all subsequent discussions, yield gap refers to yield gap II.

Four criteria commonly used for including any factor as a test factor are: (a) it is expected to be a major yield constraint; (b) the technology involving the factor is well established; (c) it is required for the success of another test factor; (d) its inclusion as a test factor does not unduly complicate the conduct of the experiment. A factor like water management is suited for inclusion as a test factor in the experiment because water level cannot be easily manipulated in farmers' fields (IRRI 1974).

Three to 5 test factors are usually used. The 4 most commonly used test factors among IRAEN participants are fertilizer, insect control, weed control, and land preparation. Whether or not a proper choice of the test factors has been made should be ascertained at the end of the test. This is done by judging whether the level of potential farm yield obtained is sufficiently high and by examining the relative contributions to the yield gap of the test factors.

The "levels" of each test factor. Two levels of each test factor must be tested in the factorial component of the yield constraints study: the farmer's level and the high level.

The farmer's level refers to what the farmer is actually doing in the current crop season, and varies from one farm to another. The high level is one that the researchers expect will produce maximum yield in the study area. It is fixed for all farms in the study area.

Although these two standard levels are the only ones required for measuring the yield gap and the contribution of individual test factors, there are cases where it is also desirable to test some intermediate levels. For example, when researchers are not certain of the right choice for the "high level" of some test factors, or when there is a need to pinpoint an economically optimum level of test factors for recommendation to farmers. The inclusion of many levels for each test factor in the test could result in a large number of treatments. To maintain a reasonably small experiment size, the technique of two-stage testing may be employed. The first stage should attempt to test as many factors as are hypothesized to be important yield constraints, each at two levels: the farmer's and the high. In the second stage, those test factors identified from the first-stage test as really important yield constraints will be more thoroughly tested, each at several levels, probably through incomplete factorial treatment combinations. Information obtained from the first-stage test about the probable absence or presence of certain interactions among test factors is useful in choosing the specific set of incomplete factorial treatments to be tested in the second stage.

Factorial treatment combinations. Treatments in the factorial component are either complete or incomplete factorial *combinations* of the test factors, each at two standard levels.

If a reasonable experiment size is to be maintained, the choice of treatments to be tested is crucial. Too many treatments make the experiment unwieldy and too few treatments can result in a worthless experiment.

The three sets of treatments tested by IRAEN participants are complete factorial, minifactorial, and supplemental (see Table 1).

If the number of test factors, n, is large, the use of the 2^n *complete factorial* treatment combinations requires a very large number of treatments resulting in an unwieldy experiment. Its use is necessary, however, if interaction effects among some or all test factors are deemed appreciable and their effects need to be measured.

For cases where interaction effects among test factors are not expected to be appreciable, *minifactorial* treatment canbinations are commonly used. For the minifactorial, the number of treatments to be tested is always two more than the number of test factors. They consist of a treatment with all the test factors at the high level, another with all test factors at the farmer's level, and treatments corresponding to keeping each of the test factor one at a time at the farmer's level (i.e., all other test factors are at the high level).

The *supplemental* set of treatments consists of only two treatments: one with all test factors at the high level and another with all test factors at the farmer's level.

Because the size of the yield gap depends on the level of technology actually used by the individual farmer, and because this level varies greatly from one farm to another, experiments must be conducted on a large number of farms in the study area if representative and meaningful information is to be produced. To cover as many farms as may be required and still be able to obtain the needed information, a proper combination of the number of farms testing each of these three sets of treatments is essential. (For more detailed discussion, refer to the section on number of farms and number of replications.)

Management package component treatments

The management package component tests the different input combinations selected to represent different yield levels and production costs. Treatments are designed to represent levels

Table 1. Three sets of treatments commonly tested in the factorial component of the IRAEN yield constraints project, assuming three test factors: fertilizer, insect control, and weed control.

Treatment no.	Input levels[a]			Treatment included in		
	Fertilizer	Insect control	Weed control	Complete factorial	Mini-factorial	Supplemental
1	H	H	H	X	x	X
2	F	H	H	X	X	
3	H	F	H	X	X	
4	H	H	F	X	X	
5	H	F	F	X		
6	F	H	F	X		
7	F	F	H	X		
8	F	F	F	X	X	X

[a]H = high level; F = farmers' level.

intermediate between the farmers' practices and the high level of practices. The incremental steps between treatments usually involve a simultaneous change in more than one input. Hence, this component does not measure the individual contribution to the yield gap of a particular input (this is the purpose of the factorial component), but it allows a meaningful look at the question of cost and returns for each management package. Moreover, one or more management packages may be suitable for immediate recommendation to farmers.

Any number of management packages can be tested. The farmer's practices, which are tested in the factorial component are usually designated as M_1; the high level of all inputs are called M_5. The three other packages that are tested in the IRAEN project are:

M_2 : a modest level of inputs that may be chosen by attempting to obtain the greatest added yield per added unit of input.

M_3 : a level of inputs with a cost about midway between the cost of M_2 and M_4. This might be the technology package being currently recommended to farmers in the area.

M_4 : the level of inputs that is expected to give maximum profit under good weather conditions and will not result in excessive lushness, lodging, or other yield reductions if poor weather occurs during the crop season.

The management package component is to be integrated with the factorial component into a single experiment. Theoretically it can be integrated with any one of the three sets of factorial treatments: the complete factorial, the mini-factorialand the supplemental. In practice, it should be tested either together with the minifactorial set or the supplemental set of both because adding to the complete factorial set (which is generally already large) will result in a very large experiment and will make it difficult to incorporate the whole set of experimental plots into a single paddy.

Other treatments

In addition to testing the treatments from the factorial component and the management package component, other treatments are sometimes tested. When the researcher is uncertain about whether or not the choice of the test factors used was correct, a treatment with all factors thought to affect the yield (i.e., test factors plus others), each set at the high level is usually added. A small difference in yield between this treatment and the one with only the test factors at the high level would give an indication that the researcher has already made a proper choice of the test factors. Other additional treatments commonly tested are one where all test factors are at the high level plus a high level of certain cultural practices (like age of seedlings and plant spacing); and another where all test factors are at the high level plus a micronutrient, say, Zn, if Zn is suspected to be deficient in the area.

Experimental procedures

Other practiced besides test factors. In the experiment, all other management and cultural practices besides the test factors are the same as those of the farmer on whose farm the experiment is located, and as much as possible they are managed by the farmer in the same manner that he uses for the rest of his farm.

Simulation of farmer's level of each test factor. There are two important concepts in the IRAEN approach to the yield constraints study that differ significantly from most experimental research.

(1) The improved technology is compared with the farmer's level and not to the zero level. There is more interest in finding out what improvement can be made over that of the farmer's inputs than in studying the effects of various inputs per se. For example, while we may be convinced that proper weed control is better than no weeding, we do not know whether a certain treatment for weed control is better than the farmer's method under his own environment.

(2) A comparison (or test) is made within each farm. While both physical environment and production practices affect yield, it is the changes in the production practices that are of immediate interest. In other words, the fitting of technology to a given physical environment is emphasized rather than changing the environment itself. Hence, by making comparisons within a given farm, the difficulty posed by the differences in the physical environments among farms is avoided.

The key ingredient in achieving the above two concepts is to establish and implement the farmer's level of each test factor in the experiment. The farmer's level is expected to vary from farm to farm. The farmer's level must be established separately for each farm.

The improved level of each test factor is specified before the start of the experiment on each farm. The farmer's level of each test factor, on the other hand, is not known in advance and needs to be determined though observation of the farmer's actual operations throughout the cropping season. Because farmer's practices may vary from one paddy to another, even on the same farm, the *comparable paddy* technique is used to determine the farmer's level of each test factor (IRRI 1977). That is, the same paddy in which the experiment is located, or a nearby paddy, is chosen as the comparable paddy before the experiment is set up. Whatever the farmer does in the comparable paddy is used as the farmer's level in the experiment.

The task of establishing and implementing the farmer's level of each test factor in the respective experimental plots can be done either completely by the researcher, completely by the farmer, or partly by each. Three major difficulties when the researcher is the one performing the simulation tasks are:

(i) the researcher cannot determine the farmer's level of a test factor from what the farmer says he will do; he must determine it from what the farmer actually does. This follow-upis quite time-consuming;

(ii) the unavoidable time lag in following the farmer's operations can at times produce a difference in the outcome (in particular, from insecticide application);

(iii) the exact level of certain operations, such as hand weeding, cannot be easily duplicated.

Thus, in establishing the farmer's level in experimental plots, as many test factors as possible should be done by the farmer himself. Factors that are amenable to having the farmer's level performed

by the farmer are insect control and mechanical weed control. For fertilization, the researcher should be the one to perform the simulation, but he must employ a procedure that can give an accurate determination of the farmer's fertilizer rate such as the marked – containertechnique.

Number of farms and number of replications. In a yield constraints study there are two major sources of variation: variation among farms and variation within farms. The use of several farms takes care of the first, and replication within farms takes care of the second type of variation. Of the two major sources, variation among farms is expected to be larger. Consequently, yield constraints experiments should be conducted with emphasis on including a sufficiently large number of farms rather than on having a large number of replications per farm. Under normal conditions it is not necessary to have more than two replications per farm.

The 3 – year experience of IRAEN participants indicates that at least 20 farms are needed for a study area, if an acceptable degree of precision in estimation of yields is to be achieved. Because yields and yield gap can be estimated from either the supplemental trial, the minifactorial trial, or the complete factorial trial, a decision on an appropriate canbination of these trials making up 20 farms must be made, The supplemental trial is the simplest to conduct, followed by the minifactorial, and finally the complete factorial trial, which is the largest in size. On the other hand, only the minifactorial or the complete factorial trials can provide information on the contribution of test factors; and only the complete factorial trial can provide information on interactions among test factors. Hence, an appropriate canbination of these 3 types of trials has a larger proportion of supplemental trials and a smaller proportion of minifactorial and complete factorial trials. The combination used by the IRAEN participants is 12 supplemental, 4 minifactorial, and 4 complete factorial trials giving a total of 20 trials. The total number of farms, as well as the proportion of the 3 types of trials, should be modified to suit a specific condition. The major factors affecting the choice are the resources available, the farm – to-farmvariation, and the importance of interaction effects between test factors.

Experimental design and plot layout. The choice of specific plot layout to be used depends upon

- whether or not plots have levees;
- whether the farmer's level is simulated by the researcher or actually implemented by the farmer;

- whether one or more of the test factors require a special plot arrangement (e.g., application of a high level or a low level of insect control in adjacent small plots is expected to bias the effect of insect control).

For a complete factorial trial or a minifactorial trial, especially with the management package component, leveed plots are generally used. An experiment is laid out in much the same way as one at an experiment station except that as much as possible all operations management and cultural practices except the test factors should be performed by the farmer himself as a part of the whole field. For operations like transplanting or land preparation (if neither is a test factor) where the presence of levees could considerably alter the farmer's normal operation the researcher may decide to take over the operations. In such cases it is essential for the researcher to simulate as closely as possible the farmer's procedures.

Yield from a leveed plot tends to be higher than that from a non-leveed plot (Rahim 1978). Leveed plots retain water and chemicals better. Thus, whenever the nature of the test factor permits, nonleveed but larger plots should be used. Eliminating levees reduces costs of constructing and maintaining than throughout crop growth and provide more uniform operation of the farmer's level for such practices as land preparation, transplanting and water management. Consequently, a better estimate of the various yield levels desired is obtained.

A nonleveed plot should be used for a supplemental trial. A plot of size 60-100 m^2 is placed at one end of the field (under irrigated conditions, preferably opposite to the entrance of irrigation water). The treatment with a high level of all test factors is applied to this plot by the researcher. All other practices are kept at the farmer's level and are performed by the farmer. The actual farm yield (with all practices, including the test factors, at the farmer's level) is obtained by harvesting from one or more nearby sample areas (crop cutting).

When insect control is used as a test factor, plots receiving the farmer's level and the high level should not be placed side by side. Yields from plots under the farmer's level of insect control adjacent to high insect control plots could be expected to be higher than those in plots located a distance away. Thus, an experimental design like the split-plot design should be employed, because it allows for greater separation of the two sets of plots: one with the farmer's level and another with the high level of insect control,

Data to be collected. Data from two units of observation are

collected, one with the comparable paddy as the unit and another with each experimental plot as the unit. The first type of data describes the farmer's practices, the corresponding growing conditions, and crop performance. The second describes the same but under varying levels of the test factors. Data collection in an on-farmyield constraints experiment need not be as detailed as that normally collected in agronomic trials at experiment stations, either in terms of the number of characters measured or in the measurement procedures used. Only data that are essential for explaining the contributions of the test factors should be collected in yield constraints experiments. For example, if insect control is a test factor, data on pest and disease incidence are essential. Similarly, if weed control is a test factor, data on weed incidence are essential. On crop performance, data such as plant height and tiller number should be collected periodically; data on yield components are not generally required. For most practical purposes, only grain yield data are needed.

SURVEYS

The socioeconamic aspects of the investigation are carried cut at the same time as the experiments and with the assumption that the available technology will result in higher yields under farmer's conditions. The objective of the socioeconamic investigation is to determine why farmers are not using the new technology at the level needed to achieve potential yields. If, after the crop season the experiments on farmers' fields prove that potential yields are not substantially higher than actual yields, then the socioeconamic reasons are not needed to explain farmer behavior. However, the experimental and the survey aspects proceed simultaneously.

Preliminary survey

A preliminary survey is conducted to (i) describe the farms in the study area, (ii) provide a basis for selecting farms on which to place the experiments, and (iii) gain an idea of the yield constraints perceived by the farmers. Farms are described by size, tenure, irrigation, and production of rice and other crops. If this information and that about perceived constraints are already available to the researchers, the preliminary survey may be dispensed with. Otherwise, a simple one-pageinstrument may be used for gathering data.

For the preliminary survey, the farmers are selected by a stratified sampling procedure. The strata may include units like agroclimatic area, municipality, and village, perhaps with the

subvillage as the final stratum. Because the objective is to represent an entire area and not specific villages or subvillages, proportional sampling may be used. The total number of farmers interviewed in the preliminary survey should be roughly twice the number that will be interviewed in the follow-up survey. There should be at least 100 farmers for the preliminary survey in each area. Sufficient units of final strata are chosen to represent the diversity in the study area. Farmers are sampled at random from the final strata.

Farms selected for the experiments should represent the spectrum of tenure, size, and production conditions encountered in the presurvey. Of course, relatively few of the survey farms will have experiments.

Follow-up survey

In general, the follow-up survey sample includes all farms with experiments plus *at least* an equal number of nonexperimental farms. The total number should be large enough to represent the study area.

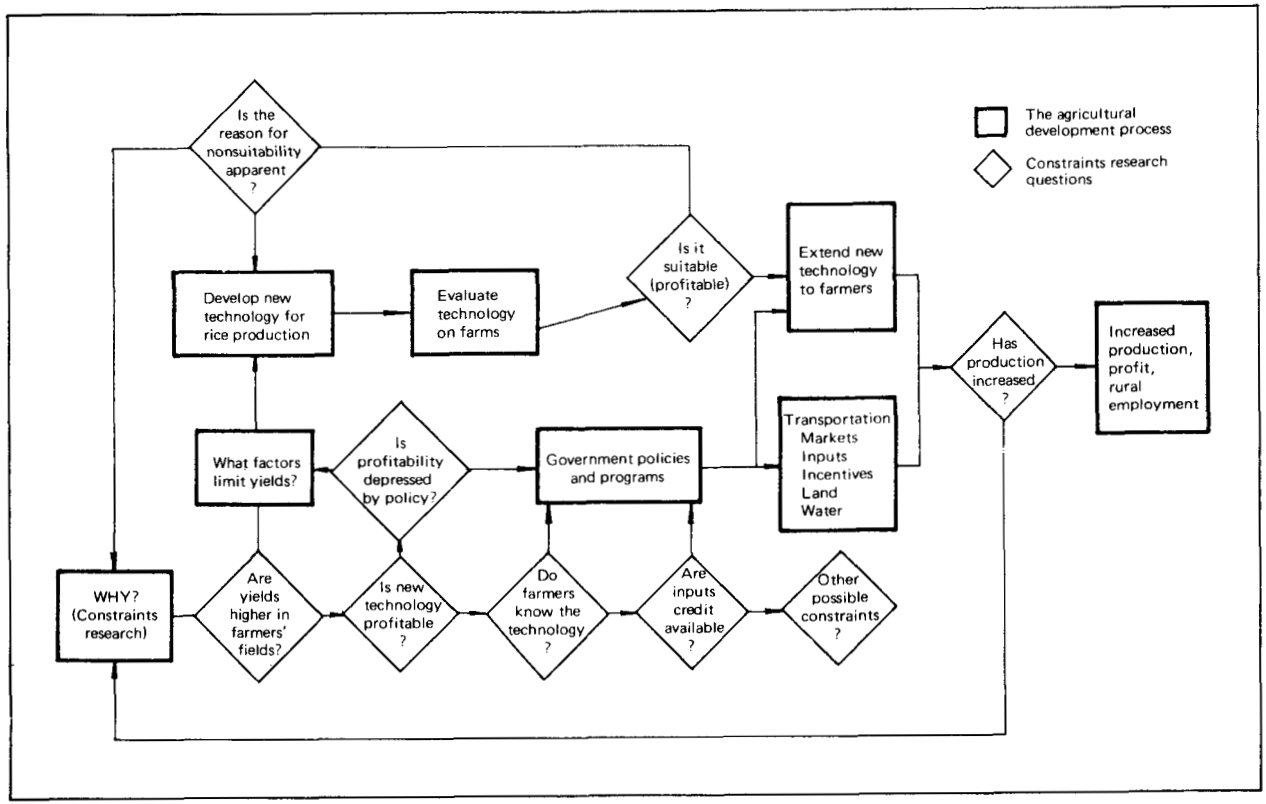
Figure 2 illustrates the constraints research process and the relationship of the methodology to the goals of agricultural development -- increased production, profit, and rural employment. Attaining these goals requires that new technology appropriate to the environment be extended to farmers. An opportunity for profitable sales of farm output must also exist. If production does not increase or does not increase at an appropriate rate, the reasons are sought by asking the following questions.

- When the new technology is used in farmers' fields, are yields increased over fields under the farmers' technology? If not, what factors restrict yields? Answers to these questions cane from the experiments described above.

- Is the new technology more profitable than the technology now used by the farmers? If not, it is not reasonable to expect the new technology to be adopted.

- Is the level of profitability restricted by government policies? If so, can the policies be changed, or can the technology be redesigned? The answers provide feedback to policy makers and researchers.

- Do farmers have a level of knowledge adequate for effective use of the technology? Are the necessary inputs and cash or credit required for use of the technology available to farmers? If



2. Constraints research in the development process.

not, how can programs ensure the availability of such inputs? The answers provide feedback to government programs and to the extension system.

In the surveys, attention is given to the economic, institutional, social, and psychological constraints. The major issues addressed by the survey and subsequent analysis are:

- Is the maximum yield level of one of the management packages tested in the experiments more profitable than present practices (given prevailing costs, prices, tenure, market discrimination) on the farms where experiments are conducted, or on other typical farms?

- Are inputs available at the time needed and in markets accessible to the farmers?

- Do farmers have the cash needed to use improved technology from institutional credit sources, from noninstitutional credit sources, or from their own resources?

- How well do farmer understand the following components of the technology: brands, chemicals, problems; use of the technology; where to get materials and their costs; what inputs to use for what problems?

- How do farmers perceive the reasons for their present levels and methods of input application, especially the three or four critical inputs tested in the factorial experiments? What do farmers believe are the major factors that keep their yields low?

The follow-up survey focuses on this limited set of questions. Only data that answer the questions are included. In this respect the constraints survey is much more limited than the usual socioeconomic research survey. The follow-up survey is reproduced in the HANDBOOK.

ANALYSIS OF DATA

The three major types of constraints data analysis usually performed are:

(i) estimation of yield gap and contributions of test factors to the yield gap;

(ii) costs and returns analysis;

(iii) identification of socioeconomic constraints contributing to the yield gap.

The first analysis utilizes experimental data from supplemental, minifactorial, and complete factorial trials. The second analysis utilizes all experimental data (including the management package component) and sane survey data. The third primarily utilizes the survey data.

Procedures for the first and second analyses have largely been standardized; those for the third analysis are still quite flexible and depend greatly upon the specific biological constraints identified. For the third analysis, therefore, only procedures common to most conditions are discussed here.

Estimation of yield gap and contribution of test factors to the yield gap

The yield gap for each farm is computed as the difference between the potential farm yield and the actual farm yield of that farm. Data from all three types of trials (supplemental, minifactorial, and complete factorial) are used to calculate the mean yield gap over all farms which represents the estimate of the yield gap for the study area.

The contributions of test factors to the yield gap can only be determined from the complete factorial or minifactorial treatments.

The computational method for the contributions depends upon the presence or absence of interaction effects among the test factors. Interaction effects are examined through standard analysis of variance technique, using data from the complete factorial treatments.

When interaction is absent, only the individual contributions of each test factor need to be determined one at a time. Using the data of the complete factorial treatments, the individual contribution of a factor is computed as the difference between the average yield of all treatments with that factor at the farmer's level and the average yield of all treatments with that factor at the high level. Using the data of the minifactorial treatments, the individual contribution of a factor is computed as the difference between the potential farm yield and the yield of the treatment with only that factor kept at the farmer's level and all other test factors at the high level.

When interaction is present, both individual contributions and joint contributions should be determined. From data of complete factorial trials, the individual contribution of a factor is computed as the yield increase over the actual farm yield when that particular factor is raised to the high level. The joint contribution of any two factors is computed as the increase in yield over the actual farm yield when the levels of these two

test factors are raised to the high level. Unlike the individual contributions which can only be computed from the complete factorial treatments, the joint contributions can be computed from both the complete factorial and minifactorial treatments.

Determining the profitability of the technology

It is a basic economic hypothesis that farmers will not adopt technology without sane incentive; that is, the new technology must carry with it sane advantage over their existing technology. Perhaps the measure that most accurately reflects incentive is the return to family-owned resources. The returns to family-owned resources with the actual technology and the technology necessary to get potential yields must be calculated. Costs and returns data from the survey are used to determine such returns.

One of the difficulties in broadly interpreting the profitability of physically effective technology is individual variation in the economic attributes of farms. Farms are owner-operated or operated under various forms of rental; some use a large and others use a small labor force. There is no *a priori* reason for the physical effectiveness of technology to vary among farms with different economic attributes, but the returns to family resources will differ depending upon how large a share of the total resources is contributed by the family.

Partial budgeting to compare the economics of the actual with the alternative technological packages is carried out for each farm on which a constraints experiment is conducted and for each typical or representative farm type. Returns to family resources are calculated by subtracting "paid-out" costs of test factors from gross returns. On farms where experiments are located, actual paid-out costs associated with the test factors are noted and returns to family-owned resources are calculated for the actual farmers treatments. For the alternative treatments, a judgment about which costs would be paid out and which would be met from family resources is made. (The nature of certain labor costs will depend upon the tenure and size of the farm, while other costs always involve payments off the farm. For example, in most cases transplanting and harvesting are done by hired labor.) Partial budgeting is used to compare both complete packages and single factors. This may lead the analyst to conclude that a package is not profitable but overcoming one constraint is.

Identifying socioeconomic constraints

One of the major purposes of the survey aspect of the research is to understand why farmers are not using the inputs needed for high yields or are not using them at the recommended rates. Farmers'

perceptions of the important constraints are valuable for understanding farmers' actions. If farmers do not see a particular factor as a constraint, one would not expect them to take action to overcome it.

Representativeness of experimental farms. It is important to know whether the farms with experiments are similar to or different from the average farms in the area being studied because the researcher would like to generalize his results. A canparison of the type of farm and level of input use and reported yield of farms with experiments and farms without experiments is the best way to determine this,

Size, input use, and tenure of the two groups may be canpared. Irrigation status might also be shown. The average and standard deviation of the farmers' levels of the test factors included in the experiment are calculated. The levels can be tested statistically to determine whether the differences are significant or not. If the two groups are substantially different, the researcher must be cautious in drawing conclusions from the experimental farms to the other farms.

Availability of technology requirements. Appropriate varieties, fertilizer, chemicals, knowledge, credit, and markets are necessary conditions for successful use of the new technology. Without then high yields would not be expected. Suitable varieties or fertilizer can be classed as available or not; in the case of credit or knowledge degrees of availability exist. In either case there is a methodological problem in measuring their availability to farmers. The methodology used is a series of index numbers or scales. Each scale measures a distinct condition that is hypothesized to necessary for successful use of the new technology.

Scales reflecting each of the following are constructed for each farmer studied:

(a) cash or credit to buy each input evaluated in the experiments;

(b) input availability and the availability of labor and/or capital required for using each input;

(c) knowledge of how to use each input;

(d) belief in the effectiveness of the technology.

Construction of b, c, and d depends directly upon the experimental variables. For example, if the experiments test insect control as a variable factor, the survey must be designed to determine

the availability, knowledge, and belief of the farmer about insect control, and possibly even about the specific types of insect control used in the experiment. Thus, the design of factor-specific survey questions depends upon the fixed and variable factors for the experiments.

The functioning of input and product markets is also studied. Issues related to the functioning of the input markets may include possible discrimination against farmers of certain sizes or tenure classes, the timeliness and availability of credit and inputs, and marketing costs in addition to the posted prices. Some insight into these issues is obtained in the farm interviews. In addition, visits to the local input and product markets help to determine the extent to which substantial increases in production could be absorbed. Interviews with market intermediaries help to describe the marketing system. Data on product prices are ascertained from interviews with market intermediaries. Similar prices are obtained from farmers. Marketing charges are determined from the differences between these two prices.

Possible credit constraints are investigated from the farm survey data and by examining the functioning of institutional credit sources. Interviews with the lending officers of local institutional credit sources help determine the total amount of credit that could be available under present regulations for the area being considered. The farm surveys provide information for determining the cost of credit from institutional and noninstitutional sources as well as farmers' preferences for credit from each source.

Cultural valuation of the outcome of the innovation process may slow its acceptance. An attempt is made to determine: whether farmers believe that the technology will increase their yields, incomes, and well-being; whether the use of certain practices or inputs is socially acceptable; whether the labor tasks that are part of the potential package are socially acceptable; whether the increase in labor use or change in type of labor are acceptable; the general assessment by individuals of the social stature of innovators; and the value to individuals of higher incomes and higher output (which may be related to the alternative consumption goods available).

REFERENCES CITED

De Datta, S. K., K. A. Gomez, R. W. Herdt, and R. Barker. 1978. A handbook on the methodology for an integrated experiment–survey on rice yield constraints. International Rice Research Institute, Los Baños, Laguna, Philippines.

Gomez, Kwanchai A. 1977. On–farmassessment of yield constraints: methodological problems in International Rice Research Institute. 1977. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Philippines.

International Rice Research Institute (IRRI). 1974. Annual report for 1973. Los Baños, Philippines.

International Rice Research Institute (IRRI). 1977. Annual report for 1976. Los Baños, Philippines.

Rahim, Kamal. 1978. A technique to identify constraints to high rice yields in farmers' fields. Unpublished MS thesis, University of the Philippines at Los Baños, Laguna, Philippines.

Constraints to High Rice Yields, Bangladesh, 1975 to 1977

M. Zahidul Hoque, Ekramul Ahsan, and Mukarram Hossain

Rice dominates Bangladesh agriculture, occupying about 80% of the country's total cropped area and yielding about 1.8 t/ha. Bangladesh agriculture has a low resource base and traditional production technology, resulting in inadequate local production of food grains. Because Bangladesh has reached the limit of its land potential, the only hope for increased food production appears to be technological innovation.

Successes in developing new rice varieties are particularly significant. Results at research stations reveal that modern rice varieties, with improved cultivation technology, have the potential to produce up to 6.5 tons of paddy per hectare. But few farmers' fields yield up to the known potential.

Modern rice varieties in Bangladesh

Modern rice varieties were introduced in Bangladesh in the mid-1960s when about 400 hectares were planted to IR8. That variety showed its tremendous yield potential, but it was not adapted to many of the rice-growing conditions encountered in Bangladesh. Since that time, with the intensive effort of rice scientists in Bangladesh, in cooperation with IRRI scientists, a number of other rice varieties have been developed. The modern varieties presently in fanners' fields are IR5, IR8, Irrisail (IR20), Purbachi, Chandina (BR-l), Mala (BR-2), Biplab (BR-3), and Brrisail (BR-4). Some of these varieties are specifically adapted to particular conditions and seasons. During 1976-77 the modern varieties were grown on about 13% of Bangladesh's total rice area and contributed about 26% of the total rice production (Table 1).

The socioeconomic characteristics of Bangladesh rice farmers appear to be complex. There is wide variability in the prices of inputs and output and in the availability of inputs and credit. The prices of inputs -- seed, fertilizer, and pesticides -- are determined by the government and are supposed to be fixed for all farmers. In reality, however, the price levels of various inputs, particularly fertilizer, is influenced by the distribution system and the supply at any given time.

Paddy price is partially determined by market forces and partly by government purchases. The purchase price set by government is usually a little higher than the market price at the time of harvest. However, since the government procurement is small, the government price has little impact on market price. Prices are usually lowest during harvest, increasing until the time of the next harvest. The low paddy price at harvest is a disincentive to the rice fanners in Bangladesh because that is also the time of planning for the next crop. In fact, harvesting the current crop and land preparation for the next crop are simultaneous.

Research Objectives

The constraints research has the general objective of determining the potential contribution of modern rice technology and the status of adoption of new varieties and improved technology among the rice farmers of Bangladesh. There were five specific objectives:

1. to determine the yield potential of the modern rice varieties when grown with improved technology on farmers' fields;

2. to determine the gap between farmers' yields and the potential yields of modern rice varieties with the improved technology;

3. to determine the relative contribution of different production factors to the yield gap on farmers' fields;

4. to determine the level and efficiency of technology adoption and the impact of adoption on productivity;

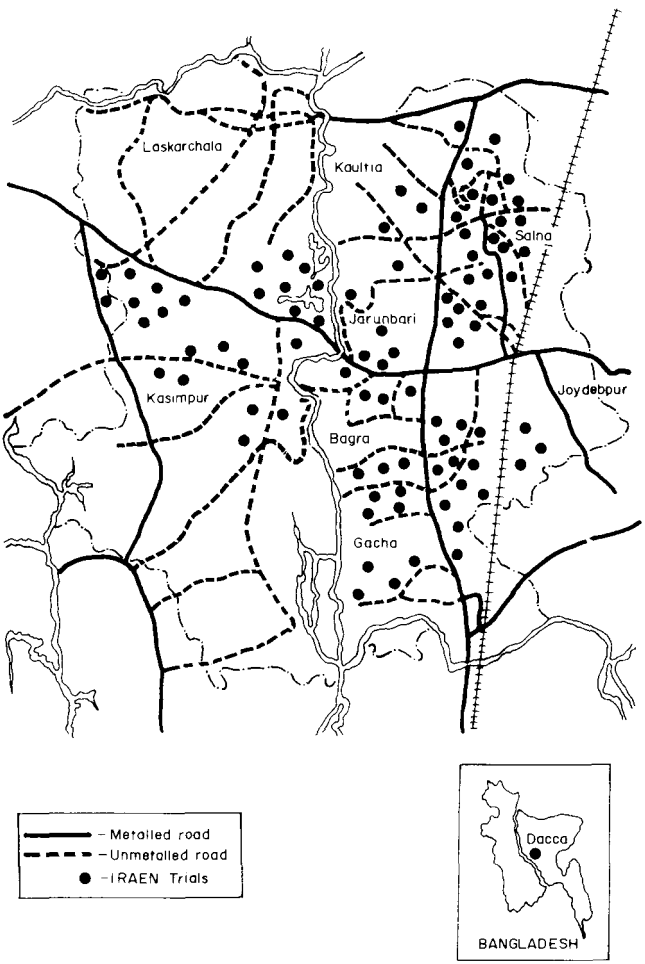
Table 1. Area and production of modern varieties and all rice. Bangladesh, 1969 – 70 to 1974 – 75. (Bureau of Agricultural Statistics, Ministry of Planning, Bangladesh).

Year	Rice area (1000 ha)			Rice production (1000 t)		
	All rice	Modern varieties	% of modern to total	All rice	Modern varieties	% of modern to total
1969 – 70	10,318	264	2.6		952	8.1
1970 – 71	9,917	420	4.2		1,505	13.7
1971 – 72	9,302	624	6.8		1,791	18.3
1972 – 73	9,634	1,065	11.1	14,895	5,729	25.0
1973 – 74	9,883	1,549	15.7	17,581	2,924	33.7
1974 – 75	9,796	1,452	14.8	16,663	5,091	30.6
1975 – 76	10,330	1,552	15.0	18,840	5,549	29.4
1976 – 77	9,881	1,329	13.4	17,350	4,533	26.1

5. to identify the factors associated with adoption of modern rice production technology for increasing rice yields.

Methodology

The methodology for the project included coordinated field trials and socioeconomic farm surveys in the study areas. The study areas were within the Bangladesh Rice Research Institute project area, a consolidated block comprised of 9 unions of 4 *thanas* in the Dacca district (Figure 1). The area represents one of the



1. BRRI Pilot project area showing the distribution of IRAEN field trials.

agroclimatic zones of Bangladesh in which rice is the main crop. Trials were conducted during all three of the rice-growing seasons -- aus, aman, and boro. The aman trials were grown as transplanted rice and are referred to as t. aman.

Beginning in t. aman 1975, experiments in farmers' fields enabled measurement of the influence of some of the physical and biological factors on the yield of modern rice varieties. Experiments were carried out on rainfed, partially irrigated, and fully irrigated fields. The major criteria used in the selection of the experimental sites were: the representativeness of the site for the type of rice-growing situation, the willingness of the farmer to cooperate, and the accessibility of the site.

The type and number of trials, experimental factors, and varieties used in the constraints project studies in different seasons are presented in Table 2. A total of 83 trials were successfully completed in 7 seasons. The experimental factors tested included variety, fertilizer (N, P, K, S), weed control, insect control, and land preparation. Eleven varieties of rice were grown by farmers on whose fields the trials were conducted.

The experimental designs were consistent with the decisions of the working group of the IRAEN project. The methodologies developed and presented in the IRAEN conferences were used in conducting the studies. However, some designs other than those presented in the IRAEN working papers were used for specific purposes (e.g., simple factorial experiments and replicated trials with management levels). Data analysis and interpretation of results were done in accordance with the IRAEN methodology.

The socioeconomic sample survey was conducted in eleven villages during the three seasons of 1976. All farmers growing rice in each season were first recorded and 10% of the total was selected at random in each village. This gave a sample of 70 in the boro, 105 in the aus, and 121 in the t. aman seasons.

In 1977 a random sample of 10 farmers was selected for interview from each of the 6 villages having t. aman experiments. In addition to these 60 farms, all of the 18 farms with t. aman experiments were also interviewed. The same 18 were interviewed a second time to obtain information about their boro and aus crops. Socioeconomic interviews were also conducted on 23 farms in boro and 11 farms in aus on which experiments had been conducted. For each farm, a first interview and a follow-up interview were conducted to obtain information about the other rice crops the farmers produced in that year.

Thus, the total number of interviews in 1977 was 34 for boro, 69 for aus, and 85 for t. aman, comprising a total of 188 interviews involving 96 farmers (Table 3).

Table 2. Types of trials, test factors, varieties, and number of farms on which constraints experiments were conducted in the BRRI pilot project area. Bangladesh, 1975 – 77.

Year	Type of trial	No. of trials	Test factors[a]	Varieties
	Boro season			
1975 – 76	Constraint series	6	F, W	IR8, BR3, Chandina
	Management package	1	F, W, I	
1976 – 77	Supplemental	14	F, W, I	IR8, BR3, Muktahar
	Minifactorial	4		
	Complete factorial – management package	5		
	Aus season			
1976	Complete factorial	9	F, W, I	IR8, Chandina Pukhi
1977	Supplemental	5	N, P, K, W	IR8, BR3, Chandina, Pukhi
	Minifactorial	4		
	Complete factorial – management package	2		
	T. aman season			
1975	Constraint series	3	F, W, I	IR20, Pajam Bairagisail
	Management package	1	F, W, I	
1976	Complete factorial	11	F, W, I	BR4, IR20, Pajam, Nizersail,
1977	Supplemental	9	N, S, I	BR4, Pajam, Nizersail, Chandrasail
	Minifactorial	5		
	Complete factorial – management package	4		

[a]W = weed control, I = insect control N = nitrogen, P = phosphorus, K = potassium, S = sulfur, F = fertilizer where N, P, K were varied together.

A follow-up interview covering the entire year on the same set of farms was conducted rather than shifting the sample by season, for the following reason. Farmers normally plant a t. aman crop and either a boro crop (if water is available in the dry season) or an aus crop. If the farmers planted an aus crop, the choice of a t. aman variety, input use, and yield would be affected by the management practices and date of harvest of the aus. For example, if the aus were harvested late and the t. aman were transplanted late, then the t. aman yields would be low. For this reason, it is important to examine the cropping pattern on a given farm for the entire year.

Physical and biological constraints

The results of the IRAEN experiments measuring the yield gap, contribution of different factors to the yield gap, and management packages are discussed below. The experiments conducted during the 1976 t. aman, 1976–77 boro, 1977 aus, and t. aman seasons are discussed in detail, while the previous seasons' experiments, which were reported in the *Interim report,* are briefly summarized.

Input levels and yield gaps

The gap between the farmers' yield and the potential yield is measured through experiments that compare the farmers' technology and the input levels needed for potential yields. In this section, the results of experiments are reviewed for each of the three

Table 3. Total number of interviews made of experimental and sample survey farms in three seasons. Bangladesh, 1976–77.

Kind of farm	Boro 1976–77	Aus 1977	T. Aman 1977	Total
Experimental farms				
boro experiment	23	-	3	26
aus experiment	-	11	4	15
t. man experiment	3	5	18	26
Subtotal	(26)	(16)	(25)	(67)
Sample survey farms				
t. aman	8	53	60	121
Grand total	34	69	85	188

seasons, showing first the input levels and then the yield gap.

Baro. Farmers applied fertilizer levels 40 – 70% lower than the level judged to be needed to get potential high yields (Table 4). Both farmers and researchers used higher fertilizer levels in 1976 – 77 than during the first year. Farmers' levels of weed control were lower in the second year than the first. Insect control was a test factor in the second year but not in the first.

The potential yield with modern varieties in the boro season was found to be about 5 t/ha (Table 5). On the 5 farms still growing local varieties, the potential yield was only 3.3 t/ha. Farmers' yields averaged 3.8 t/ha for modern varieties and 2.5 t/ha for local varieties.

The yield gap was 0.8 t/ha for modern varieties during 1976 – 77 and 0.9 t/ha for local varieties. This is a surprising change

Table 4. Farmers' level's and high levels of inputs in yield constraints experiments in farmers' fields. BRRI pilot project area, Bangladesh, 1975 – 77.

Variety type	Farms (no.)	Input level	Fertilizer [a] (kg/ha) N	P_2O_5	K_2O	Weed control (no.)	Insect control [b] (no.)
			Boro 1975 – 76				
Modern	4	Farmers'	25	20	0	4	-
		High	100	60	40	4	-
Local	2	Farmers'	50	50	45	3	-
		High	100	50	45	3	-
Al1	6	Farmers'	33	30	15	4	-
		High	100	57	27	4	-
			Boro 1976 – 77				
Modern	19	Farmers'	87	55	17	2.1	0.8
		High	176	80	60	3	3
Local	4	Farmers'	66	55	19	1.8	0.5
		High	156	80	60	3	3
All	23	Farmers'	83	55	18	2	0.7
		High	172	80	60	3	3

[a] N = nitrogen, P_2O_5 = phosphorus, K_2O = potassium.

[b] Insect control was not tested in boro 1976 – 77.

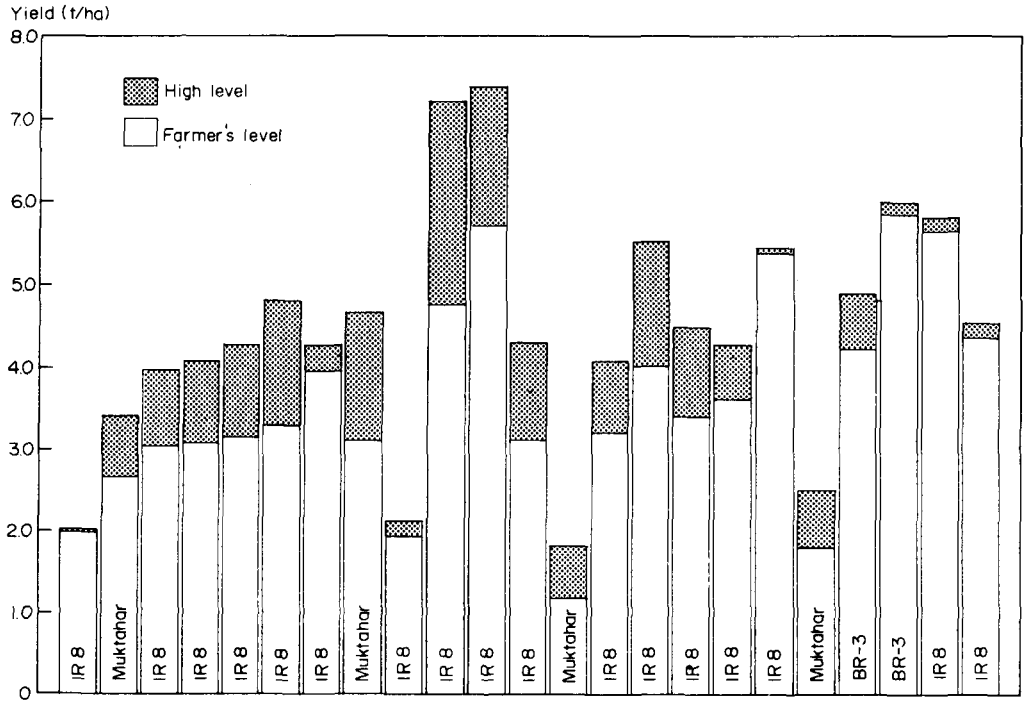
from 1975–76, when the gaps were 1.9 t/ha for modern varieties and 0.4 t/ha for local varieties. Taken together, a yield gap of 1 t/ha is a reasonable estimate for the boro season based on the 30 trials.

The variability in the yields and yield gap among the 23 test sites in 1976–77 is shown in Figure 2. Farms were arranged in order of fertilizer application, with the lowest on the left and the highest on the right. While there is no relationship between farmers' yields or potential yields and farmers' fertilizer levels, there does seem to be a clear tendency for farms with low fertilizer levels (on the left) to have larger yield gaps than the seven farms with the highest fertilizer levels.

Aus. The farmers' levels and the high level of inputs and management for the 1976 and 1977 aus seasons are given in Table 6. Farmers' fertilizer levels were low. None of the farmers applied insecticides and, except for one farmer, all weeded.

Table 5. Summary of yields with farmers' inputs and high inputs in constraints experiments. BRRI pilot project area, 1975–77.

Year	Modern varieties				Local varieties			
	Trials (no.)	Yield (t/ha)			Trials (no.)	Yield (t/ha)		
		Farmers' inputs	High inputs	Yield gap		Farmers' inputs	High inputs	Yield gap
Boro season								
1975–76	6	3.5	5.4	1.9	1	3.5	3.9	0.4
1976–77	19	3.9	4.7	0.8	4	2.2	3.1	0.9
Av	25	3.8	4.9	1.1	5	2.5	3.3	0.8
Aus season								
1976	6	3.5	3.6	0.1	3	1.2	1.3	0.1
1977	7	2.8	3.8	1.0	4	2.2	2.6	0.4
Av	13	3.1	3.7	0.6	7	1.8	2.0	0.2
T. aman season								
1975	4	1.6	2.6	1.0	0	-	-	-
1976	ll	3.2	4.8	1.6	0	-	-	-
1977	9	3.6	4.6	1.0	9	2.7	3.4	0.8
Av	24	3.1	4.4	1.3	9	2.7	3.4	0.8
Overall av	62	3.4	4.5	1.1	21	2.4	2.9	0.6



2. Potential farm yield and actual farm yield from yield constraints experiments in farmers' fields, BRRI project area, Bangladesh, Boro 1976–77. Each bar represents one farm. The farms to the right successively represent the higher use of fertilizer at farmers' levels.

In aus 1977, farmers applied higher levels of fertilizer and weeded. The high level of fertilizer was also higher than in aus 1976. During aus 1977, insect control was not a test factor.

Modern varieties averaged 3.7 t/ha with the high level of inputs during the aus season, while local varieties, which received a lower "high"rate averaged only 2 t/ha (Table 5). Thus, the yield potential seems lower in the aus than in the boro. Farmers' yields were also lower in the aus, averaging 3.1 t/ha with modern varieties and 1.8 t/ha with local varieties.

The yield gap was slight in the 1976 aus season, perhaps because the high level of nitrogen was rather modest, averaging 60 kg/ha. This rate was recomended by the BRRI fertilizer task force, based

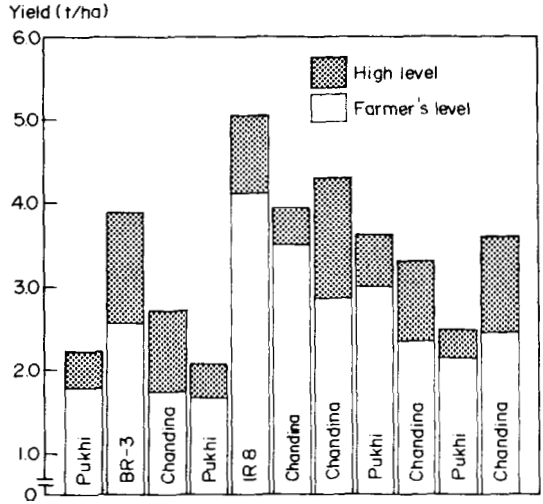
Table 6. Farmers' levels and high level of inputs in yield constraints experiments in farmers' field. BRRI pilot project area, 1976–77 aus season.

Variety type	Farms (no.)	Input level	Fertilizer[a] (kg/ha) N	P_2O_5	K_2O	Weed control[b] (no.)	Insect control[c] (no.)
			Aus 1976				
Modern	6	Farmers'	21	40	10	1.7	0
		High	60	40	40	WF	2
Local	3	Farmers'	13	21	12	1.0	0
		High	60	40	40	WF	3
All	9	Farmers'	18	34	11	1.4	0
		High	60	40	40	WF	2.5
			Aus 1977				
Modern	7	Farmers'	61	40	19	1.86	-
		High	144	80	60	3	-
Local	4	Farmers'	50	41	4	1.75	-
		High	76	40	40	3	-
All	11	Farmers'	60	41	13	1.82	-
		High	119	65	53	3	-

[a] N = nitrogen, P_2O_5 = phosphorus, K_2O = potassium.

[b] WF = weed-free.

[c] Insect control was not tested in Aus 1977.



3. Potential yield and actual farm yeld in constraints experiments. BRRI project area, Bangladesh, Aus 1977. Each bar represents one test farm.

on some previous experimental data. But during the course of experimentation it was felt that: this was really inadequate to constitute a high-input level and as such might have limited yield potential. In 1977 the high level of N was 76 kg/ha for local varieties and 144 kg/ha for modern varieties (Table 6). The gaps were 0.4 t/ha and 1.0 t/ha respectively for the two types in that season (Table 5).

Figure 3 shows the variability in the yields and yield gap during the aus season. On four farms the yield gap was small, but this was not identified with any particular variety nor fertilizer level. Maximum yield was achieved on the one farm growing IR8.

T. Aman. Farmers' fertilizer levels in t. aman were intermediate between boro and aus (Table 7). Weed and insect control levels were approximately the same as for other seasons. In 1977 it was decided to use an application of sulfur instead of P_2O_5 and K_2O in the high level of experiment.

In 1975 t. aman, all 3 farms with tests grew modern varieties. Farmers' yields were 1.6 t/ha and high yields were 2.6 t/ha (Table 5). In 1976 and 1977 both farmers' and potential yields were much higher. The yield gap averaged 1.3 t/ha over the 24 trials with modern varieties and 0.8 t/ha for the 9 trials with local varieties.

Variability in the yield gap in 1976 and 1977 t. aman seasons is shown in Figures 4 and 5. Yield gaps were substantial in all but two farms in 1976. In 1977 t. aman, the yield with farmers'

Table 7. Farmers' levels and high level of inputs in yield constraints experiments in farmers' fields. BRRI pilot project area, 1975 – 77 t. aman.

Variety type	Farms (no.)	Input level	Fertilizer[a] (kg/ha) N	P_2O_5	K_2O	S	Weed control[b] (no.)	Insect control (no.)
			T. Aman 1975[c]					
Modern (IR20)	3	Farmers'	0	0	0	-	0	0
		High	80	60	40	-	WF	3
			T. Aman 1976[d]					
Modern	3	Farmers'	21	17	7	-	1	0
		High	120	80	60	-	3	3
Loca1	8	Farmers'	35	35	27	-	1	0
		High	80	60	60	-	2	2
A11	11	Farmers'	31	30	22	-	1	0
		High	91	65	45	-	2	2
			T. Aman 1977					
Modern	9	Farmers'	51	43	9	0	1	1
		High	108	0	0	34	0	2
Local	9	Farmers'	47	49	7	0	1	1
		High	75	0	0	34	0	2
All	18	Farmers'	49	47	8	0	1	1
		High	-	0	0	34	0	2

[a] N = nitrogen, P_2O_5 = phosphorus, K_2O = potassium, S = sulfur.

[b] WF = weed – free.

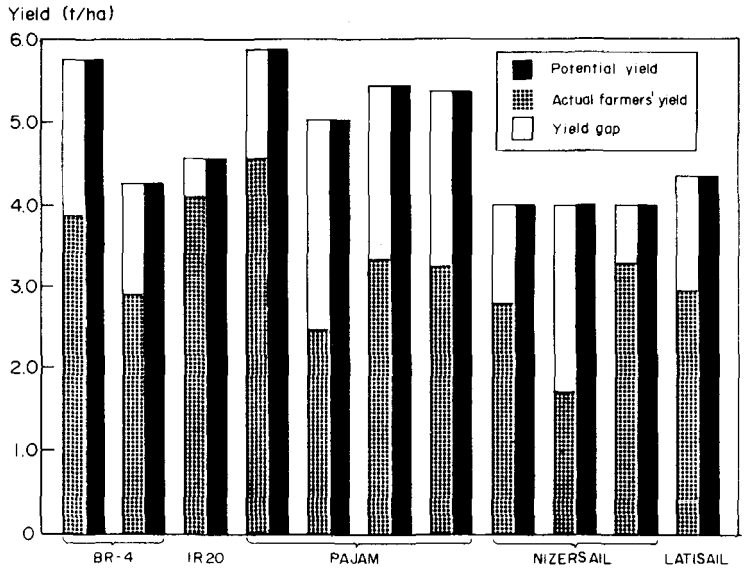
[c] Comparable paddy technique was not used. Low levels of fertilizer were used. See *Interim report* p. 26 for complete details.

[d] In t. aman 1976, Pajam was considered to be the local variety in terms of the use of fertilizer.

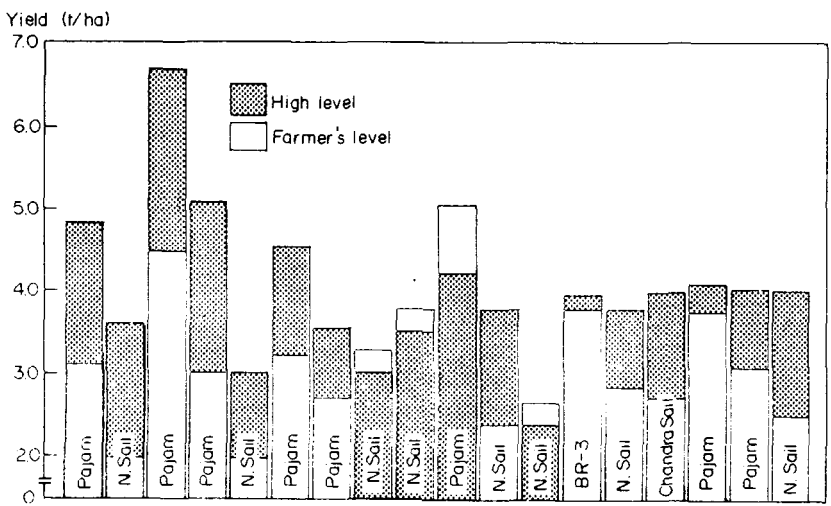
levels of inputs was higher than the yield with high levels of inputs in four trials.

Contributions of test factors

The discussion on contributions to yield is made quite complex by the changing test factors over different seasons and by the fact



4. Actual farmers' yield, potential yield and yield gaps in different varieties and farms of BRRI project area, 1976 T. Aman season.



5. Potential farm yield and actual farm yield from yield constraints experiments in farmers' fields, BRRI project area. Bangladesh, T. Aman, 1977. Each bar represents one farm. The farms to the right successively represent the higher use of fertilizer at farmers' levels.

that in some seasons interactions were found to be significant and so had to be taken into account in calculating the effects on yield. It should also be remembered that in 1976–77 there were a number of trials of different designs and, as a consequence, the number from which contributions can be measured is less than shown in Table 5.

Boro. Table 8 shows the contribution of various test factors to the boro season yield gap. For the 11 trials reported, fertilizer was by far the dominant factor. The main effects of fertilizer averaged 0.85 t/ha -- 64% of the total gap. The analysis of the

Table 8. Average contributions (individual and joint) of test factors estimated from complete factorial and minifactorial trials.[a] 1975–77 boro season.

	Boro 1975–76	Boro 1976–77		Average
	MV	LV	MV	
Farms (no.)	6	1	4	11
Yield at:				
Farmers' inputs (t/ha)	3.50	1.18	3.48	3.28
High input (t/ha)	5.20	1.82	4.43	4.61
Yield gap (t/ha)	1.70	0.64	0.95	1.33
Yield contribution (t/ha):				
Fertilizer (F)	1.30	0.02	0.38	0.85
Weed control (W)	0.40	0.05	0.10	0.26
Insect control (I)	n.t.	0.02	0.09	0.08
Residual	0	-	-	-
Farms (no.)	-	1	8	9
Yield effect of interactions:				
(F + W) (t/h)	-	0.37*	0.65	0.33
(F + I) (t/h)	-	0.09	0.62	0.29
(W + I) (t/h)	-	-0.07	0.21	0.08

*Significant at the 5% level.

[a] MV = modern varieties, LV = local varieties, n.t. = not used as a test factor.

complete factorial trials in 1976-77 indicated that interaction was significant between the three factors.[a] As a result, the minifactorial trials were used to calculate only the joint effects of pairs of factors, while the 5 complete factorials could be used to determine both main effects and joint effects. The

[a] See Hossain (1978) for the complete statistical analysis.

interaction effects show that fertilizer interacting with the other two factors was most important, while the insect control – weed control interaction was small.

Aus. Six different factors were tested in two seasons of aus trials. Interactions were significant in 1977, making the presentation quite long (Table 9). No factor dominated the contributions, although nitrogen and phosphorus made rather large contributions, alone and in combinations. In this season

Table 9. Average contributions (individual and joint) of test factors estimated from complete factorial and minifactorial trials. 1977 aus season.

	Aus 1976		Aus 1977		Average
	LV	MV	LV	MV	
Farms (no.)	3	6	-	2	11
Yield at:					
Farmers' inputs (t/ha)	1.20	3.50	-	2.30	2.65
High input (t/ha)	1.30	3.60	-	3.50	2.95
Yield gap (t/ha)	0.10	0.10	-	1.20	0.30
Yield contribution (t/ha):					
Fertilizer (F)	–0.10	0.10	-	-	0.10
Nitrogen (N)	-	-	-	0.40	0.40
Phosphorus (P)	-	-	-	0.27	0.27
Potassium (K)	-	-	-	0.10	0.10
Weed control (W)		0-0.10	-	0.09	–0.05
Insect control (I)	0	0	-	-	0
Residual	0.20	0.10	-	-	0
Farms (no.)	-	-	-	2	2
Yield effect of interactions:					
(N + P)	-	-	-	0.47**	0.47
(N + K)	-	-	-	0.14*	0.14
(N + W)	-	-	-	0.12*	0.12
(P + R)	-	-	-	0.15	0.15
(P + W)	-	-	-	0.20*	0.20
(K + W)	-	-	-	0.02	0.02
Farms (no.)	-	-	2	4	6
Yield effect of interactions:					
(N + P + K)	-	-	0.22	0.57*	0.45
(N + P + W)	-	-	0.09	0.61	0.44
(N + K + W)	-	-	0.22	0.45	0.37
(P + K + W)	-	-	–0.24	0.42	0.20

* Significant at the 5% level; ** Significant at the 1% level.

even the three-factor interactions were significant.

T. aman. Table 10 shows the consolidated statement of contributions for the three T. aman seasons. As in the boro season fertilizer's contribution dominated that of weed and insect control (about 0.2 t/ha). In 1977 the contribution of sulfur (0.65 t/ha) was nearly as large as that of nitrogen (0.71 t/ha). A significant interaction between nitrogen and sulfur contributed 0.9 t/ha.

Economic attractiveness of high levels of test factors

The yield contribution of the test factors is highlighted above and indicates that during the boro and t. aman seasons farmers' low level of fertilizer, either alone or interacting with other factors, was the major factor contributing to a yield gap of 1 t/ha or more. In this section, the costs associated with the high input level and the value of output obtained therefrom are discussed. In determining the costs and returns, the inputs used

Table 10. Average contributions (individual and joint) of test factors estimated from complete factorial and minifactorial trials, 1975–77 t. aman.

	T. Aman 1975	T. Aman 1976		T. Aman 1977		Av
	MV	LV	MV	LV	MV	
Farms (no.)	3	4	7	2	2	18
Yield at:						
Farmers' inputs (t/ha)	1.60	2.70	3.50	2.26	3.38	2.85
High input (t/ha)	2.60	4.10	5.20	3.82	4.66	4.31
Yield gap (t/ha)	1.00	1.40	1.70	1.54	1.28	1.45
Yield contribution (t/ha):						
Fertilizer (F)	0.60	1.10	1.30	-	-	1.09
Nitrogen (N)	-	-	-	0.88	0.54	0.71
Sulfur (S)	-	-	-	0.74	0.56	0.65
Weed control (W)	0.20	0.20	0.20	-	-	0.20
Insect control (I)	0.20	0.20	0.30	0.54	0.31	0.25
Residual	0	-0.10	-0.10	-	-	-0.10
Farms (no.)	-	-	-	5	4	9
Yield contribution at interactions:						
(N + S)	-	-	-	1.07	0.64*	0.88
(N + I)	-	-	-	0.58	0.17,	0.40
(S + I)	-	-	-	0.50	0.26	0.39

* Significant at the 5% level,

Table 11. Prices (Tk/kg) of paddy and of rice production inputs in the study area.[a] Bangladesh, 1975–1977.

Season	Prices (Tk/kg)						
	Paddy	Urea	TSP	MP	Basudin	Diazinon	Hand weeding (Tk/ha)
				1975			
T. Aman	2.00	1.33	1.06	0.80	-	-	150
Boro	2.00	1.33	1.06	0.80	-	-	150
				1976			
Aus	2.00	1.33	1.06	0.80	-	-	150
T. Aman	1.74	1.33	1.06	0.80	-	-	150
Boro	2.10	1.61	1.29	1.07	4.41	33.06	150
				1977			
Aus	2.10	1.61	1.29	1.07	4.41	33.06	150
T. Aman	2.28	1.61	1.29	1.07	4.41	33.06	150

[a] Exchange rate used: US$1 = Tk15. TSP = triple superphosphate, MP = muriate of potash.

in the experiments were costed at the prices prevailing in the study area during each season (Table 11). Paddy was valued at the price prevailing each season in the region.

Boro. Table 12 shows that the high level of fertilizer was highly attractive during Boro 1975–76, but the high level of weed control was less profitable than the farmers' levels. In 1976–77 the combined effects of fertilizer with weed control and fertilizer with insect control increased the value of rice output far more than their increased costs on modern varieties. However, on the one farm with a local variety the high inputs were less profitable than the farmers' levels of inputs.

Aus. In aus 1976 the high inputs were less profitable than the farmers' inputs (Table 13). In the 1977 aus season, the combined three–factorinteractions in the four–factor experiments were highly profitable on modern varieties and marginally profitable on local varieties, except for P + K + W. This indicates that high levels of inputs are more profitable than farmers' levels in the aus season.

T.aman. In the 1976 t. aman season the high level of fertilizer

was very much more profitable than the farmers' levels (Table 14). High insect control was also profitable, while high weed control was less so. In the 1977 t. aman season the interactions increased value of output more than cost of inputs, indicating the profitability of increasing all inputs.

Management package trials

To determine approximately the most profitable levels of input combinations, management package trials were undertaken. In these experiments some or all test factors were increased simultaneously. Economic analysis can indicate the best combination from among the ones treated.

Table 15 shows the levels of inputs used in the management package trials. In general, the lowest level tested was either the farmers' levels or zero, and the highest level was the same

Table 12. Economic performance of the individual and joint contributions of test factors from the high level of input in farmers' fields. Bangladesh, 1975–77 boro season.

	Boro[a] 1975–76	Boro 1976–77		
		Local[b]	Modern[c]	Average
	Fertilizer	Fertilizer + Weed control		
Farmers' cost (Tk/ha)	183	743	1014	984
Increased cost (Tk/ha)	274	909	745	763
Increased value (Tk/ha)	2300	770	1364	1298
	Weed control	Fertilizer + Insect control		
Farmers' cost (Tk/ha)	600	493	481	482
Increased cost (Tk/ha)	0	515	519	519
Increased value (Tk/ha)	700	187	1313	1188
	Insect control	Weed + Insect control		
Farmers' cost (Tk/ha)	-	250	573	537
Increased cost (Tk/ha)	-	594	384	407
Increased value (Tk/ha)	-	-146	443	378

[a] 6 farms. [b] 1 farm. [c] 8 farms.

Table 13. Economic performance of the individual test factors and their joint contribution at the high level of input use in yield constraints experiments in farmers' fields, Bangladesh, 1976 – 77 aus season.

Farms (no.)	Fertilizer (Tk/ha) Farmers' cost	Fertilizer (Tk/ha) Increase to high cost	Fertilizer (Tk/ha) Increase to high value	Weed control (Tk/ha) Farmers' cost	Weed control (Tk/ha) Increase to high cost	Weed control (Tk/ha) Increase to high value	Insect control (Tk/ha) Farmers' cost	Insect control (Tk/ha) Increase to high cost	Insect control (Tk/ha) Increase to high value
				Aus 1976					
9	143	176	200	216	WF[a]	– 200	0	100	200

Aus 1977

	N + P + K (Tk/ha) Farmers' cost	N + P + K (Tk/ha) Increase to high cost	N + P + K (Tk/ha) Increase to high value	N + P + W (Tk/ha) Farmers' cost	N + P + W (Tk/ha) Increase to high cost	N + P + W (Tk/ha) Increase to high value	N + K + W (Tk/ha) Farmers' cost	N + K + W (Tk/ha) Increase to high cost	N + K + W (Tk/ha) Increase to high value	P + K + W (Tk/ha) Farmers' cost	P + K + W (Tk/ha) Increase to high cost	P + K + W (Tk/ha) Increase to high value
4[b]	378	508	1220	1004	675	1305	947	615	968	774	449	899
2[c]	261	163	488	952	280	184	836	360	467	807	251	– 521
6	339	393	976	987	543	932	910	530	801	785	383	426

[a]WF = weed – free. Weed control data were not available, so additional weed control cost could not be computed. [b]Modern varieties. [c]Local varieties.

Table 14. Economic performance of the individual and joint contributions of test factors from the high level of input use in farmers' fields. Bangladesh, 1976 – 77 t. man.

Farms (no.)	Fertilizer (Tk/ha) Farmers' cost	Fertilizer (Tk/ha) Increase to high cost	Fertilizer (Tk/ha) Increase to high value	Weed control (Tk/ha) Farmers' cost	Weed control (Tk/ha) Increase to high cost	Weed control (Tk/ha) Increase to high value	Insect control (Tk/ha) Farmers' cost	Insect control (Tk/ha) Increase to high cost	Insect control (Tk/ha) Increase to high value
				T. Aman 1976					
	187	437	2144	n.a.[a]	245	202	n.a.	98	621
				T. Aman 1977					
		(N + S)			(N + I)			(S + I)	
4[b]	125	361	1471	179	146	395	54	283	601
5[c]	247	166	2449	258	-544	1313	11	282	1145
9	193	253	2014	223	62	905	30	262	903

[a]n.a. = data not available. [b]Modern varieties. [c]Local varieties.

as the high level in the factorial experiment. Average yield obtained at each input level is shown in Table 16.

Boro. Table 16 indicates that the grain yield of both local and modern varieties in the boro season increased gradually with increase in the level of management in 1976 – 77. This indicates the potential for increasing rice production in the boro season by adopting a higher level of management. Increased response of the rice crop to increasing management intensity in the boro season is partly the result of favorable weather conditions, especially increased solar radiation and lower incidence of insect pests and diseases.

Aus. The grain yield of the modern rice variety Chandina increased with increase in the intensity of management up to M_3, and then gradually declined at M_4 and M_5. M_3 appeared to give the highest yield of 3.6 t/ha. Data indicated that grain yield could be increased by as much as 1.29 t/ha by the high level of management in the aus season.

T. Aman. The average yield of the t. aman crop increased with successive increases in level of management up to M_4. However, the yields of modern varieties with M_3 and M_4 were Identical. On the average, the maximum yield increase from a higher level of management was 1.42 t/ha.

Table 15. Average farmers' levels (M_1) and management package level of inputs in yield constraints experiments in farmers' fields[a], BRRI pilot project area. Bangladesh, 1975–77.

Package level	Fertilizer (kg/ha) N	P_2O_5	K_2O	S	Total fertilizer (kg/ha)	Weed control (no.)	Insect control (no.)
				Boro 1975–76			
M_1	0	0	0	–[b]	0	0	0
M_2	40	40	0	-	80	1	0
M_3	60	40	20	-	120	2	2
M_4	80	60	40	-	180	3	3
				Boro 1976–77			
M_1	101	56	14	-	171	1.8	0.8
M_2	100	40	40	-	180	1	1
M_3	120	60	40	-	220	2	2
M_4	160	80	60	-	300	3	3
M_5	190	80	60	-	330	4	4
				Aus 1977			
M_1	52	44	21	-	117	2.5	–[b]
M_2	71	40	30	-	141	2	-
M_3	91	60	40	-	191	2	-
M_4	131	80	60	-	271	3	-
M_5	151	100	80	-	331	3	-
				T. Aman 1975			
M_1	0	0	0	0	0	0	0
M_2	60	0	0	0	60	1	1
M_3	60	40	40	0	140	2	2
M_4	80	60	40	0	180	3	3
M_5	100	60	40	0	200	WF[c]	4
				T. Aman 1977 local variety			
M_1	52	-	-	0	52	–[b]	0.5
M_2	50	-	-	17	67	-	1
M_3	70	-	-	26	96	-	1
M_4	90	-	-	34	124	-	2
				T. Aman 1977			
M_1	54	-	-	0	54	-	0.5
M_2	84	-	-	17	101	-	1
M_3	104	-	-	26	130	-	1
M_4	124	-	-	34	158	-	2

[a] Modern varieties were used in all seasons unless where indicated.
[b] Not used as test factor. [c] WF = weed-free.

Table 16. Average grain yield of farmers' and alternative input management packages. Bangladesh, 1975 – 77.

Year	Variety[a]	Farms (no.)	Grain yield (t/ha)					
			M_1	M_2	M_3	M_4	M_5	Av
			Boro season					
1975 – 76	LV	1	2.42	2.64	3.43	3.38	-	2.97
1976 – 77	LV	1	1.18	1.25	1.62	1.82	2.23	1.62
	MV	4	3.48	4.11	4.36	4.43	4.87	4.25
	LV + MV	5	3.02	3.54	3.81	3.91	4.34	3.72
			Aus season					
1977	MV	2	2.32	2.82	3.61	3.50	3.48	3.15
			T. Aman season					
1975	LV + MV	3	1.71	2.16	2.61	2.96	2.87	2.46
1977	LV	2	2.27	3.45	3.77	3.82	-	3.33
	MV	2	3.34	3.94	4.65	4.65	-	4.16
	LV + MV	4	2.82	3.69	4.21	4.24	-	3.74

[a]LV = local variety, MV = modern variety.

Table 17. Economic comparison of different levels of management. Bangladesh, 1975 – 76 boro season.

Management levels	Yield (t/ha)	Additional yield over M_1 (t/ha)	Value of added yield (Tk/ha)	Cost of added inputs (Tk/ha)	Added net returns over M_1 (Tk/ha)
M_1	2.42	-	-	a	-
M_2	2.64	0.22	433	432	1
M_3	3.43	1.01	1992	786	1206
M_4	3.38	0.97	1907	1031	876

[a]M_1 was set at zero level of inputs.

Table 18. Economic comparison of different levels of management. Bangladesh, 1976 – 77 boro season.

Management level	Input cost (Tk/ha)	Gross returns (Tk/ha)	Net returns (Tk/ha)	Comparison with farmers' level (M_1) Added input cost (Tk/ha)	Added gross returns (Tk/ha)	Added net returns (Tk/ha)
			Modern variety[a]			
M_1	1078	7338	6260	-	-	-
M_2	907	8680	7773	– 171	1342	l513
M_3	1356	9002	7846	278	1864	1586
M_4	1850	9350	7500	772	2112	1240
M_5	2093	10267	8174	1015	2929	1914
			Local variety[b]			
M_1	743	2456	1713	-	-	-
M_2	862	2603	1741	119	147	28
M_3	1258	3374	2116	515	918	403
M_4	1751	3780	2029	1008	1324	316
M_5	1994	4647	2653	1251	2191	940

[a] Average of four sites.

[b] One site.

Economic performance of different levels of management

The relative economic performance of different levels of management in the three seasons is presented in Tables 17 through 21. Results are briefly discussed below by season.

Boro. Tables 17 and 18 present the data on the relative economic advantage of different levels of management in the boro. In 1975 – 76, M_3 gave the largest increase in net returns and the largest increase in yield over M_1. In 1976 – 77 (Table 18) the highest net returns among the management levels came from M_5, indicating the high response of boro rice to the high management level. Higher profits were obtained at high management levels with the modern varieties than with the local varieties.

Aus. Data in Table 19 indicate that all higher levels of management increased profits over the farmers' levels. However, the highest increased net returns (Tk2668) came from M_3. This

Table 19. Economic comparisons of different levels of management over farmers' (M_1) level. Bangladesh, 1977 aus season.

Management level	Input cost (Tk/ha)	Gross returns (Tk/ha)	Net returns (Tk/ha)	Comparison with farmers' level (M_1): Added input cost (Tk/ha)	Added gross returns (Tk/ha)	Added net returns (Tk/ha)
			Modern varieties[a]			
M_1	1063	4936	3873	-	-	-
M_2	1045	6033	4988	-18	1097	1115
M_3	1188	7729	6541	125	2793	2668
M_4	1683	7500	5817	620	2564	1944
M_5	1844	7439	5595	781	2503	1722

[a]Averaged over 2 sites.

Table 20. Economic comparisons of different levels of management over farmers' levels (M_1) using modern varieties. Bangladesh, 1975 t. aman season.

Management level	Yield (t/ha)	Added yield over M_1 (t/ha)	Value of added yield (Tk/ha)	Cost of added inputs (Tk/ha)	Added net returns over M_1 (Tk/ha)
M_1	1.7	-	-	[a]	-
M_2	2.2	0.5	1000	367	633
M_3	2.6	0.9	1800	695	1105
M_4	2.9	1.3	2600	944	1656
M_5	2.9	1.2	2600	ll93	1407

[a]M_1 set at zero level of inputs.

particular level of management also gave the highest benefit: cost ratio of 38.81, computed from the increased cost and returns over farmers' levels.

T. Aman. Tables 20 and 21 show that all higher levels of management over the farmers' levels were economically profitable in the t. aman season for both local and modern varieties. M_4 gave the greatest increase in 1975. M_3 gave the highest increased

Table 21. Economic comparisons of different levels of management and farmers' level (M_1). Bangladesh, 1977 t. aman season.

Management	Input cost (Tk/ha)	Gross returns (Tk/ha)	Net returns (Tk/ha)	Comparison with farmers' level (M_1)			
				Added input cost (Tk/ha)	Added gross returns (Tk/ha)	Added net returns (Tk/ha)	% of farms with increased net returns
				Modern varieties [a]			
M_1	212	7,748	7,536	-	-	-	-
M_2	392	9,017	8,625	180	1,269	1,089	100
M^3	498	10,655	10,157	286	2,907	2,621	100
M_4	629	10,657	10,028	417	2,909	2,492	100
				Local varieties [a]			
M_1	214	5,165	4,951	-	-	-	-
M_2	272	7,864	7,592	58	2,699	2,641	100
M_3	377	8,889	8,512	163	3,724	3,561	100
M_4	508	8,713	8,205	294	3,548	3,254	100

[a] Average of two sites.

net returns in 1977 t. aman. However, the highest benefit–cost ratios from the extra inputs over farmers' levels were obtained from M_2 with local varieties and M_3 with modern varieties.

Table 22. Proportion of survey farmers' area planted to modern and local varieties and reported yields. Joydebpur, Bangladesh.

Season	Percent of rice area		Yield (t/ha)	
	Modern varieties	Local varieties	Modern varieties	Local varieties
Aus 1976	43	57	3.39	1.64
Aus 1977	70	30	3.63	2.02
T. aman 1976	41	59	2.86	1.95
T. aman 1977	37	63	3.13	2.75
Boro 1976–77	88	12	4.26	2.82

Social and economic constraints

Earlier studies revealed that variability in the productivity of rice farming in Bangladesh was primarily associated with the use of modern and local varieties and levels of fertilizer use. A socio economic investigation for identifying constraints to the cultivation of modern varieties and the application of adequate fertilizer constitutes the framework of this analysis. In addition, farmers' knowledge of improved technology and improved practices and their economic behavior are also included in the framework of analysis in an attempt to ascertain their relative significance as constraints to higher productivity in rice cultivation.

Modern rice varieties

In the study area the proportion of land planted to modern varieties varied in different seasons. A larger proportion of the area is planted to modern varieties during the boro season (Table 22), when the yield is highest. The average yield of modern varieties was consistently higher than the average yield for the local varieties in all seasons.

In spite of the evidence that modern varieties are relatively more productive, and even with the conclusion of earlier IRAEN studies that cultivation of modern varieties is more profitable, the nationwide adoption has been rather slow, and their impact on rice production in the country is not significant at present.

Table 23. Percent distribution of reasons for not growing modern rice varieties on farms. Joydebpur, Bangladesh, 1976–77.

Reasons	Crop season	
	Boro 1976–77	T. Aman 1977
Land is suitable for local variety (LV)	-	19.48
Modern variety (MV) is not suitable for crop sequence	-	44.16
MV requires more time than LV	88.89	3.90
LV are suitable for late sowing	-	11.69
Lower product price for MV	11.11	9.39
MV for transplanted Aman season not known	-	2.60
Scarcity of water	-	6.49
MV seeds not available	-	1.30

Table 24. Percentage of survey farmers' responses to the availability of factors. Joydebpur, Bangladesh, 1976.

Factor	Type of availability	Farmers (%) Aus 1976	T. Aman 1976
Seed of modern varieties	Available in time	98	99
	Adequately available	94	99
Fertilizer	Available in time	69	88
	Adequately available	78	95
Insecticide	Available in time	43	47
	Adequately available	43	28
Credit	Available in time	16	27
	Adequately available	14	26

Perceptions. Farmers' responses to the question of why cultivation of the modern varieties was not expanded reveals a number of interesting findings (Table 23).

Cultivation of modern rice varieties, particularly in either the aus or t. aman season, does not fit into the cropping sequence. An early-maturing variety for the aus season or a photosensitive rice variety for the t. aman season must be developed if rice cultivation is to be intensified. Other important factors are land suitability and water depth, growth period, and suitability for late sowing.

Seed supply. The seed supply situation for the modern rice varieties was reasonably good in the study area. Seeds were available to most of the farmers (Table 24) because a farmer-to-farmer seed exchange program was initiated and coordinated in the study area by the Bangladesh Rice Research Institute. Elsewhere in Bangladesh, however, the seed supply situation was not good.

Fertilizers: level of use and availability

One of the consistent findings of the field trials was that the low level of fertilizer used was the basic constraint to higher productivity, despite the proven profitability of higher levels of fertilizer.

Table 25. Average inputs used and yields of paddy plots planted to modern and local varieties. Bangladesh, 1976 – 77.

Variety	Fertilizer[a] (kg/ha) Urea	TSP	MP	Total fertilizer cost[b] (Tk/ha)	Weeding cost (Tk/ha)	Yield (t/ha)
			Aus 1976			
Modern	97	72	9	257.25	478.35	3.4**
Local	62	56	4	176.10	336.75	1.6
Difference	35	16	5	81.15**	141.60	1.8
			T. Aman 1976			
Modern	86	87	-	251.25	383.55	2.9
Local	60	52	-	169.05	293.55	2.0
Difference	25**	35**	-	82.20**	90.00**	0.9**
			Boro 1972 – 77			
Modern	156	116	36	420.60	601.05	4.3
Local	120	95	5	319.80	498.00	2.8
Difference	36	21	31	100.80	103.05	1.4*
			Aus 1977			
Modern	124	81	11	308.85	533.70	3.6
Local	90	66	7	243.15	383.10	2.0
Difference	34	15	4	65.70	150.60**	1.6**
			T. Aman 1977			
Modern	133	100	17	361.95	375.45	3.1
Local	114	79	12	294.90	429.60	2.8
Difference	19	21	5	67.05	– 54.15	0.4

*significant at 5% level.
**significant at 1% level.
[a]TSP = triple superphosphate, MP = muriate of potash.
[b]Exchange rate used: US$1 = Tk15.

Table 25 shows the average level of fertilizer and weeding used by the sample rice farms in different seasons in 1976 and 1977. It appears that farmers' levels of urea in aus 1976 and boro 1975 – 76 and 1976 – 77 were quite low compared with the recommended level F_4 for the constraints field trials. Rice farmers did use nearly adequate amounts of urea in aus 1977, t. aman 1976, and 1977 seasons. The yields were not consistent with the level of fertilizer used, indicating low levels of fertilizer efficiency.

Farmers were asked if fertilizer was available at the time of land preparation and topdressing. In early 1976 during the aus season, 21% reported not getting enough fertilizer and 30% reported not receiving it at the proper time. However, most believed fertilizers were available at the time of land preparation and topdressing in boro 1976 – 77, aus 1977, and t. aman 1977. Nonavailability of fertilizers could not have been a serious constraint in 1977.

A high proportion of those farmers who did not get fertilizer in time during 1976 aus and t. aman (71% during aus and 43% during t. aman) did not find the fertilizers at the sales center, whereas a much lower proportion could not buy additional fertilizer for want of money (Table 26). About 6% of the farmers in the aus season and 13% of the farmers in the t. aman season considered the price of fertilizer too high. During the aus season about 15% of the farmers reported that the fertilizer dealers demanded prices higher than the government price; so they did not buy enough.

For the 1976 – 77 boro season, 54% of the farmers considered their present level of fertilizer use optimal compared to about 80%

Table 26. Percentage distribution of farmers' reasons for not obtaining fertilizer in time. Bangladesh, 1976.

Reason	Farmers (%)	
	Aus 1976	Aman 1976
Dealer cannot supply in time	70.59	43.33
Lack of money	8.82	13.33
High price	5.88	13.33
Dealer demands more money	14.71	-
Soil becomes hard	-	23.33
Productivity of land becomes low	-	3.33
Soil becomes acidic	-	3.33

Table 27. Percentage distribution of farmers' reasons for not applying more fertilizer.

Reason	Farmers (%)	
	Boro 1977	Aman 1977
The amount was optimal	54.08	79.71
Want of money	33.68	7.25
Price was high	5.10	6.52
Didn't receive in time	3.06	3.62
Scarcity of fertilizer	3.06	2.90
Could not apply because of excess water on the land	1.02	-

Table 28. Summary of chi-square and Fisher's exact probability test results.

Season	Variable 1	Variable 2	x^2	Fisher's one-tailed test
Aus 1976	Credit availability	Weed control	-	0.185 ns
		Fertilizer cost	0.07 ns	-
T. Aman 1976	Credit availability	Weed control	0.02 ns	-
		Fertilizer cost	0.54 ns	-
Boro 1977	Credit availability	Weed control	-	0.600 ns
		Fertilizer cost	-	0.600 ns
Aus 1977	Credit availability	Weed control	-	0.400 ns
		Fertilizer cost	-	0.600 ns
T. Aman 1977	Credit availability	Weed control	0.02 ns	-
		Fertilizer cost	0.16 ns	-

ns not significant.

in t. aman (Table 27). These farmers did not consider further increases in fertilizer use. The other important stated reason for not using more fertilizer was lack of cash (34% in boro 1976–77and 7% in t. aman 1977) and non–availabilityof credit. About 5% of the farmers studied opined that the price of fertilizer was too high to use more.

Credit: availability, utilization, and farmers' reactions

Most of the rice farmers in the study area have small plots and are short of capital for investment in rice cultivation. Sixty–nine percent had holdings below 2.5 acres, and 89% had holdings below 5 acres. Surveys in different seasons revealed a varying picture of credit availability, based on farmer's perceptions of whether they could obtain credit,

Chi–square tests of independence between credit availability and levels of weed control and fertilizer used revealed that these variables were independent (Table 28). This was perhaps because credit availability and credit use for crop production were so rare that meaningful relationships could not be derived.

A supplementary survey on availability of credit from three banks in the study area revealed that credit for farming purposes was very limited (Table 29). So it was not surprising that farmers' use of credit was slight.

Experimental results and perceived constraints compared

The perceptions of participating farmers about the constraints were compared with their experimental results. Nine farmers on whose farms a yield gap was measured in the boro season were interviewed. Four believed that their yield could not be increased with higher inputs (Table 30). Of the 5 others, only one mentioned inadequate fertilizer and insect control as possible contributors to the gap. Three identified inadequate insect control alone and another mentioned inadequate use of fertilizer alone. By contrast, the experiments showed that the joint contributions of test factors were important while the individual contributions were not.

In the aus season, out of 6 farms having a yield gap, 4 farmers believed yield could not he increased with higher inputs, while only 2 mentioned inadequate use of fertilizer as a yield constraint. In the t. aman season, out of the 9 farmers having a yield gap, 7 reported that yield could not be increased with increased inputs. One referred to inadequate insect control, and another referred to inadequate use of fertilizers and insect control as yield constraints,

Table 29. Credit programs and repayment records of three banks in the Joydebpur area, 1977 (Division of Agricultural Economics and Statistics, BRRI).

Bank	Target amount (Tk)	Distri-buted amount (Tk)	Amount repaid (Tk)	Amount unpaid (Tk)	No. of farms taking loans	No. of farms that repaid	No. of defaults
Rupali	65,000	25,240	4,450	20,790	47	10	37
Janata	65,000	56,000	19,000	37,000	111	56	55
Agrani	70,000	70,585	20,000	50,585	130	31	99

It is evident that most of the farmers who experienced gaps were unaware that their yields could be profitably increased with higher levels of inputs. The economic analysis of the experimental data showed that in most cases farmers can profitably achieve at least 1 t/ha increase in yield with the use of high inputs. Moreover, among those who identified yield constraints, most mentioned only one test factor as responsible for the low yield. Although experimental results showed that fertilizer, in combination with another factor, is the most important yield-contributing factor in all seasons, most farmers believed that inadequate insect control was the primary yield constraint.

Table 30. Number of farms on which the constraints experiments showed a yield gap and the farm operators' perceptions of major yield constraints. BRRI pilot project area, 1977.

	Boro	Aus	T. Aman
Number of farms on which trials showed a yield gap	9	6	9
Number reporting each yield constraint			
No perceived constraints	4	4	7
Inadequate fertilizer	1	2	0
Inadequate insect control	3	0	1
Inadequate fertilizer and insect control	1	0	1

Insufficient availability of fertilizer was identified as the second most important reason for its low use. To confirm this contention, two c^2 tests between fertilizer use and availability were made for each season -- one on the availability and use of fertilizer at the tine of basal application, and the other on availability and use at the time of top dressing. The c^2 values derived were not significant, indicating that farmers who replied fertilizer was insufficiently available or unavailable used the same level of fertilizer as those who replied that fertilizer was sufficiently available. This implies that perceived availability of fertilizer made no difference to the actual level used by farmers in the study area during the study period.

The most important socioeconomic constraint identified for the low use of fertilizer in all seasons by both experimental and survey farmers was the lack of cash. Farmers who used low fertilizer levels for that reason were asked why they did not borrow. Most replied that credit was not available to them (Table 31). The second most important reason given was unwillingness to accept the risk associated with borrowing.

Two important reasons identified by farmers for using inadequate insect control measures were: (1) the insecticides were not available, and (2) delays in taking insect control measures. The primary reason given for such delays was that they were unable to identify insect infestation well ahead of its occurrence. In general, it was observed that the farmers had poor knowledge of insect control. Interviewed farmers were asked to identify the insects found in each season. In most cases, they mentioned only

Table 31. Socioeconomic constraints stated by farmers as reasons for not using credit to buy fertilizer. BRRI pilot project area, 1977.

Socioeconomic constraint	Farmers reporting each season			
	Aus		T. Aman	
	Number	Percent	Number	Percent
1. Credit not available	11	64.7	5	27.8
2. Credit is risky	2	11.8	4	22.2
3. Too much red tape	1	5.9	1	5.6
4. Still in debt from last year	1	5.9	0	0
5. Inadequate information about credit	1	5.9	0	0
6. No response	1	5.8	8	44.4
Total	17	100.0	18	100.0

stemborer, irrespective of the season. Many also mentioned that they did not know about most of the insects.

Summary and implication

The average yield gap over all farms in the study was about 1.6 t/ha (rough rice) in the boro season. In aus the yield gap ranged from zero to 0.5 t/ha (rough rice). In t. aman, the gap ranged from 0.9 t/ha to 1.6 t/ha. Fertilizer was the most important contributing factor, but significant interactions showed that failure to use two or three inputs together resulted in lower productivity.

Modern rice varieties consistently gave significantly higher yields than local varieties. Cultivation of modern varieties was profitable, but intensive rice farmers found it difficult to fit these varieties into the cropping system and crop sequence.

Farmers were aware of modern varieties and other technology components. Most believed that their present level of fertilizer use was adequate. Others were sensitive to the price of fertilizers

Most of the farmers had small plots, and it was difficult for them to obtain sufficient capital for achieving high levels of production. Limited credit was available, but farmers were not interested in using it because of various problems associated with the system.

Future constraints studies

Farmers' yields averaged 2.9 t/ha in the Bangladesh Rice Research Institute (BRRI) project area. These are significantly higher than the national average of 1.8 t/ha. Sufficient work has been done in the area to get some idea of the yield gap and the quantitative contribution of various factors to it. Attention will now be given to other rice areas.

In the Bangladesh Rice Research Institute (BRRI) project area, constraints studies will be continued at the specific sites where cropping systems research is being continued. At these sites, constraints trials will be conducted across selected cropping patterns rather than on individual crops in specific cropping seasons.

Designs for experiments in farmers' fields will include supplementary, minifactorial, and complete factorial trials. A long-termresearch program will be established in some selected farmers' fields to identify the constraints to high yields on

sequential crops. Sixteen fields have already been selected at one site for this purpose, and detailed monitoring of weather and soil parameters has been planned to supplement the constraints experiments.

Detailed records will be kept on stratified sample farms to determine the productivity and constraints for each parcel of a farm. This project should give us comprehensive information about the total production constraints within each farm size group. Four Cooperative farms at one site (Bhogra) in each of 4 farm size groups (0 – 0.5ha, 0.5 – 1.5ha, 1.5 – 2.0ha, >2 ha) have already been selected through a pre – survey.

A large – scale constraints study has been initiated at the national level, with the objective of helping the government production programs in irrigated northwstern and southwestern parts of Bangladesh. The area being considered for this project constitutes about 35% of the total cultivable area of Bangladesh. At first, nine supplementary and one complete factorial experiments have been proposed in each of 140 locations under the project. Field – level workers to whom these studies are being assigned include subject matter specialists and local extension officers with at least a bachelor's degree in agriculture, local agriculture officers with diplanas in agriculture, and unit and section officers with diplomas in engineering. Test factors will be established according to area and season, and the studies will be made across location – specific cropping patterns.

REFERENCE CITED

Hossain, Md. Mukarram. 1978. Socio – economic factors constraining yields of rice in selected sites in the Bangladesh Rice Research Institute Pilot Project Area, Bangladesh 1976 – 77. Unpublished MS thesis in Agricultural Economics. University of the Philippines, Los Baños.

Rice and Indonesia's Agriculture

Sri Widodo, Nasrullah, and Hidajat Nataatmadja

Rice occupies about half of Indonesia's food crop land. It is the main agricultural product in all islands of Indonesia and the staple food for most of the population. Corn, cassava, soybeans, and peanuts are important supplementary foods. The importance of rice in agricultural production and as a basic Indonesian food is reflected in Tables 1 and 2. Rice contributes 44% to the total value of agricultural products. Most rice production is from *sawah* or lowland rice, and only a small proportion is from upland rice.

Of the total Indonesian population of 125 million, about 85 million are engaged in agriculture. Of the roughly 50 million engaged in food production, all but a small portion produce some rice during the year.

For several decades, growth in rice production has been slow. To match the growth in demand, imports from other countries have been necessary. Hence, increased production has been a goal of basic national agricultural policy. The price of rice is a matter of public and government concern in the fight against inflation and in the effort to achieve economic stability.

Attempts to increase production, which had been under way for a long time, recently increased in intensity, but increases in production have not been able to keep pace with increases in demand.

Through the recent international exchange of knowledge, research, and genetic materials, improved rice technology has become available. The introduction of the semidwarf fertilizer-responsive rice varieties appeared to show great promise. The new varieties significantly increased farmers' yields, but the average yields were still substantially lower than those demonstrated to be possible at experiment stations. The constraints project therefore seemed appropriate.

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Table 1. The value of agricultural production by regions of Indonesia, 1973 (Strout 1977).

Island	Value (billion rupiah)						
	Rice	Palawija[a]	Vegetables	Fruit	Tobacco and sugar cane	Perennial crops	Total
Jawa/Madura	835	162	52	126	55	46	826
Sumatra	131	29	11	25	4	123	323
Kalimantan	31	6	b	5	-	17	59
Sulawesi	43	27	2	11	2	22	107
Other islands	33	32	3	8	1	13	70
Total Indonesia	622	255	68	176	61	222	1404
In percentage	44	18	5	13	4	16	100

[a]Dryland field crops like corn, soybean, peanut, cassava.

[b]Less than 0.5 billion rupiah.

Table 2. Indonesia's food production, 1970 – 76 (Biro Pusat Statistik).

Crop	Food production (1000 t)		
	1970 – 72 av	1973 – 75 av	1976
Rice	25,671	28,889	30,470
Sawah rice	23,619	26,899	26,575
Upland rice	2,051	1,997	1,895
Corn	2,562	3,201	2,572
Cassava	10,518	12,277	12,191
Sweet potato	2,151	2,430	2,381
Peanut	282	326	341
Soybean	511	567	522

Table 3 shows the area planted to rice, production, yield, imports, and per capita availability from 1968 through 1975. During this period rice production increased more than 4% a year, with substantial growth in both yield and area. Most of the growth was from yield, which increased from about 1.5 t/ha in the late 1960s to 1.8 t/ha by the middle 1970s.

The harvested area increased at an average rate of 1.2%, total production at 4.8%, and yield at 3.3% a year over the 1968-75 period. The corresponding figures for 1955-67 were 0.5%, 1.3%, and 0.8%. The small increases in area can be attributed to spontaneous land opening, irrigation system improvements, and new irrigation construction.

Despite the increasing production in recent years, substantial imports have been required. The need has arisen in part from the government's policy of providing subsidized rice to certain groups of consumers and the general subsidy involved in maintaining a ceiling price through government financed imports. As a result, per capita consumption has increased. At the same time population has increased at an average annual rate of 2.5%, making total demand grow even faster.

Table 3. Area, production, yield, imports, and per capita availability of milled rice, Indonesia, 1968-75 (Statistik Indonesia 1975).

Year	Harvested (1000 ha)	Production (1000 t)	Yield (t/ha)	Imports (1000 t)	Production plus imports (1000 t)	Availability Per capita (kg)
1968	8,021	11,666	1.45	486	12,152	108.2
1969	8,014	12,249	1.53	238	12,487	108.7
1970	8,135	13,140	1.62	324	13,464	114.6
1971	8,324	13,724	1.65	120	13,844	115.2
1972	7,898	13,183	1.67	335	13,518	109.8
1973	8,403	14,607	1.74	1,863	16,470	130.6
1974	8,537	15,280	1.79	1,132	16,412	127.1
1975	8,760	15,340	1.75	692	16,032	121.4

CHARACTERISTICS OF RICE PRODUCTION

Table 4 shows that 62% of the harvested lowland rice area and 66% of the production of lowland rice are concentrated on the "inner islands" (Java and Bali), which account for only 7.3% of the nation's total land but contain 67% of the population. Upland rice occupies 16% of the total rice area. The upland average yield is less than half of the lowland average yield.

The main rice harvest (55%) is from April through June, at the end of the wet season. A second harvest peak (20%) occurs from August through October. The remaining 25% of the harvest is distributed over the remaining six months. In Java, the seasonal peaks are less pronounced because of extensive irrigation systems.

Water control

The geographic area used for lowland rice is about 5.6 million ha. Of this, 3.5 million ha are served by irrigation. At the start of the first 5-year plan (1969-73), an estimated 60% of the irrigation systems and flood-control structures needed repair

Table 4. Harvested area, production, and yield of lowland and upland rice. Indonesia, 1974 (Biro Pusat Statistik).

Island	Lowland rice[a]			Upland rice		
	Area ('000 ha)	Production ('000t)	Yield (t/ha)	Area ('000 ha)	Production ('000t)	Yield (t/ha)
Java	4,438	13,573	3.1	286	345	1.2
Bali	155	569	3.7	16	15	0.9
Sumatra	1,468	4,169	2.8	449	599	1.2
Kalimantan	504	885	1.8	221	234	1.1
Sulawesi	582	1,370	2.4	88	107	1.2
Other islands	229	620	2.7	102	101	1.0
Indonesia[b]	7,376	21,186	2.75	1,162	1,401	1.1

[a]Dry-wet rice (*gogo rancah*) included; found only in Java; less than 50,000 ha.

[b]Area and production data are totals; yield data are averages.

and improvement. In the ensuing period, irrigation systems serving 930,000 ha of lowland fields were rehabilitated by improvements and repairs on primary and secondary canals, dams, and irrigation structures. An additional 193,000 ha were provided with irrigation, and flood-control measures protected an estimated additional 339,000 ha.

The second 5-year program has targets of 835,000 ha of rehabilitated systems and 950,000 ha of new construction. River basin management programs and swamp reclamation projects should also improve water control in an additional 680,000 ha.

Varieties fertilizer, and pesticides

In 1953, the Balai Padi began releasing improved varieties, some of which are still in use. These are at times referred to as national improved varieties and include Syntha and Sigadis. With the release of shorter, stiff-strawed, nitrogen-responsive varieties (IR8 and IR5), the Bogor breeding program altered its breeding objectives and consequently developed Pelita I/1 and I/2, which were released in 1971. These modern varieties possess a grain quality better suited to Indonesian tastes. The plant types are similar to IR5 but have somewhat stronger bacterial leaf blight resistance. As a result, Pelita varieties have generally replaced IR5 in all areas except parts of Sumatra, where dry-cooking rice is acceptable. Table 5 gives the area of traditional, national improved, and modern varieties harvested in the 1974 dry season and the 1974-75 wet season.

Fertilizer use increased rapidly as both the government and the farmers realized its importance in exploiting the yield potential of the modern varieties (Table 6). Urea and triple superphosphate are by far the most widely used materials. Insecticides and rodenticides have also been encouraged, but their use has not increased as rapidly as that of fertilizers. Diazinon is the most extensively distributed and used insecticide, and zinc phosphide is the major rodenticide.

Mechanical technology

With a few exceptions, recently developed engine-powered production technology has yet to be introduced into the rice-growing sector. In contrast, wide and rapid distribution of small rice-milling equipment has taken place. Timmer (1973) estimated that the capacity of milling equipment sold in Java and Bali in the 1970-72 period was sufficient to mill 70 to 80% of the production of the two islands.

Table 5. Rice varieties and harvested areas. Indonesia, 1974 dry season and 1974–75 wet season (Directorate Bina Produksi).

Variety	1974 dry season		1974–75 wet season	
	1000 ha	%	1000 ha	%
Pelita I/1	345	11.9	855	16.4
Pelita 1/2	153	5.3	244	4.7
IR5	398	13.7	663	12.8
C4	222	7.7	388	7.5
Other modern	76	2.6	96	1.8
National improved	306	10.6	433	8.3
Local	1400	48.3	2521	48.5

Table 6. Fertilizer and insecticide use on rice. Indonesia, 1968–1975 (Ministry of Agriculture for 1968–72; BIMAS Project for 1973–75).

Year	Fertilizer (t)		Insecticide (t)	Rodenticide (t)
	N	P_2O_5		
1968	95,000	24,000	630.6	40.2
1969	155,200	36,200	1,209.3	33.7
1970	162,100	31,300	1,075.6	52.4
1971	219,200	24,200	1,555.6	33.0
1972	257,600	58,400	1,362.7	44.5
1973	307,400	53,800	n.a. [a]	n.a.
1974	277,700	77,300	n.a.	n.a.
1975	308,300	93,000	n.a.	n.a.

[a] n.a. = data not available.

GOVERNMENT POLICIES

The tight fiscal (balanced budget) policy of the Indonesian Government established in 1966-67 was implemented to reduce inflation and promote economic stability. The price of rice, regarded as an index for all other prices, influenced the people's inflation rate expectations. The government has attempted to stabilize rice price by fixing prices and by increasing production.

Rice policy has traditionally been consumer oriented, with the goal of adequate supply at a low price. A ceiling price protected consumers. In 1970, the government decided on a floor price at harvest time to protect rice farmers.

The government agency responsible for carrying out the price policy is the Food Logistic Board (BULOG). BULOG maintains the rice stock necessary to keep the rice price above the floor price and below the celling price. Quantities are marketed when the retail price exceeds (or threatens to exceed) the ceiling price, and rice is purchased in the rural areas to maintain the floor price at harvest time. Rice is distributed as payment in kind -- an indirect device -- to military personnel and civil servants.

Bimbingan Massal (BIMAS)

Following several seasons of successful, small, localized extension programs, the government initiated the national Bimbingan Massal (BIMAS) or Mass Guidance program in the 1965-66 wet season in 172,500 ha. In the years since, the program has been modified and expanded in response to improvement in the government's ability to coordinate a large multifaceted program, the availability of inputs and the means to distribute them, and the changes in production technology.

The objective of the BIMAS program as a mass extension effort is to increase agricultural production and the farmer's income through crop intensification. The current program version is called the Improved BIMAS and, under it farmers receive loans through village units organized by Bank Rakyat Indonesia. A village unit consists of about 4 adjoining villages covering 600 to 1,000 ha farmed by 1,800 to 3,000 farmers. Loans are made to individual farmers in the form of vouchers redeemable for seed, fertilizer, and pesticides at a retail outlet in the village area. An additional cash loan is made to cover living expenses.

As soon as BIMAS areas are adjudged capable of functioning without the government credit component, they are converted to mass intensification (INMAS) program areas, a less intensive, no-credit version of BIMAS. The first INMAS areas were designated in advance of the 1967-68 wet season crop. Combined BIMAS and INMAS hectarages, reported from 1966 to 1973 and targeted from 1974 to 1978, are presented in Table 7.

Within the intensification programs, the BIMAS Baru (new) program produced the highest yield, as the data from 1969 to 1973 show. An analysis by Van der Goot and Shaw (1975), based on national statistics, attributes an increase of 500 to 550 kg/ha in realizable genetic potential to the modern varieties directly, and another 12 to 13 kg/ha to nitrogen applied.

Table 7. Annual BIMAS and INMAS hectarages, Indonesia, 1966-78 (Badan Pengendali and Buku Repelita II).

Year	Area (1000 ha)	Year	Area (1000 ha)
1966	341	1973	4064
1967	522	1974	4306
1968	1596	1975	4616
1969	2130	1976	4995
1970	2084	1977	5344
1971	2886	1978	5632
1972	3263		

POTENTIAL RICE TECHNOLOGY

Although average national yields have increased in recent years, it is quite apparent that, even in the BIMAS Baru program, yields do not approach the levels obtained in experiments conducted on research stations. In experiments in four seasons at several Java stations, the yields of Pelita at the 100 kg N/ha level averaged 5.4 t/ha and never dropped below 3 t/ha. In 12 out of 22 cases, yields exceeded 5 t/ha. Even at 0 kg N/ha, Pelita yields averaged 3.7 t/ha and were below 3 t/ha in only 7 cases.

Experiment station trials using insecticides had similar dramatic responses. In summarizing 69 trials conducted from 1968 to 1973, scientists of the Central Research Institute for Agriculture found that the most effective treatment per experiment produced 70% higher yields than the untreated plots (5,180 kg/ha vs 3,024 kg/ha).

When evaluated in farmers' fields in 1970-71, the new seed-fertilizer-insecticide technology again demonstrated its potential and reinforced the government's decision to make it available to the rice farmer.

It is not surprising that the seed-fertilizer-insecticide technology has been a central element in the government's intensification program. That the technology has had an impact on rice yields is unquestioned. The yield data in Table 8 demonstrate that impact most noticeably in the BIMAS Baru program. The demand for rice continues to grow, however, and the unexploited yield potential is apparent in program areas other than BIMAS Baru.

Table 8. Rice intensification program yields during the First 5-Year Plan, Indonesia, 1969-73 (Buku Repelita II).

Year	Yield (t milled rice/ha)			
	BIMAS Biasa (original)	BIMAS Baru (new)	INMAS Biasa (original)	INMAS Baru (new)
1969	1.9	2.2	1.7	1.9
1970	2.1	2.8	1.8	2.1
1971	2.0	2.8	1.6	2.2
1972	2.2	2.9	1.9	2.3
1973	2.3	3.0	1.9	2.3

RECENT TRENDS

From 1969 to 1976, Indonesia's rice production grew at a rate of 3.8%/year. During the first 3 years of Pelita II (1974-76), the annual rate of increase slowed to only 2.8%, compared with 4.6% during Pelita I. (Pelita I, the first national plan, covered the period 1968-72. It was followed by Pelita II, which

ended in 1978.) On the other hand, consumption rose between 4 and 5% per year (Mears 1976), forcing rice imports to soar to about 2.5 million t in 1977 (Teken and Kuntjoro 1978).

The leveling off of the rate of increase in production was caused partly by extensive crop damage from the brown planthopper. Of equal importance were difficulties met in extending the intensification program beyond the well-irrigated rice areas and in collecting production loans provided through BIMAS. In the past, the agricultural development program relied on intensification of land use primarily in the well-irrigated areas. Although the rice area will be extended in Pelita III, higher per-hectare rice yields are expected to contribute about half of the planned increase in production.

Policy makers are beginning to realize that BIMAS' *thin spectrum* technology is probably one of the major causes of the production shortfall and of the difficulty met in extending the program to marginal areas where environmental conditions differ significantly from those in the conventional well-irrigated areas. If the BIMAS program is to perform as expected in Pelita III, it must offer technology that is more specific to the locality and that takes into account the larger variations in soil fertility, water availability, and pest ecology. To accomplish this fine-tuning of the technology, researchers must conduct adaptive trials in all major agroclimatic areas throughout the country.

OBJECTIVES AND METHODOLOGY

Because increased rice production is a major goal of the Indonesian Government and because there is a large gap between farmers' yields and potential yields under most conditions, investigations have been undertaken to identify and quantify the physical and socioeconomic factors that contribute to the gap. After the identification and quantification of the contributing factors, it is expected that future biological and socioeconomic studies will focus on the factors that would yield the greatest return. Production program administrators and policy makers may make program and policy adjustments warranted by the outcome of the studies.

As in the other studies reported in this volume, field experimentation and survey methods, combined with appropriate data analysis techniques, were used. Field experimentation that employed factorial designs and a series of management-package treatments were used for identifying feasible techniques for obtaining higher yields and for characterizing the biological factors that led to the yield increases. Experiments were

conducted in farmers' fields. Of the several treatments in each experiment, one set was used to simulate farmers' practices. Fertilizer and insecticide treatments were limited to materials available to the farmer.

Surveys to determine the physical, economic, and human resources of the farmers and to characterize the institutional structures in which they operate were used to understand why farmers did not use the inputs needed to get higher yields. Data were collected from the farmers in the villages where the field experiments were conducted.

Two separate research groups conducted constraints research in Indonesia. The Central Research Institute for Agriculture, headquartered at Bogor, did its studies on the north coast area of West Java province, an area noted for relatively low rice yields and many environmental problems. The Faculty of Agriculture of Gadja Mada University carried out its research in Yogyakarta Special province, an area with very intensive rice production and high yields. Each group's work is reported in a separate chapter.

REFERENCES CITED

Mears, L. A. 1976. Indonesia's food problems, Pelita II/III. Ekonomi Dan Keuangan 24(2).

Strout, A. M. 1977. Pertumbuhan pertanian, tenaga Kerja dan pembagian pendapatan; dilema bagi Pelita III. Ekonomi Dan Keuangan Indonesia 25(4):284–285.

Teken, I., Gusti Bagus, and Kuntjoro. 1978. Mimber Sosial Ekonomi, 1.

Timer, C.P. 1973. Choice of technique in rice milling in Java. Bull. Indon. Econ. Stud. 9, 2:57–76.

Van der Goot, P.F., and H.R. Shaw. 1975. Medium term new land and irrigation requirements for rice and other basic food crops. FAO Planning Team Working Paper, Jakarta.

Note: Data sources for tables, other than those listed above, are the Indonesian government agencies, or periodic publications of these agencies.

Constraints to High Yields in Subang, West Java, Indonesia

Hidajat Nataatmadja, Prabowo Tjitropranoto, Richard H. Bernsten, Al Sri Bagyo, and Aten M. Hurun

Following the 1975–76 research reported in the *Interim report* (IRRI 1977), the constraints research team of CRIA continued working in the same area of West Java. The research was conducted in the *kabupaten* (district) of Subang, 175 km east of Jakarta. Pusakanegara, one of 11 *kecamatan* (subdistricts), was chosen as the study site because its cropping patterns and geography are representative of the north-coast area of West Java, and it is accessible by road (Fig. 1).

Pusakanegara has a population density of 570 persons/km^2 (1974 data from the *kecamatan* office in Pusakanegara). Its total land area is 14,215 ha, 79% of which is planted to wetland irrigated rice.

The study area is on the eastern end of the north coastal plain of West Java, where the elevation ranges from sea level to 25 m. Because of the relatively flat topography, inadequate field drainage is frequently a problem during the wet season. The soil is classified as alluvial clay. Soil analysis for the sites where the main wet season 1976–77 experiments were conducted indicated an average pH level of 5.25. Available nitrogen and phosphorus among the sites varied; potassium was high at all locations.

Weather data for the 1976–77 wet season and 1977 dry season indicate a total October–July rainfall of 2,890 mm, compared with a 10-year average of 1,744 mm. Much of the above-normal rainfall was during February, April, and May.

The physical infrastructure serving the area is relatively well-developed. Pusakanegara is serviced by 7.6 km of highway and 89 km of feeder roads (1974 data from the *kecamatan* office) During the dry season, the area is integrated into the transportation network of the province and is well serviced by both local and transisland vehicular traffic. But during the

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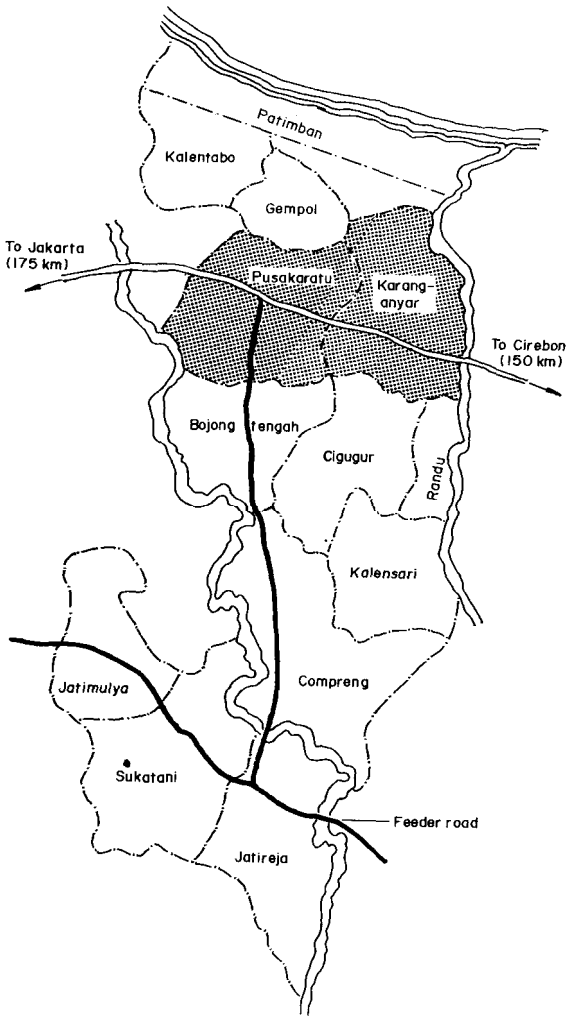


1. Pusakanegara *Kecamatan* in Subang, West Java.

wet season, 92% of the roadways are muddy and provide limited accessibility.

About 96% of the farm area in Pusakanegara is irrigated. Eighty-fourpercent of the service area is classified as technical (high water reliability) and 16% as semitechnical. The Jatiluhur irrigation system -- the source of water -- irrigates about 300,000 ha for double-cropping. Although the system is capable

of providing water all year-round, during moderately dry spells all tertiary canals receive a proportionally reduced supply from the secondary canals. In extremely dry seasons water is distributed by rotational blocks. In 1974 a major rehabilitation program costing US$40 million was initiated to improve water distribution over two-thirds of the service area.

Government agricultural services functioning in each village (*desa*) include a branch bank (Bank Rakyat Indonesia Unit Desa) that extends production credit, a general agricultural cooperative, and agricultural extension field staff. Almost all farmers in the area participate in BIMAS (Bimbingan Massal or mass guidance) or INMAS (Intensifikasi Massal or mass intensification). BIMAS program participants receive production credit. INMAS farmers are generally former BIMAS members who are now able to finance input purchases from their own resources.

To maximize the impact of extension, the extension agent organizes contact farmers, each of whom in turn communicates program information to farmer cultivators. Eight field extension agents are assigned to the project area, which has about 11,000 farmers.

FARMERS AND FARM TECHNOLOGY

About 90% of Pusakanegara's population is either directly or indirectly engaged in agriculture. The level of technology used by farmers is quite high because of the presence of the BIMAS program since 1964. Estimates by local agricultural officials show that yields obtained by BIMAS participants increased from 3.1 t/ha in 1969-70 to 5.6 t/ha in 1975-76. These figures appear somewhat inflated, however.

Forty-four farmers were selected at random from a 150-ha production area that had been chosen to demonstrate improved practices to farmers in Pusakanegara. Records were kept of the farmers' activities throughout the cropping seasons. The records gave insights into the institutions, cropping practices, and resources available to the farmers of the area.

Seed is purchased both through the BIMAS program and from free market sources. Farmers seldom save seed from the previous crop. Modern varieties have been adopted extensively. The area planted to them was about 78% of the rice area in the 1976-77 wet season. Although farmers prefer the Pelita varieties, the presence of brown planthopper forced them to plant brown planthopper-resistant varieties such as IR26, IR30, and IR36 as these became available.

In the wet season, farmers generally prepare the land in November – December and harvest in April – May. The dry season crop is typically planted in May – June and harvested in August – September.

Land preparation is done almost totally by male human labor as there are only 5 two-wheel tractors and about 1,200 carabaos in Pusakanegara. The labor – intensive nature of land preparation is indicated by both the large share of total labor input allocated to this activity (30 – 40%) and the large absolute number of work – days used (Table 1). About 90% of the labor for land preparation is hired.

Transplanting is done primarily by hired labor. When labor is abundant, young seedlings are usually sown in straight rows. In recent seasons when labor bottlenecks have arisen, less labor – intensive scatter planting has tended to become more

Table 1. Preharvest labor input in Subang, Indonesia, 1976 – 77.[a]

Farm task	Labor input (workdays)					
	Wet season (20 farmers)			Dry season (44 farmers)		
	Days[b] (no.)	Hired labor (%)	Total labor (%)	Days[b] (no.)	Hired labor (%)	Total labor (%)
Seedbed preparation	5.2	72	4.3	6.2	53	4.8
Land preparation[c]	49.0	93	39.2	40.1	88	31.1
Transplanting	17.4	94	14.4	26.4	91	20.5
Fertilizer	5.7	62	4.7	5.6	62	4.4
Pest control	4.7	74	3.9	3.6	35	2.8
Weeding	36.7	86	30.3	42.9	88	33.1
Others	2.4	76	2.0	4.0	52	3.1
Total[d]	121.1			128.8		

[a]Where hired labor is used, labor input may be inflated. When the farmer pays a day's wage for a given task, he reports this activity as taking one day. Yet the laborer may actually complete the work in less time. [b]Labor input data were recorded daily by the farmers. One work – day has been standardized to 8 hours of work. [c]Animal labor was used only in the wet season when an average of 1.5 days/ha was used. [d]Harvest labor is excluded because of the difficulty in measuring this input. Previous research in lowland rice areas indicates that harvesting with an *ani-ani* knife requires approximately 11.8 workdays per ton harvested.

popular. Farmers' seedlings were often transplanted later than the recommended age of 21 to 25 days. In the wet season when all respondents planted intermediate-maturing (140 days) Pelita varieties, late transplanting was probably not a major yield constraint. On the other hand, 15% of the farmers who in the dry season planted early-maturing IRRI varieties and transplanted seedlings older than 30 days of age may have incurred substantial yield losses.

Agricultural chemicals were widely used, with fertilizer applied at moderately high levels. But in the wet seasons, farmers' fertilizer applications were somewhat less than those recommended by BIMAS (Tables 2 and 3). Pest control was achieved through applications at a level higher than recommended.

Timing of chemical application varied widely among farms. Table 4 shows that triple superphosphate and urea are seldom applied as a basal dressing. Inefficient fertilizer use is further suggested by the practice of the 12 farmers who used a

Table 2. Average level of chemical application by farmers applying each input. Subang, Indonesia, 1976-77.

Season	Fertilizer (kg/ha)		Pesticide[b]		
	Urea	TSP[a]	Diazinon EC (liter/ha)	Sevin WP (kg/ha)	Furadan or Ekalux G (kg/ha)
Wet					
Mean	154	43	1.9	2.1	13.5
Standard deviation	58	22	0.9	1.4	10.1
Number using	19	12	19	10	13
Dry					
Mean	208	54	2.6	2.0	19.2
Standard deviation	55	22	1.7	0.8	15.5
Number using	44	33	41	3	33

[a]TSP = triple superphosphate. [b]EC = emulsifiable concentrate, WP = wettable powder, G = granular.

Table 3. BIMAS credit packages[a] for irrigated rice. Indonesia, (October – March) 1976 – 77 (USDA 1978).

Item	Packet A		Packet B		Packet C	
	Quan – tity	Rp value	Quan – tity	Rp value	Quan – tity	Rp value
Urea	200 kg	16,000	LOO kg	8,000	250 kg	20,000
Triple superphosphate	50 kg	4,000	35 kg	2,800	75 kg	6,000
Insecticide	21	2,460[b]	21	2,460[b]	21	2,460[b]
Rodenticide	100 g	230	LOO g	230	100 g	230
Seed	-	2,750	-	-	-	3,750
Spraying costs	-	27000	-	2,000	-	2,000
Living expenses	-	6,000	-	4,000	-	6,000
Total value		33,440		19,490		40,440

[a]Package A uses HYV seed, package B uses improved national varieties. In 1976 – 77 BIMAS instituted Package C for particular areas where further increases in yields were believed to be possible through additional fertilizer application. Exchange rate: US$1 = Rp. 415. [b]Price of rebottled pesticides: Rp 615/ one – half liter. Price without rebottling: Rp 900/liter.

second topdressing in the wet season but applied it at an average of 53 days after transplanting. Pesticides also appear to be applied inefficiently. Farmers' first application of insecticides diverged widely from the recommendation of 14 days after transplanting (DT).

Weed control was achieved by hand weeding, with about 70% of the labor provided by women. All farmers used the spike – toothed push weeder followed by hand weeding; chemical herbicides were never used. The typical two complete weedings per season appeared to provide good control.

Harvesting was done largely by women. They used the traditional *ani-ani* knife and received one – seventh of the crop. On farms harvested by sickle, only men were employed. Generally IR varieties were harvested by sickle.

Table 4. Time of first application of chemical inputs. Subang, Indonesia, 1976 – 77.

Input	Wet season			Dry season		
	Farmers responding	Days after transplanting		Farmers responding	Days after Transplanting	
	(no.)	Mean	Range	(no.)	Mean	Range
Superphosphate	10	21	9 – 83	30	10	1 – 23
Urea	12	24	9 – 40	37	14	1 – 30
Diazinon	18	44	23 – 82	38	27	14 – 71
Furadan [a]	11	44	9 – 70	28	20	4 – 60

[a] Or Ekalux.

SELECTION CRITERIA AND THEIR LIMITATIONS

The wet season research was in the same four hamlets of two villages in Pusakanegara, where 1975 – 76 trials were located (IRRI 1977, PP. 86 – 119). The sites were originally selected because they were representative of the range in productivity found in the area.

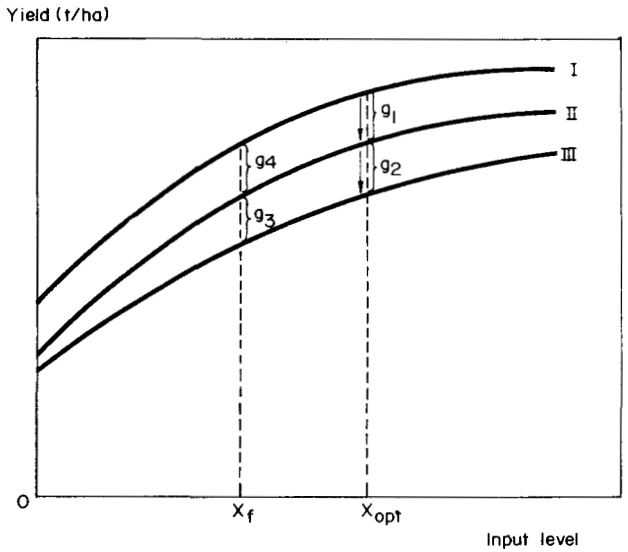
In the 1977 dry season, the research continued in only one of the four hamlets (Pusakaratu), where the extension service had established a demonstration area. Because it was conducted in an area targeted for intensive extension supervision, farmers' practices may have been superior to those followed in non – demonstration areas. The choice of the site was justified by the aim of the research: to provide insight into the yield potential under good management and thereby indirectly measure the impact of an intensive extension effort.

RESEARCH METHODOLOGY AND PREVIOUS FINDINGS

Methodological appoach

For two previous seasons (1975 – 76 wet seasons and 1976 dry season), the analytical procedure was designed to estimate the three hypothetical production functions shown in Figure 2.

Curve I represents the production function associated with a fully controlled experiment at the research station. Curve II represents



2. Curves representing three hypothetical production functions for the Indonesian study of the constraints to rice yields, 1975–76.

the production function characterizing the farmers' field experiments Curve III represents the production function facing farmers.

With X_{opt} representing the optimal input level for Curve 11, the gaps are identified as follows:

g_1 = first order gap due to factors that can be controlled at a research station but not in farmers' fields. This gap cannot be avoided.

g_1 = technical efficiency gap at the hypothetical optimum. This results from farmers' incorrect use of the inputs.

With the average farmers' input at X_f, then:

g_3 = farm technical efficiency gap arising from farmers' incorrect input use.

g_4 = farm allocative efficiency gap due to farmers' suboptimal input use.

Because of serious pest infestation, it was impossible to estimate meaningful production curves. Even without serious pest infestation, the precise data requirements may make the procedure inappropriate. For this reason, the simpler and more straightforward technique for identifying the gap was adopted, as outlined in the methodology paper (Gomez, this volume).

In the experiments, the concept of *comparable paddy* or *typical farmers' practice* was not used. It was realized from the beginning that the variation in farmers' practices was so large that it would be difficult to select the typical farmer. Instead, average farmers' practices were determined from a baseline survey conducted in 1974, and farmers' treatment levels were made approximately equal to those levels.

The experimental design

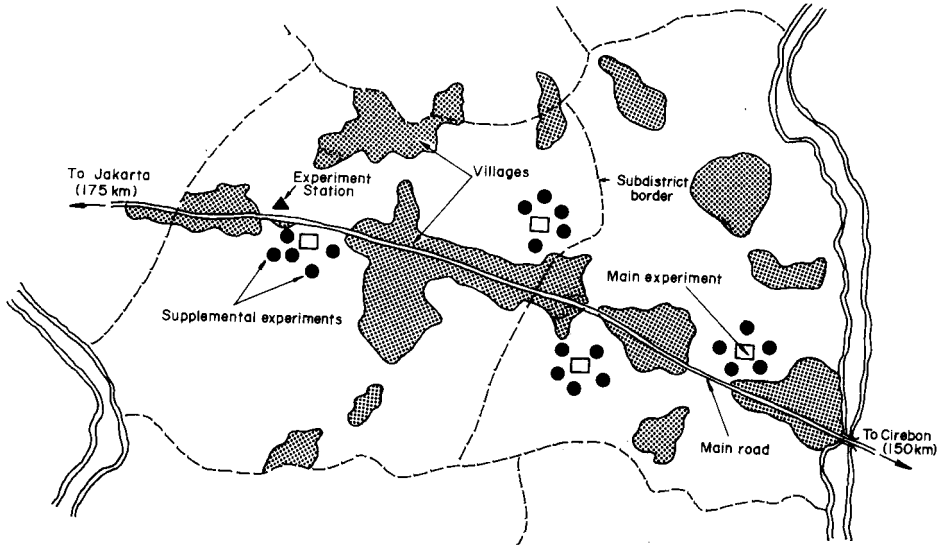
The 1975–76 experiments had two levels of land preparation including weeding (L_1 and L_2), three levels of fertilizer (F_1, F_2, and F_3), and three levels of insecticide (I_1, I_2, and I_3). The so-called management packages (M_1, M_2, M_3, M_4, and M_5) were not explicitly included as plots, but certain treatment combinations were selected *ex post* to approximate incrementally higher input intensities.

Four hamlets in Pusakanegara -- two in Pusakaratu and two in Karanganyar -- were chosen as the experimental sites. A factorial design with two replications at each site was used. Five supplemental trials were laid out near each factorial experiment, using input levels I_1, I_2, F_1, and F_2 to measure the insecticide and fertilizer response under farmers' management. To test the effectiveness of the entomologists' fixed-package technology, it was agreed that no other treatment would be applied, even in cases of high insect incidence.

The results of the earlier wet and dry season (1975–76 and 1976) experiments were revealing. The fixed-package pest control treatment failed to protect the crop from extensive pest damage. Dominant pests, in order of importance, were stem borers, rats, and gall midges. Brown planthoppers also appeared toward the end of the season and army worms damaged some of the experiments. In the dry season many plots suffered from drought. Consequently, no meaningful yield differences associated with the treatment levels or between the supplemental plots and the factorial experiments were observed. Yields averaged only 2.5 t/ha. The major constraint to high yield during the 1975–76 wet season was the ineffectiveness of the fixed-package pest control technology. During the dry season, it was lack of water.

IDENTIFYING BIOLOGICAL CONSTRAINTS

The study reported here is a continuation of the 1975–76 research. A more comprehensive evaluation of the 1975–76 study is in *Yield constraints to high yields on Asian rice farms: an interim report* (IRRI 1977). The previous research identified little or no pap between farmers' actual and potential yields, even if more



3. Experiment sites in Pusakaratu and Karanganyar villages, Subang, West Java (see Fig. 1 also),

of the readily available inputs had been used. It suggested that an improvement in the recommendations for insect control would be needed to increase yield substantially. The trials also pointed out the importance of urea application for high rice yields. Consequently, the 1976-77 research focuses only on insect control and urea application.

Experimental design

All experiments were conducted in Pusakanegara, Subang district, West Java. The four wet season sites -- two in (Pusakaratu village and Curugjati) and two in Karanganyar village (Karanganyar and Kubangjaran) -- are shown in Figure 3.

The wet season research consisted of a main experiment (factorial) surrounded by five supplemental trials at each of four sites. One crop-cut was also taken from the farmer's rice field adjacent to each supplemental experiment. Both the main and the supplemental experiments were planted in November 1976 in the fields of farmers who used the Mass Guidance (BIMAS) package.

A split-plot design was used in the main experiment, with fertilizer as the main plot and insecticide as the subplot (Table 5). All participating farmers grew the Indonesian-bred varieties Pelita I/1 and Pelita I/2.

Because the number of brown planthoppers caught in a light trap rose from 135 in December 1976 to 6.4 million in March 1977, the following additional insecticide treatment was applied to all plots in the main experiment:

1. Two applications (at 70 and 84 DT) of Furadan 3G, 20 kg/ha per application.

2. Six applications (at 3-day intervals starting at 56 DT) of 3.5 kg Sevin 50 (WP)/ha per application.

The supplemental experiments used two levels of fertilizer and insecticide (Table 6). These levels were the same as F_1, F_3, I_1, and I_3 in the main experiment, except that the plots were not given the additional insecticide treatment.

In the 1977 dry season, only the supplemental experiments were continued. Two levels of insecticide were applied on plots in farmers' fields in the extension demonstration area of Pusakaratu village (Table 6). The selection of that site coincided with the establishment of a new demonstration area where the BPH-tolerant varieties IR26, IR30, and IR36 were grown. The area was divided into 4 sections, covering a total of about 120 ha of rice fields.

Table 5. Experimental factors and levels used in the main experiment. Subang, Indonesia, 1976–77 wet season.[a]

Code	Treatment	Application	
		Method	Time
Main plot	Fertilizer		
F_1	100 kg urea/ha	BC	T, 21 DT and PI
	50 kg TSP/ha	BC	T
F_2	200 kg urea/ha	BC	T, 21 DT and PI
	50 kg TSP/ha	BC	T
F_3	200 kg urea/ha	DP	T, 21 DT and PI
	50 kg TSP/ha	BC	T
Subplot	Insecticide[b]		
I_1	2 liters Diazinon 60 (EC)/ha	FS	14, 42 and 70DT
I_2	4 liters Diazinon 60 (EC)/ha	FS	35, 63 DT
I_3	50 kg Ekalux 5G/ha	BC	14, 35 DT
I_4	Monitoring	-	when needed

[a] TSP = triple superphosphate, DT = days after transplanting, T = transplanting, PI = panicle initiation, BC = broadcast, DP = deep placement, FS = foliar spray. [b] Extra treatment: Furadan 3 G at 70 and 84 DT, 20 kg/ha per application; 6 applications of Sevin 50 (WP), applied at 3-day intervals, starting at 56 DT.

Ten supplemental experiments were placed in each section. In addition, crop-cuts were taken from farmers' fields adjacent to each supplemental experimental plot.

Evaluation of the yield gap

In the main experiment in the wet season, the high input level produced an average yield of 5.4 t/ha (Table 7). In contrast, yields averaged only 3.6 t/ha with simulated farmers' input levels. Of the gap of 1.7 t/ha, about 0.2 t/ha can be attributed to high fertilizer and 1.6 t/ha to high insect control (Table 7).

Data from the main experiment showed that insecticide consistently increased yield at all sites except in Pusakaratu (Table 8).

Table 6. Experimental factors and levels used in the supplemental experiments. Subang, Indonesia, 1976–77.[a]

Treatment	Material	Amount (kg/ha)	Application	
			Method	Time[b]
		Wet season		
F_1	Urea	100	BC	T, 21DT, PI
	TSP	50	BC	T
F_3	Urea	200	DP	T, 21DT, PI
	TSP	50	DP	T
I_1	Diazinon 60 (EC)	2[c]	FS	14, 42, 70DT
	Furadan 3G[d]	40	BC	70, 84DT
	Sevin 50 WP[d]	21	FS	56,59,62,65,68,71DT
I_3	Ekalux 5G	50	BC	14, 35DT
	Furadan 3G[d]	40	BC	70, 84DT
	Sevin 50 WP[d]	21	FS	56,59,62,65,68,71DT
		Dry season		
I_1	Furadan 3G	30	BC	14, 42, 70DT
	Diazinon 60 (EC)	2[c]	FS	35, 63DT
I_2	Furadan 3G	50	BC	14,35,56,77DT
BIMAS	Diazinon 60 (EC)	2[c]	FS	35, 63DT

[a] TSP = triple superphosphate, DT = days after transplanting, T = transplanting, PI = panicle initiation, BC = broadcast, DP = deep placement, FS = foliar spray.

[b] Total amount split equally between times of application.

[c] liters/ha.

[d] Applied only on the main experiments, and not on the supplemental trials.

Yields were highest on plots receiving 50 kg Ekalux 5G/ha (I_3). In addition, I_3 gave a significant increase in yield over I_2 (4 liters Diazinon 60 (EC)/ha), although the active ingredients of the insecticides were similar. On the other hand, the 2– and 4–liter Diazinon 60 (EC)/ha treatments (I_1 vs I_2) gave significant yield differences in only 2 locations.

Table 7. Yield gap and contribution of each factor in main experiments on four farms. Subang, Indonesia, 1976–77 wet season.

Site	Yield (t/ha)			Contribution (t/ha)		
	High inputs (F_3I_3)	Farmers'[a] inputs (F_2I_1)	Gap	Fertilizer	Insect control	Residual
Pusakaratu	4.7	3.9	0.8	0.1	0.5	0.2
Curugjati	6.0	3.9	2.1	0.2	1.5	0.4
Karanganyar	5.5	4.1	1.4	0.2	1.7	-0.5
Kubangjaran	5.3	2.7	2.6	0.1	2.6	0.0
Average	5.4	3.6	1.7	0.2	1.6	0.0

[a]Simulated farmers' levels of input use based on recommendation (F_2I_1). But late in the season a protective insecticide treatment was added to reduce brown planthopper damage. The additional insecticide application raised the I_1 level substantially above farmers' actual pest control practices.

At Pusakaratu, the interaction between insecticide and fertilizer was significant. The high level of insecticide (I_3) resulted in highest yield when combined with the highest level of fertilizer (F_3). The lowest insecticide treatment (I_1) yielded best when combined with the lowest fertilizer level (F_l).

In the wet season supplemental experiments, the high level of insecticide (I_3) gave a higher yield than either the low level (I_1) or the farmers' level at all sites except Curugjati (Table 9). The effect of the high level of fertilizer (F_3) varied from site to site, and the low level (F_1) resulted in a lower yield than at the farmers' level. The yield variation might be the result of both the brown planthopper outbreak and variations in the farmers' input levels (Table 2). For example, the farmers in Curugjati and Kubangjaran, who used more insecticide than those at other sites, obtained higher yields at farmers' input levels.

In the 1977 dry season, the supplemental plots given the high level of insecticide (I_2) yielded 4.8 t/ha (Table 9). In contrast, actual farmers' yields averaged 4.1 t/ha. Farmers' insecticide level (Table 2) was slightly higher than the recommended Bimas rate, but it was lower than the I_1 level (Table 6). The results in both seasons confirm the importance of insecticide as a yield-increasing technology.

Table 8. Yield (t/ha) in the main experiment. Subang, Indonesia, 1976 – 77 wet season.[a]

Insecticide	Yield (t/ha)							
	Pusakaratu				Curugjati			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
I_1	4.1	3.9	4.1	4.0 c	3.6	3.9	4.1	3.9 c
I_2	3.5	3.4	3.5	3.5 d	3.7	4.2	4.1	4.0 c
I_3	4.3	4.7	4.7	4.6 b	4.9	5.1	6.0	5.3 b
I_4	3.1	3.6	3.8	3.5 d	4.4	4.0	4.0	4.1 c
Mean	3.8	3.9	4.0	3.9	4.2	4.3	4.6	4.4

Insecticide	Yield (t/ha)							
	Karanganyar				Kubangjaran			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
I_1	3.2	4.1	3.7	3.7 c	2.4	2.7	2.9	2.7 d
I_2	4.8	3.8	4.4	4.3 bc	3.2	4.0	3.7	3.6 c
I_3	5.5	5.1	5.5	5.4 b	5.2	5.3	5.3	5.3 b
I_4	3.6	3.9	4.4	40 c	3.2	2.7	3.3	3.1 c
Mean	4.3	4.2	4.5	4.3	3.5	3.7	3.8	3.7

[a] Numbers followed by the same letter within the column do not differ significantly from each other at the 5% level. I and F levels are defined in Table 5.

DISCUSSION

The experiments showed that insect control contributed significantly to increased yields, especially in the 1976 – 77 wet season when the study area was seriously infested with brown planthopper. The intensive protection applied to the high input

Table 9. Yield in supplemental experiments and adjacent farmers' fields. Subang, Indonesia, 1976 – 77.[a]

Site	Yield (t/ha) at input level					
	Farmers'[b]	F_1	F_3	I_1	$I_3(I_2)$[c]	Main, high[d]
			Wet season			
Pusakaratu	0.6	0.5	0.8	0.6	1.4	4.7
Curugjati	0.7	0.7	0.7	0.7	0.7	6.0
Karanganyar	0.4	0.4	0.4	0.9	1.4	5.5
Kubangjaran	1.4	0.9	1.2	0.9	1.5	5.3
Av	0.8	0.6	0.8	0.8	1.3	5.4
			Dry season			
Pusakaratu	4.1	-	-	4.5	4.8	-

[a]Experimental results based on 5 trials/per hamlet in the wet season and 40 trials in the dry season.

[b]Estimated by crop – cut.

[c]The high insecticide level was I_3 in the wet season and I_2 in the dry season.

[d]The F_3I_3 level used in the main wet season experiment.

plots (F_3I_3 in the main experiment) resulted in a 3.9 to 5.3 t/ha yield gap between the yields of such plots and farmers' yields estimated by crop – cuts (Table 9). Within the main experiments' intensively protected plots, insect control contributed from 0.8 to 2.6 t/ha to the yield gap between the high input level and the simulated farmers' input level (Table 7). Within the regular protected plots in the supplemental experiments, the high level insect control (I_3) contributed an average of only 0.5 t/ha to the yield gap (Table 9). In the 1977 dry season, when all plots used brown planthopper – resistant varieties, the high – level insect control contributed 0.7 t/ha to the yield gap (Table 9). The data indicate not only the contribution of insect

control but also the importance of using the proper rate and kind of insecticides for a given field situation. With a severe pest outbreak, a much higher than normal rate of insecticide must be applied.

Another important point revealed by the experiments was that at a comparable level of active ingredient, the granular insecticides provided more effective protection against pests than the liquid formulations, perhaps because greater skill is needed in applying liquid insecticides.

Finally, farmers' yields were higher in the dry season than in the wet season because of the use of brown planthopper-resistant varieties (IR26, IR30, and IR36) and the decline in the pest populations, especially of brown planthopper. But part of the yield difference between seasons could also be the result of the effectiveness of nitrogen fertilizer. The farmers used higher levels of nitrogen in the dry season (Table 2). In addition, the dry season rice plants were not seriously damaged by pests, climate was favorable, and adequate irrigation water was available. Such conditions provided a better environment for effective use of the available nitrogen by the crop. Yet, the small contribution of fertilizer to the yield gap in the main experiment, which was intensively protected against pests, indicates that fertilizer efficiency was lower during the 1976-77 wet season.

IDENTIFYING SOCIOECONOMIC CONSTRAINTS: ECONOMIC ANALYSIS OF THE YIELD GAP

In the Subang research trials, farmers' practices were simulated but not replicated. As a result, no plot accurately reflected farmers' practices and associated yield. In this analysis the survey data, crop-cutestimates of farmers' yields, and the experiment results are all used to evaluate the economics of input use.

The yield gap identified during the 1976-77wet season was 4.6 t/ha -- the difference between farmers' crop-cutyields and the maximum experimental plot yield. There was a difference of 1.8 t/ha between the level representing farmers' practices and the maximum experimental yield (Table 9). With the prices paid by farmers and input levels they applied (Table 5), the partial budget analysis for farmers' levels and the maximum-yieldinput levels was calculated (Table l0). The maximum level of inputs increased output by Rp 230,000 over farmers' gross return at an added cost of Rp 53,726. Consequently, the maximum input package gave a marginal benefit-cost ratio of 3.3. The difference between the

Table 10. Partial budget analysis of the main experiments. Subang, Indonesia, 1976 – 77 wet season.[a]

Input level	Yield (t/ha)	Value of product (Rp/ha)	Fertilizer (Rp/ha)	Insecticide (Rp/ha)	Total cost (Rp/ha)	Net return (Rp/ha)
Farmers' crop – cut[b]	0.8	40,000	12,040[e]	4,728[e]	16,768	23,232
Low, experiment[c]	3.6	180,000	17,500[f]	32,700[f]	50,200	129,800
Maximum, experiment'	5.4	270,000	17,500[f]	53,000[f]	70,500	199,500
Diff:maximum -farmers	4.6	230,000	5,454	48,272	53,726	176,274
Diff:maximum -low	1.8	90,000	0	20,300	20,300	69,700

[a]In 1976 – 77 farmers paid the following prices for input: urea and triple superphosphate, Rp 70/kg; Diazinon, Rp 900/liter; Sevin, Rp 900/kg; Ekalux 5G, Rp 500/kg; Furadan, Rp 200/kg. Farmers received Rp 5O/kg for their paddy.[b]Farmers' yield taken from crop – cut of 20 farmers' fields (Table 9).[c]Low level was F_2I_1 in experiment (Table 7).[d]Maximum yield represents F_3I_3 in 4 main experiments (Table 9).[e]Farmers' input cost based on average input levels applied (Table 2).[f]Experimental input costs based on experimental input levels (Table 5).

maximum and low level in the experiment also showed a very attractive return to high inputs.

The supplemental experiments in the wet season provide another estimate of marginal returns to higher input levels (Table 11). For fertilizer, an increase in expenditures from Rp 10,500 (F_1) to Rp 12,047/ha (farmers' level) gave a marginal benefit – cost ratio of 5.5, but a further increase to Rp 17,50O/ha (F_3) reduced net returns. For insecticide, an increase from Rp 1,800 (I_1) to Rp 4,728 (farmers' level) reduced net returns by Rp 2,928, the value of the additional insecticide. A further increase in insecticide expenditures to Rp 25,00O/ha (13) resulted in a marginal benefit – cost ratio of 0.23.

A complete budget analysis of farmers' net returns shows that average farmers' losses were Rp 48,656/ha during the 1976–77 wet season when cost of production included that of seed (Rp 3,750), fertilizer (Rp 12,047), insecticide (Rp 4,752), hired labor (Rp 60,644), and land rent (Rp 7,463). Only 5 tenants or leaseholders paid land rent. Their average expenditure was Rp 29,855/ha per season.

If farmers had used the maximum levels of insecticide and fertilizer (F_3I_3) employed in the main experiment, their net returns would have been Rp 71,560/ha. This figure slightly overestimates net returns because two of the 20 farmers in the sample were share–tenants who would have paid a higher rent if yields had been at the F^3I_3 level. Also, the higher input levels would have required slightly higher costs for fertilizer and hired labor for pest control.

Partial budget analysis of the dry season supplemental experiments showed that increasing insecticide intensity from Rp 4,768/ha (farmers' level) to Rp 7,800/ha (I_1) increased the value of output by Rp 28,000/ha, resulting in a marginal benefit–cost ratio of 9.2. Farmers received Rp 70/kg of paddy. A further investment in insecticide (up to Rp 10,000/ha, or I_2) increased gross returns by an additional Rp 21,000 and gave a marginal benefit–cost ratio of 9.5.

Table 11. Partial budget analysis of supplemental experiments. Subang, Indonesia, 1976–77 wet season.

Input level[a]	Yield (t/ha)	Value of product (Rp/ha)	Input cost (Rp/ha)	Net returns (Rp/ha)
		Fertilizer		
F_1	0.6	30,000	10,500	19,500
Farmers'	0.8	40,000	12,047	27,953
F_3	0.8	40,000	17,500	22,500
		Insecticide		
I_1	0.8	40,000	1,800	38,200
Farmers'	0.8	40,000	4,728	35,272
I_3	1.3	65,000	25,000	40,000

[a]Input levels are defined in Table 5.

A complete budget analysis of farmers' net returns shows that average farmers' profits were Rp 109,119 during the 1977 dry season. Cost of production included expenditures for seed (Rp 3,750), fertilizer (Rp 17,290), insecticide (Rp 4,768), hired labor (Rp 83,667), and land rent (Rp 68,256). Only 22 tenants or leaseholders paid land rent. Their average expenditure was Rp 136,512/ha per season.

If the farmers had used the high level of insecticide (I_3) employed in the supplemental experiments, their net returns would have been Rp 145,257. This figure overestimates actual net returns since share-tenants would have paid a higher rent. if yields had been at the I_3 level.

Constraints to higher input use

The partial budget analysis indicates that, on the average, farmers were using close to the optimum fertilizer level, even though it was only two-thirds of the BIMAS recommendation for the wet season. Farmers' reluctance to use the BIMAS level of fertilizer appears rational in the light of the experimental results. When asked why they applied less than the recommended level, 50% of the farmers cited aversion to debt and 35%, lack of capital; 15% believed the suggested level was too high. It is probable that the farmers who used either the BIMAS recommendation or a higher level were in a better capital position and could better afford to risk a large loss should crop failure occur.

Table 12. Technical inefficiency in insecticide usage, International Rice Agro-Economic Network (IRAEN) field experiments. Subang, Indonesia, 1976-77 wet season.[a]

Farmers' expenditure for insecticide	Number of farmers	Av expenditure (Rp/ha)	Farmers' av yield (t/ha)	Av I_1 yield (t/ha)
<Rp 1800	5	962	0.2	0.6
>Rp 1800	13	4675	0.8	0.8

[a]The analysis excludes 1 farmer who spent Rp 1,80O/ha and another who spent Rp 15,20O/ha.

In the wet season when insect damage was severe, the farmers on the average applied 92% (in value terms) more than what was recomended. Seventy-fivepercent of the respondents said they did so to ensure high yields. Yet, the partial budget analysis shows that farmers' insecticide level was suboptimal. The farmers' failure to respond to the insect problem was probably due to its unprecedented nature. The control obtained in the main experimental plot (F_3I_3) was achieved at an application level 29 times greater than the BIMAS recommendation. It is unreasonable to expect farmers to take the initiative to apply such high insecticide levels: the cost is beyond their financial means, and purchase could not be financed through BIMAS. The BIMAS program could provide only the recommended input level. input level.

Technical inefficiency - a contributing factor to the yield gap

Yield may be thought of as a direct consequence of both quantity of inputs applied and quality of input usage. Higher levels of inputs applied incorrectly may not increase yields. Insecticides are chemicals too complex for farmers to utilize. Most are toxic only to specific insects, can be washed off by rain, may require being placed on a specific part of the rice plant, and must be mixed correctly.

The possible existence of technical inefficiency is suggested by the results of the wet season supplemental experiments. Farmers applied more than 2.5 times the value of insecticide used in I_1, but harvested the same amount of grain (Table 9). Partitioning of the data shows that the five farmers who used the I_1 insecticide level costing less than Rp 1,800 had yields of 0.2 t/ha, compared with the yield of 0.6 t/ha on the I_1 plot (Table 12). In sharp contrast, farmers who spent more than Rp 1,80O/ha (average expenditure, Rp 4,675/ha) achieved yields of 0.8 t/ha -- the same as on the I_1 plot where only Rp 1,800 was spent to protect the crop. Although farmers did not necessarily use the same chemical for insect control that the experimenters applied on I_1, the results provide strong evidence of the probable existence of technical inefficiencies in insecticide use. This hypothesis could not be tested on the dry season data because farmers applied a level of insecticide lower than the I_1 experimental level.

The cause of the observed technical inefficiency is an important research issue. In the dry season, each respondent was asked which chemical should be used to control stemborer, gall midge, and brown planthopper. Table 13 suggests that farmers' knowledge of the correct insecticides for the control of brown planthopper is low; only 51% gave the right answers.

Table 13. Farmers' responses to questions indicating knowledge of insecticides for controlling pests. Subang, Indonesia, 1976.

Pest	Responses (%)		
	Wrong	Partly correct	Correct
Stemborer	13	27	60
Gall midge	15	25	60
Brown planthopper	23	26	51
Percent of total	17	26	57

A point-scoring system (correct = 2, partly correct = 1, wrong = 0) was used to evaluate the distribution of farmers' combined insecticide-knowledge responses. The data showed that 15% answered 0-2 questions correctly, 43% answered 3-4 correctly, and only 42% answered 5-6 correctly. It appears that a large portion of the observed technical inefficiency in insecticide use is due to farmers' lack of knowledge of correct practices.

Previously presented data documenting farmers' fertilizer and pest-control practices give further evidence of incorrect input use (Table 4). In the wet season, the farmers' first application of triple superphosphate and urea was at an average of 21 and 24 days after transplanting (DT), respectively. The first dosage of both granular and sprayable insecticide was not applied until 44 DT. The dry season cooperators were all located within the intensively serviced demonstration area. They applied their first fertilizer 10-11 days before the farmers observed in the wet season did. They applied insecticide 17 to 24 days earlier than the wet season cooperators. It appears that the intensive extension project improved farmers' management practices.

Finally, because the government plays a critical role in the Indonesian rice production milieu, farmers were asked their expectations regarding the role government should play in increasing rice production. Twenty-eight percent cited the need €or government to provide inputs at the correct time, 23% wanted credit for the purchase of a tractor, and 23% suggested areawide pest control. The data indicate that the late application of chemicals due to their unavailability may be an additional source of technical inefficiency.

SUMMARY AND CONCLUSION

The constraints experiments conducted during the 1976 – 77wet and dry seasons provided some useful insights into the rice farming situation in Subang, West Java. The experiments showed that insect control is the most important factor contributing to the gap between the yields obtained at farmers' input levels and those at high input levels, and that the effectiveness of various levels of fertilizer application depends on the season and the level of plant damage by pests.

The economic analysis showed that the farmers are economically rational, and the average fertilizer level appears to be optimal. It was profitable, however, to apply higher insecticide levels in response to observed high pest infestation. This suggests that farmers apply suboptimal levels of insecticides. Farmers probably did not use the amounts required to give full protection because insecticides could not be acquired on credit through BIMAS and because the farmers had no previous experience with such intensive use of pesticides.

As agriculture becomes more technologically sophisticated, it becomes increasingly necessary to train farmers in the correct use of modern inputs. Farmers' yields and profits could be increased through the more efficient use of the insecticides applied. Major sources of technical inefficiency appear to be the farmers' low technical knowledge and incorrect timing of application. Some farmers reported that insecticide and fertilizer were not available when needed, and so timely application was impossible.

The situation casts some doubt on the efficiency of extension and the BIMAS supporting system in general. It should be realized that the higher the technology is, the higher will be the need for more qualified service.

Events during the 1976 – 77wet season illustrate the problem of institutional rigidity in a dynamic agricultural environment. To effectively serve the farmers, rural institutions must be capable of responding to the changing needs of their constituents. Flexibility must be built into programs such as BIMAS so that credit and input levels may be rapidly increased to combat fluctuations in insect populations. Monitoring of insect movements on a nationwide basis would provide not only some lead time in developing supplemental recommendations and distributing the inputs to where they are needed, but would also provide information for the manipulation of insect populations through the synchronization of regional control efforts.

There is little doubt that the introduction of insect-resistant varieties contributed to higher dry season yields. In the wet season, all cooperators used Pelita -- an early modern variety and suffered extensive damage. In contrast, the dry season farmers who planted only IR26, IR30, and IR36 had good yields. Yet since dry season Pelita and the resistant varieties cannot be directly compared, it is not possible to explicitly measure the benefits of varietal resistance. It is probable that a large part of the increase in productivity apparently resulting from variety may actually be due to a lower brown planthopper population in the dry season. With this reservation in mind, it appears that the wide distribution of resistant varieties would have a major impact on future production, net returns, and yield stability.

Yield constraints can be expected to change in response to the interaction between environment, technology, and farmers' practices. Consequently, there is a need to continuously monitor constraints to identify the directions in which our present technologies must be modified to serve farmers better.

FUTURE CONSTRAINTS EMPHASIS

The constraints identified in the 1976-77 research must serve as a guideline for future studies. The problem of pest control must be studied more intensively. In addition to the level of input use, the effectiveness of sprayable versus granular chemicals must be evaluated. The skill of the person applying the inputs appears to be just as important a factor to increasing yields as the level of input applied. It is necessary, therefore, to develop a methodology for skill assessment that may be used to better measure the effect of technical inefficiency.

The experience gained through four seasons of constraints research has prepared the field team to expand the research methodology into a diagnostic tool. A series of constraints studies throughout the Jatiluhur irrigation system in the 1973-79 wet season is planned. The trials will cover a wide geographical area, and additional sources of farm-to-farm yield variation will be measured. They may include water availability, rat damage, insect pressure, extension intensity, and availability of inputs. Farmers' and field experiments, supplemental trials, farmers' field crop, and farm recording will all be employed in the Jatiluhur study to be undertaken in cooperation with the Extension Service and the Jatiluhur Irrigation Authority.

REFERENCES CITED

CRIA (Central Research Institute for Agriculture), 1977. Socioeconomic survey of Pusakanegara 1976-77.

Gomez, K. A., R. N. Herdt, R. Barker,.and S. K. De Datta, 1979. A methodology for identifying constraints to high rice yields on farmers' fields. Pages 27 – 47 in International Rice Research Institute. Farm-level constraints to high rice yields in Asia:1974-77. Los Baños, Philippines.

IRRI (International Rice Research Institute), 1977. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Philippines.

Mears, L. A., 1976. Indonesia's food problems, Pelita II/III, Ekonomi dan keuangan 24 (2).

USDA (US Department of Agriculture) Foreign Agricultural Service, 1978. Indonesia fertilizer report, ID-8003. Revised, 13 January 1978.

Identifying Constraints to Higher Rice Yields in Yogyakarta, Indonesia

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Constraints research in Yogyakarta was begun in the wet season of 1974 – 75and was continued for three years. Different villages in the province were selected each year. The Special Province of Yogyakarta, located south of Central Java, is one of the 27 provinces of the Republic of Indonesia. The climate is tropical and is characterized by distinct wet and dry seasons. The wet season is from October to Play and the dry season is from June to September.

Annual average solar radiation is 439 cal/cm^2 per day. The mean sunshine duration is about 75% on the Yogyakarta plain. Kind velocity is generally low, ranging from 2.0 to 3.0 m/second. Average annual rainfall in most of this area exceeds 1,500 mm; with elevation, it increases up to 2000 mm.

Most of the soils are of volcanic origin, composed largely of andesitic and some dacitic materials. Their maturity varies with the age of the present rock and sediments and also with the variation in the degree of soil development. The soils of the middle and lower volcanic slopes are generally moderately to well weathered ash soils. Most are suitable for intensive agriculture. The coarser, very permeable young ash soils on the middle to the higher slopes of Mt. Merapi are not naturally suitable for *sawah* rice but, through repeated puddling and leveling, they have become fairly suitable.

Lowland rice yields are relatively high, averaging 3.4 t/ha, compared with 2.9 t/ha for all of Indonesia in 1974. The yield level reflects good water management, high labor input, and substantial fertilizer use.

Yogyakarta cropping patterns are relatively diversified with 30%. of the staple crop area devoted to rice (the area in rice is 33% in East Java, 44% in Central Java, and 71% in West Java). Nonfarm employment is an important source of income for many families. Most of the area is well– to moderately well – irrigated. Drainage is a minor problem. Roads are good, except in the rural valleys and hillside villages.

Yogyakarta has the smallest population among the five provinces comprising Java, and is tenth among the 27 provinces of Indonesia. In 1975 Yogyakarta had a population of about 2.6 million, which was around 2% of the nation's total. But the province crowds 823 people/km^2 into an area comprising only 0.16% of the country.

METHODOLOGY

Two criteria were used for selecting the study villages: they were rice-producing villages, and they were accessible from Yogyakarta City. Kulon Progo Regency, 30 km west of the city was chosen in 1974. On the basis of water control, three villages were selected: Pengasih, with good irrigation; Sidomulyo, with moderate irrigation; and Sentolo, a rainfed area.

To make possible a more intensive visitation routine, three closer villages - Godean, Bantul, and Sleman - were selected in 1975. A shortage of water caused by the repair of the main irrigation canal to Godean forced termination of the experiments in that area after 1975–76.

Selection of experimental factors

Fertilizer and pest control appear to be the two most important factors that constrain high rice yields. Both factors were tested in all seasons. The other inputs or factors taken into account varied from one season to another. Weed control was studied at first. Because it did not account for a significant portion of the gap in the first three seasons, it was eliminated in the fourth and the following seasons. At the same time, serious damage was caused by brown planthoppers in many rice farmers' fields, despite the introduction of resistant rice varieties. So the latest modern variety was included in the study wherever insect problems had occurred. We later realized that transplanting systems might also be important, and they were studied in the last season.

Experimental design

In 1974–75 and 1975–76, the experiments consisted of two sets: a complete two-level factorial and a five-level management package. The experimental factors discussed earlier were included in the complete factorial at the farmers' levels and the high level. We used Pelita I/2 to simulate farmers' varieties and IR26 as a test variety in the dry season of 1976. Because farmers used IR26 and IR30 in the 1977 dry season, IR32 was used as a test variety in that season.

The management package consisted of M_1, with all factors at the farmers' level, M_5 with all factors at the high level, and M_2, M_3, and M_4 with factors at the intermediate level.

A plot size of 23 m^2 was used in all experiments, giving a net harvest area not less than 6 m^2 after border rows were excluded. In each site the experiment was replicated, with three replications in the 1974-75 wet season and two in the 1977 dry season.

For studies in the 1976-77 wet season and the 1977 dry season, two other types of experiments were included: the minifactorial experiment and the supplemental trial. The treatments in the minifactorial experiments equal two more than the number of factors being tested. Differing slightly from the treatments in the methodology developed by IRRI (Gomez 1977), they included one plot with all factors high, one plot with all factors at the farmer's level, and each of all the other plots with all but one factor at the farmers' level (Table 1).

The minifactorial experiments were replicated twice at each site using a plot size of 20 m^2. Four farmers in each village cooperated in this type of experiment.

The supplemental trials had one plot with all factors at the high level. The plot size was 50 m^2. The farmers' yields were obtained by harvesting a crop-cut sample from their fields. In the supplemental trials in each village 14 to 15 farmers cooperated.

Analysis

The complete, minifactorial, and supplemental trials were designed to measure the yield gap by finding the yield difference between plots with all inputs at the high level and the plots with all inputs at the farmers' level.

The contribution of the individual input to the gap was obtained from the complete and minifactorial experiments. It was measured as the yield increase in the plots with the input at the farmers' level compared with the yield in the plots with inputs at the high level.

Statistical tests were applied to the results from the complete factorial experiments to determine whether interactions were present. The management package was used to assess the economic benefits of the high inputs compared with the farmers' levels.

Table 1. The minifactorial design used for studying yield constraints in farmers' fields.[a] Yogyakarta, Indonesia 1976-77.

Treatment	Fertilizer	Insect control	Weed control
1	F	F	F
2	R	F	F
3	F	R	F
4	F	F	R
5	R	R	R

[a] F = farmer's level, R = recommended level.

Socioeconomic constraints. In the first year, surveys were carried out in the same three hamlets where the experiments were conducted, and in three other hamlets matching the first three in physical environment but different in distance from input markets and processing facilities. For each irrigation level, a pair of hamlets was selected -- one hamlet relatively near the input market and processing facilities, and the other hamlet relatively far from them. Because input depots had been well distributed by the intensive BIMAS program, choosing the hamlets was not as simple as we first thought. Distances to input depots were not as far nor as consistent among villages as desired.

The experiment sites were selected in an area that had not yet been planted by the time preparation for the project was completed. Although the area may not be truly representative of rice-growing areas in Yogyakarta, many of the problems confronting its farmers are common to other areas of Yogyakarta.

A complete enumeration presurvey was conducted to describe the population in each hamlet and to get information about tenure status and farm size to use in sampling.

The population was stratified into three by tenure-status: owner-operators, share-crop tenants, and cash-rent tenants. The owner-operators were the most numerous.

The sampling was essentially proportional. To the extent that it was not precisely proportional, the population proportion was used to weight the samples.

In the second and third years, the water control level and the distance to input markets were not used to stratify the hamlets. The sample villages and hamlets were purposively chosen in the

main rice-growing area in the *kabupaten* Bantul and Sleman, closer to Yogyakarta City.

The questionnaire was designed to search for the factors affecting the adoption of new rice technology. Individual interviews were used to collect data from the farmer respondents. The data were grouped according to hamlet. Contingency tests and regression analyses were used to analyze the relationship between the level of input used and a number of variables that might affect it, such as tenure, farm size, water problems, varieties, credit and input availability, agricultural extension, education, technical knowledge, traditional beliefs, and adoption of technology. Linear regression models were developed to examine the adoption of technology.

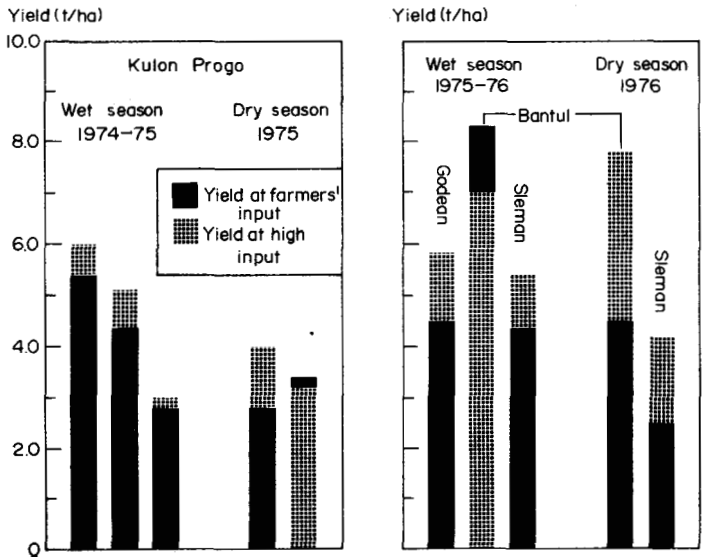
RESULTS AND DISCUSSION: BIOLOGICAL CONSTRAINTS

Figures 1 to 3 show individual yield gaps ranging from −1.2 to 1.9 t/ha in the wet season and -0.7 to 3.9 t/ha in the dry season. The average gaps are shown in Table 2. The gap was greater in the dry season (1.2 t/ha) than in the wet (0.4 t/ha). The contribution of each input to the gap is shown in Table 3. Except in Sleman in the 1976-77 wet season, fertilizer contributed the largest portion to the gap. Its contribution was substantially higher in the dry season than in the wet. It seems that the abundance of sunlight in the dry season enables the rice plants to utilize the fertilizer more efficiently.

Yield data are given here for all seasons of the research, but only the results for 1975-76 and 1976-77 are discussed. Results for the first year are discussed in the *Interim report.* Table 4 shows the average results for the first year.

High insecticide application slightly increased rice yields when fertilizer was applied at the farmers' rates, but considerably decreased yields when fertilizer was applied at the high level (Table 5). When not accompanied by weed control, high applications of fertilizer reduced rice yield. The reduction was probably the result of the inability of the rice plants to compete with the weeds, which seemed to benefit more from the increased nutrients. In the 1975-76 wet season fertilizer contributed significantly to the yield gap, except in Godean (Table 6). The three sites showed only two significant interactions: a negative interaction between insect control and fertilizer, and a positive one between fertilizer and weed control in Bantul.

Table 7 shows that in the 1976 dry season in Sleman, Pelita I/2 gave much lower yields than IR26. Pelita I/2 is susceptible to brown planthopper (BPH), which was a serious problem that year.



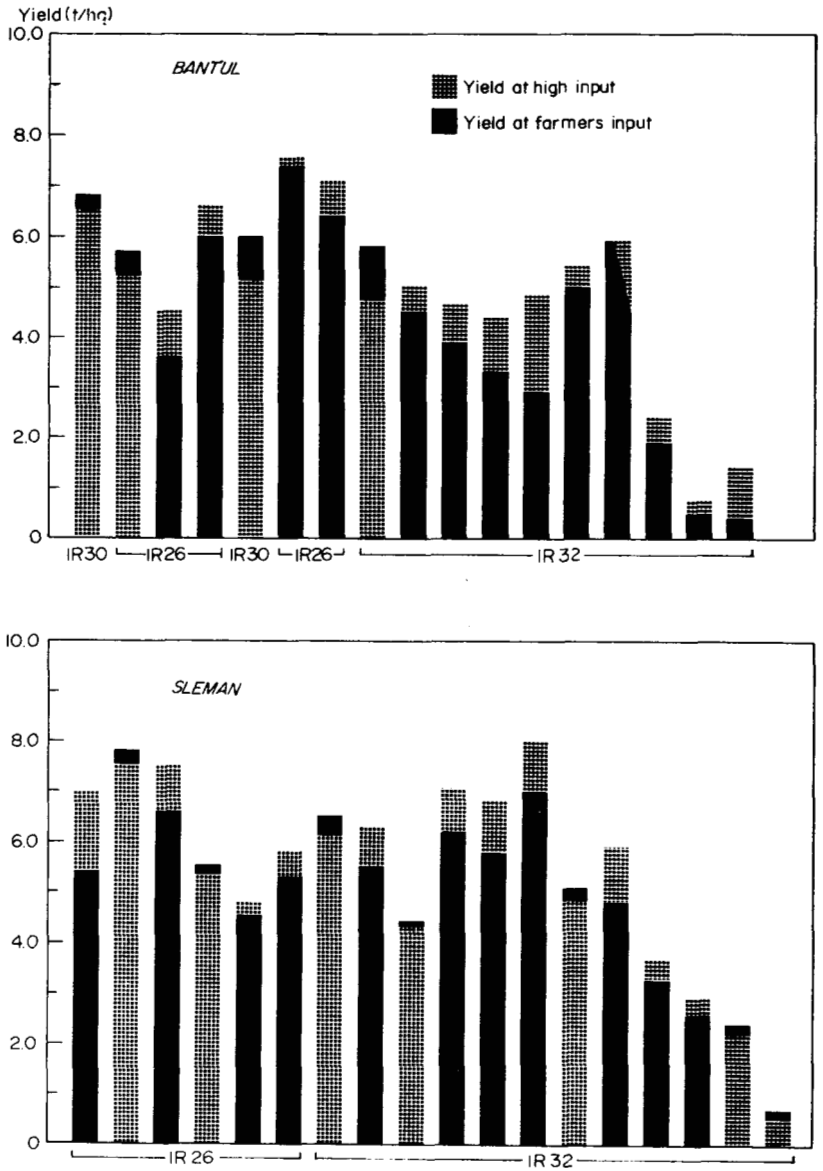
1. individual yields in Kulon Progo, Godean, Bantul and Sleman, Indonesia.

Additional losses were incurred from grassy stunt virus, which is transmitted by the BPH. Table 8 shows that variety contributed 3.7 t/ha to the difference between sites, the most important factor in increasing rice yield in Sleman. It also shows that the heavy application of insecticides contributed little, although it did increase the yield of Pelita I/2 by 0.4 t/ha and that of IR26 from 0.6 to 0.7 t/ha. For both varieties in Sleman, fertilizer made a significant contribution to the gap and was the most significant factor. This is understandable -- both varieties are responsive to fertilizer.

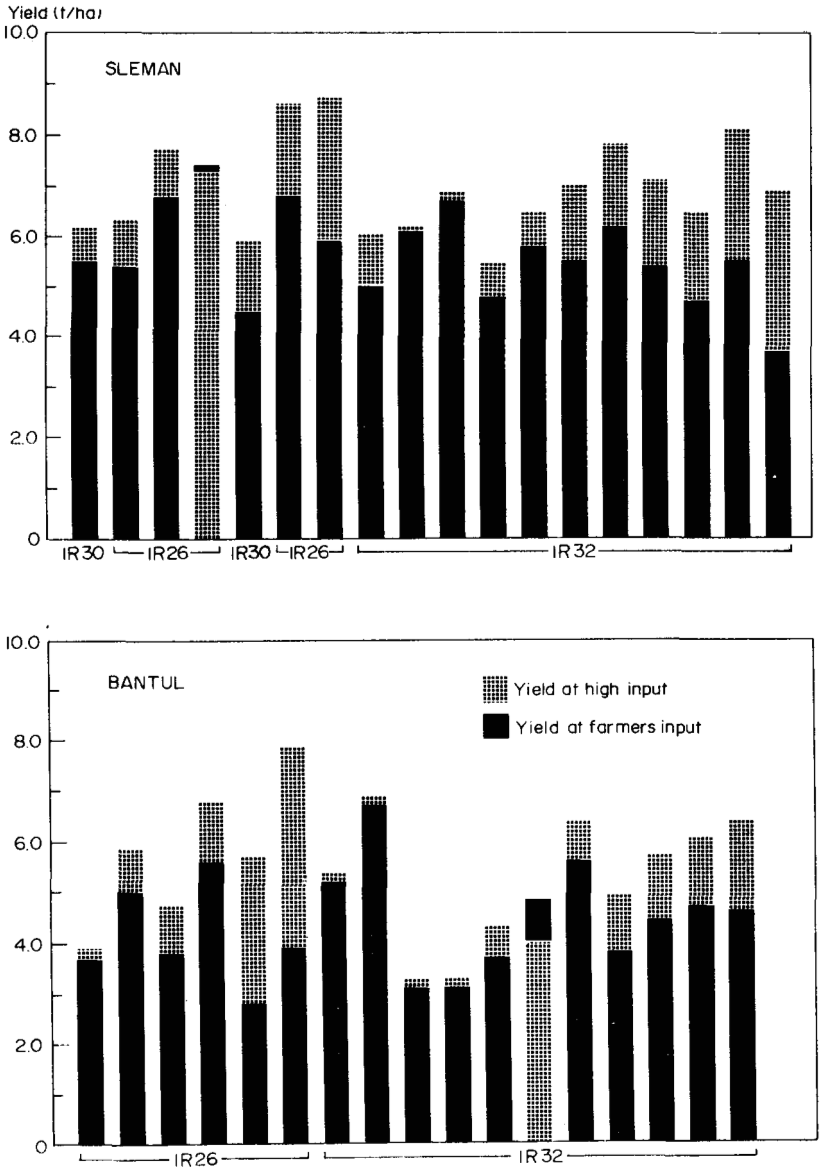
In addition, a significant positive interaction was observed between fertilizer and insect control. When fertilizer was applied at a low rate, the resistance of IR26 to the BPH appeared to be adequate. A higher rate of nitrogen fertilizer application tended, however, to increase the damage from the BPH. Hence, heavily fertilized plots that received appropriate insect control gave higher yields than fertilized plots without insect control.

Table 9 shows the treatment yields, and Table 10 shows the yield effects for experiments in the 1976 – 77wet season. The yields obtained in each area did not differ significantly. Fertilizer, which had no significant effect in Sleman, explained a significant portion (0.3 t/ha) of the yield gap in Bantul.

The yields in the complex experimental design used in the complete factorial experiment in the 1977 dry season are shown in Table 11. The analysis is shown in Table 12. The fact that IR32 gave no



2. Individual yields in Bantul and Sleman, Indonesia, 1976–77 wet season.



3. Individual yields in Bantul and Sleman, Indonesia, 1977 dry season.

Table 2. Average grain yield with farmers' inputs and with high inputs and the gap. 1974 – 75 wet season through 1977 dry season, Yogyakarta, Indonesia.

Area	No. of sites	Year	Grain yield (t/ha)		
			Farmers' inputs	High inputs	Gap
			Wet season		
Kulon Progo	3	1974 – 75	4.2	4.7	0.5
Godean	1	1975 – 76	4.4	5.8	1.4
Bantul	1	1975 – 76	8.2	7.0	–1.2
S1eman	1	1975 – 76	4.2	5.4	1.2
Bantul	17	1976 – 77	5.2	5.6	0.4
Sleman	18	1976 – 77	4.2	4.6	0.4
Av			4.7	5.1	0.4
			Dry season		
Kulon Progo	2	1975	2.6	3.9	1.3
Bantul	1	1976	4.5	7.7	3.2
Sleman	1	1976	2.5	4.2	1.7
Bantul	17	1977	4.3	5.4	1.1
Sleman	18	1977	5.6	6.9	1.3
Av			4.8	6.0	1.2

higher yield than IR26 was expected -- there was no BPH problem in that season. The presence of other insects probably explains why the results differed from those of previous experiments. Insect control contributed a significant portion of the yield gap in both Bantul (0.8 t/ha) and Sleman (0.7 t/ha).

The interactions of two factors and three factors were significant, but different in each area.

The input levels in the 1974 – 75 experiments are reported in the *Interim report.* The levels used in the 1975 – 76 wet season are shown in Table 13. The same M_2 and M_5 levels were used in 1976 – 77. Farmers' inputs varied from site to site and from year to year but were generally close to M_3. Dry season input levels for 1976 are shown in Table 14. The levels M_2 to M_5 in 1977 were the same as in 1976.

Yields of the management packages are shown in Table 15. In all dry season cases the highest input gave the highest yield, except

Table 3. Yield gap and contribution of inputs toward increasing rice yields. Yogyakarta, Indonesia, 1974–75 wet season to 1977 dry season

Area	Sites (no.)	Year	Grain yield (t/ha)[a] Farmers inputs	High inputs	Gap	Contribution (t/ha) of Fertilizer	Insect control	Weed control	Residual
				Wet season					
Kulon Progo	3	1974–75	4.2	4.7	0.5	0.7	-0.1	-0.1	0.0
Godean	1	1975–76	4.4	5.8	1.4	0.4	0.4	0.2	0.2
Bantul	1	1975–76	8.2	7.0	–1.2	-1.3	-1.0	1.0	0.1
Sleman	1	1975–76	4.2	5.4	1.2	0.7	0.3	0.3	-0.1
Bantul	4	1976–77	5.7	6.2	0.5	0.3	0.2	b	0.0
Sleman	4	1976-77	5.8	5.9	0.1	0.1	0.0	b	0.0
Av			5.4	5.8	0.4	0.3	0.1	0.3	0.0
				Dry season					
Kulon Progo	2	1975	2.6	3.9	1.3	1.0	-0.3	0.4	0.2
Bantul	1	1976	4.5	7.7	3.2	2.6	0.7	b	-0.1
Sleman	1	1976	2.5	4.2	1.7	1.3	0.5	b	-0.1
Bantul	4	1977	4.1	5.5	1.4	0.8	-0.2	b	0.8
Sleman	4	1977	5.5	7.1	1.6	0.7	0.5	b	0.4
Av			4.2	5.8	1.6	1.0	0.2	0.4	0.4

[a]Differs from data in Table 2 because not all sites had factorial experiments that allowed the separate identification of contributions
[b]Not included in the experiments.

for Bantul and Sleman in 1977. A similar result was obtained in the wet season, except for Bantul in 1975–76 and Sleman in 1976–77. The yield obtained by farmers was close to the yields obtained with M_4 and M_5.

ECONOMIC ANALYSIS OF BIOLOGICAL CONSTRAINTS

The costs of the input packages in each season were determined using the prices of inputs prevailing in the area that season (Table 16). The price of fertilizer increased by Rp 10/kg each year, but other input prices were constant over the 3 years. Rice prices fluctuated somewhat. Variations in the costs of the packages largely reflect differences in inputs used (Table 17).

Table 4. Average grain yield of experimental treatments. Yogyakarta, Indonesia.

Treatment [a]	Grain yield (t/ha)	
	1974-75 wet season	1975 dry season
$I_1F_1W_1$	4.2	2.6
$I_1F_1W_5$	4.3	2.6
$I_1F_5W_1$	5.5	4.0
$I_1F_5W_5$	4.9	3.9
$I_5F_1W_1$	4.3	2.5
$I_5F_1W_5$	4.6	2.9
$I_5F_5W_1$	5.0	2.7
$I_5F_5W_5$	4.7	3.1

[a] Subscript numbers represent factor level: 1 = farmers', 5 = high. I = insect control, F = fertilizer, W = weed control.

Management packages, first year

The higher yields that were obtained from the high input levels cost more than the farmers' levels of input. In the 1974-75 wet season, the experimental farmer in Sentolo spent Rp 31,180 for the fertilizer and weed control inputs used. The two experimental farmers in Sidomulyo and Pengasih spent Rp 19,160 for their inputs. The costs of M_5 total Rp 66,080 in both Pengasih and Sidomulyo, and Rp 69,070 in Sentolo, which had a higher wage rate. Even so, M_5 snowed an improved profit for farm owners, while tenants would have been better off at the M_1 level (Table 18).

The 1975 dry season experiment in Pengasih had a much different result. The highest level management package gave the highest net return and, at all levels of management packages, the additional return substantially exceeded the additional cost for both owner-operators and share-tenants. Additional inputs costing Rp 62,500 gave an additional net return of Rp 131,090 for owner-operators and Rp 34,000 for share-tenants.

Management packages, second and third years

In the 1975 – 76wet season at Sleman and Godean, M_4 gave the highest net return of the alternative packages, although M_5 had the highest yield. Still, on the average, the farmers' level M_1 was the most profitable. In the 1976 – 77wet season the already high input level of the farmers was the most profitable among the tested levels.

In the 1976 dry season experiment, input levels above the farmers' level gave higher net returns. Even with the use of Pelita I/1, which was seriously damaged by brown planthoppers, an input increase to M_3 was still profitable to owner – operators. With IR26, the higher input package levels of M_4 and M_5 were more profitable.

Table 5. Average grain yield of complete treatments. Yogyakarta, Indonesia, 1975 – 76 wet season.

Treatment [a]	Grain yield (t/ha)			
	Godean	Bantu1	Sleman	Av
$I_1F_1W_1$	4.4	8.2	4.2	5.6
$I_1F_1W_5$	4.8	8.1	4.5	5.8
$I_1F_5W_1$	5.9	7.1	4.7	5.9
$I_1F_5W_5$	5.8	8.9	5.1	6.6
$I_5F_1W_1$	5.7	8.4	4.5	6.2
$I_5F_1W_5$	6.1	8.2	4.5	6.3
$I_5F_5W_1$	5.8	4.7	5.2	5.2
$I_5F_5W_5$	5.8	7.0	5.4	6.1

[a] Subscript numbers represent factor level: 1 = farmers', 5 = high. I = insect control, F = fertilizer, W = weed control.

Table 6. Effects of insect control, fertilizer, weed control, and their interactions on grain yield. Yogyakarta, Indonesia, 1975 – 76 wet season.

Effect	Grain yield (t/ha)		
	Godean	Bantul	Sleman
Grand mean	5.4	7.6	4.8
Insect control (I)	.4	-1.0	.3
Fertilizer (F)	.4	-1.3*	.7*
Weed control (W)	.2	1.0*	.3
I x F	-.9	-1.2*	.1
I x W	.0	.0	.2
F x W	-.2	1.1*	.1
I x F x W	.0	.1	.0

*Significant at 5% level.

Table 7. Average grain yield of complete factorial treatments. Yogyakarta, Indonesia, 1976 dry season.

Treatment[a]	Grain yield (t/ha)			
	Bantul	Sleman		
	IR26	IR26	Pelita I/2	Av
I_1F_1	4.5	4.0	0.9	3.1
I_1F_5	6.4	6.0	1.7	4.7
I_5F_1	4.4	4.6	1.5	3.5
I_5F_5	7.7	6.5	1.9	5.4

[a] Subscript numbers represent factor level: 1 = farmers', 5 = high. I = insect control, F = fertilizer.

Table 8. Effects of fertilizer, insect control, and interactions on grain yield. Yogyakarta, Indonesia, 1976 dry season.

Effect	Bantul IR26	Sleman IR26	Sleman Pelita I/2	Sleman Av	Sleman Interaction with variety
Grand mean	5.7	5.2	1.5	3.4	3.7*
Insect control (I)	0.7	0.6	0.4	0.5	0.1
Fertilizer (F)	2.6*	2.0*	0.6	1.3	0.7*
Interaction (I x F)	0.7*	.0	-0.3	-0.2	0.1

*Significant at 5% level.

Table 9. Average grain yield of complete factorial treatments. Yogyakarta, Indonesia, 1976 – 77 wet season.

Treatment[a]	Grain yield (t/ha) Bantul	Sleman	Av
I_1F_1	5.7	5.8	5.8
I_1F_5	5.8	6.0	5.9
I_5F_1	5.9	6.0	6.0
I_5F_5	6.2	5.9	6.1

[a] Subscript numbers represent factor level: 1 = farmers', 5 = high. I = insect control, F = fertilizer.

Table 10. Effects of insect control, fertilizer, and interactions on grain yield. Yogyakarta, Indonesia, 1976 – 77 wet season.

Effect	Grain yield (t/ha) Bantul	Sleman
Grand mean	5.9	5.9
Insect control (I)	0.2	0.1
Fertilizer (F)	0.3*	0.1
Interaction (I x F)	0.1	– 0.4

*Significant at 5% level.

In the 1977 dry season the farmers' level was again improved. The lower levels of inputs (M_2 and M_3), applied with some changes in the method of input application, gave higher yields and incomes as did the higher input levels (M_4 and M_5) with higher costs. The dry season yield can be increased by improving the method of input application and increasing the input level.

Economics of separate inputs

Although fertilizer increased returns over additional costs in the first year in the wet and dry seasons, in the wet season of the following years it gave no higher return or a negative return over the farmers' level (Table 19). This is because the farmers were already using a high level of fertilizer. In the dry season, when the fertilizer application rates of the farmers were generally lower, the additional fertilizer increased returns over the additional costs, except with the Pelita variety, which was seriously damaged by brown planthopper.

The high level of insect control, in general, gave lower additional return from the additional cost, except in the 1976 dry season on IR26. The high level of weed control was no more profitable than the farmers' levels in 1974 – 75. However, in the two other seasons a modest increase in cost resulted in a considerable increase in the value of output.

Thus, it seems that higher levels of fertilizer in the dry season should be economically attractive to farmers, but they would not

Table 11. Average grain yield of complete factorial treatments. Yogyakarta, Indonesia, 1977 dry season.

Treatment[a]	Grain yield (t/ha)		
	Bantul	Sleman	Av
$F_1I_1V_1S_1$	3.4	6.3	4.9
$F_1I_1V_1S_5$	3.8	7.1	5.5
$F_1V_1I_5S_1$	3.9	4.2	4.1
$F_1I_1V_5S_5$	4.4	4.8	4.6
$F_1I_5V_1S_1$	5.2	7.5	6.4
$F_1I_5V_1S_5$	2.8	6.7	4.8
$F_1I_5V_5S_1$	6.2	5.7	6.0
$F_1I_5V_5S_5$	5.3	5.6	5.5
$F_5I_1V_1S_1$	4.9	8.3	6.6
$F_5I_1V_1S_5$	4.8	7.5	6.2
$F_5I_1V_5S_1$	4.4	5.0	4.7
$F_5I_1V_5S_5$	4.8	7.1	6.0
$F_5I_5V_1S_1$	5.3	9.6	7.5
$F_5I_5V_1S_5$	6.8	8.3	7.6
$F_5I_5V_5S_1$	4.2	8.3	6.3
$F_5I_5V_5S_5$	4.8	6.7	5.6

[a] Subscript numbers represent factor level: 1 = farmers', 5 = high. F = fertilizer, I = insect, V = variety, S = system of transplanting.

Table 12. Effects of fertilizer, insect control, variety, system of transplanting, and their interactions on grain yield. Yogyakarta, Indonesia, 1977 dry season.

Effect	Bantul	Sleman
Grand mean	4.7	6.6
Fertilizer (F)	0.6	1.3*
Insect control (I)	0.8*	0.7*
Variety (V)	0.7	−2.0*
System of transplanting (S)	0.0	−0.2
F x I	-0.2	−0.1
F x V	−1.0*	0.2
F x S	0.6	0.0
I x V	0.0	0.0
I x S	−0.3	-0.5
V x S	−0.2	0.7*
F x I x V	-0.6	−0.4
F x I x S	−0.8*	0.1
I x V x S	−0.4	0.0

*Significant at 5% level.

be attractive in the wet season. High insect control levels are likely to be attractive only with resistant varieties in seasons with considerable insect pressure.

IDENTIFYING SOCIOECONOMIC CONSTRAINTS

The objective of this portion of the research was to determine the factors that keep farmers from using the inputs that would increase yields and profit, in this case more fertilizer in the dry season. It was hypothesized that factors such as availability of irrigation, availability of inputs, credit limitations, farm size, and lack of incentive due to tenure status influence fertilizer use.

Comparison of experimental farmers and average farmers

Landholdings in the survey area are small, generally less than 0.5 ha; in the area included in the first year of this study (Kulon Progo) they are less than 0.2 ha (Table 20). However,

Table 13. Treatments in the management package and yield constraints experiments with Pelita I/2. Yogyakarta, Indonesia, 1975-76 wet season.

Treatment level[a]	Fertilizer[b] (kg/ha) Urea	TSP	Hand weeding (no.)	Insect control[c]
M_1	300	10	3	
M_2	200	50	1	Surecide 3 cc/liter water 14 DT
M_3	250	100	2	Surecide 3 cc/liter water, 14 and 45 DT
M_4	300	150	3	Surecide 3 cc/liter water ,14 and 45 DT; Sevin 85 WP applied at 70 DT
M_5	400	200	4[d]	Surecide 3 cc/liter water, 14 and 45 DT; Sevin 85 WP applied at 70 DT

[a] M_1= farmers' level, $M_2 - M_4$= intermediate levels, M_5= high level.

[b] Urea is given in three split applications, using equal amounts (basal, 4 weeks after transplanting, and at panicle initiation), and all triple superphosphate (TSP) is given as basal application.

[c] DT = days after transplanting. WP = wettable powder.

[d] The number of treatments shown plus many additional as needed to maintain weed size and insect-free conditions.

some progressive farmers and village government officials have farms of more than 2 ha. There was a significant difference in farm size between the average farmers and the cooperators on whose land experiments were conducted, especially in the first year of research.

Farm size may influence farming efficiency, farm productivity, and farmer attitudes. It is possible that cooperating farmers may have been more progressive and more dynamic than the average farmer, and better able to accept the risks of farming.

Table 14. Treatments in management packages. Yogyakarta, Indonesia, 1976 dry season.

Treatment level[a]	Fertilizer (kg/ha) Urea	TSP[b]	Insect control[c]
M_1	100	0	Sevin 85 WP : 3 g/liter[d]
M_2	200	0	Furadan 3 G: 2 kg a.i./ha, 45 DT Basudin 10 G: 2 kg a.i./ha, 60 DT
M_3	300	100	Spraying is done when insect damage is visible. Insecticide used varies, depending on the kind of insect.
M_4	400	150	Furadan 3 G: 2 kg a.i./ha, 45 DT Basudin 10 G: 2 kg a.i./ha, 60 DT Sevin 85 WP: 3 g/l, 75 DT Surecide : 3 cc/l, 90 DT
M_5	500	200	Equal to M_4 plus as many additional sprays as needed when insect attack is still visible.

[a] M_1 = farmers' level, M_{2-4} = intermediate levels, M_5 = high level.

[b] Triple superphosphate.

[c] WP = wettable powder, G = granular, a. i. = active ingredient, DT = days after transplanting.

[d] This figure is for Sleman. No insect control was used by farmers in Bantul area.

There were some differences in the levels of inputs between average farmers and experimental farmers. but they were not as large as the differences in farm size, Some experimental farmers used slightly higher input levels but in some areas and years they used lower levels. The experimental farmers used less TSP and insecticide than the average farmers, but the differences were small. We conclude that the experimental farmers represent the mass of farmers surveyed with respect to input use, but not with respect to farm size.

Table 15. Average grain yield of management packages.[a] Yogyakarta, Indonesia, 1974 – 75 wet season to 1977 dry season.

Area	Year	Grain yield (t/ha)				
		M_1	M_2	M_3	M_4	M_5
		Wet season				
Kulon Progo	1974 – 75	4.2	4.0	4.7	4.7	5.2
Godean	1975 – 76	4.4	3.7	3.8	5.3	5.3
Bantul	1975 – 76	8.2	5.9	6.6	7.1	7.0
Sleman	1975 – 76	4.2	4.2	4.4	5.3	5.4
Bantul	1976 – 77	6.5	5.1	5.9	6.6	7.2
S1eman	1976 – 77	6.3	5.1	5.6	6.3	6.0
Av		5.6	4.7	5.2	5.9	6.0
		Dry season				
Kulon Progo	1975	3.0	3.4	3.8	4.3	5.7
Bantul	1976	4.5	4.4	6.1	7.4	7.7
Sleman	1976	2.5	2.9	3.1	4.0	4.2
Bantul	1977	3.4	4.0	4.2	4.9	4.8
S1eman	1977	6.3	6.5	6.0	7.0	6.7
Av		3.9	4.2	4.6	5.5	5.8

[a] M_1 = farmers' level, M_2-M_4 = intermediate levels, M_5 = high level.

Assessment of variables affecting use of purchased inputs

The experiments reported here show that pesticides did not increase yields. Fertilizer inputs were used, but in the three villages and in both seasons, fertilizer levels were often used at less than the calculated economic optimum levels. Therefore, an analysis was made to determine the factors governing the use of purchased inputs, with special emphasis on fertilizer.

It was postulated that environmental factors, institutional factors, land tenure arrangements, knowledge, and beliefs play roles in determining the levels of inputs used. In this section, these variables are examined as they relate to the levels of

Table 16. Costs of inputs and rough rice. Yogyakarta, Indonesia, 1974-75 to 1977. [a]

Items	1974-75 wet season	1975 dry season	1975-76 wet season	1976 dry season	1976-77 wet season	1977 dry season
Urea & TSP (Rp/kg)	60	60	80	80	70	70
Diazinon (Kp/1)	900	900	900	900	900-1000	
Surecide (Rp/kg)		1200	1200	1200	1600	1500
Sevin (Rp/kg)			1200	1200	900	
Fosfel (Rp/kg)			900	900		
Furadan 39 (Rp/kg)				300	180	300
Basudin 10 g (Rp/kg)				500		
HCH (Rp/kg)					900	
Labor (Rp/day)	150-200	200-250	200	250	150-250	150 – 280
Rough rice (Rp/kg)	60	80	65	70	65	

[a] Exchange rate: US$1 = Rp 415.

inputs used, to determine which may be important. After their separate assessment, a simultaneous analysis was attempted, using regression methods.

Water problems. To investigate a possible dependence of modern varieties on fertilizer and water conditions, a c^2– test was computed from the cross tabulation frequencies in the first – year research area (Table 21). The significant calculated c^2-value indicates that farmers who experienced water problems tended to apply less fertilizer on modern varieties than farmers without water problems. A similar c^2 – test was computed for local varieties. Its value was significant at the 10% level because farmers with excessive water tended to purchase less fertilizer. The same was true in the 1975-76 wet season, although the number of empty cells in the cross tabulation made the c^2 – statistic inappropriate. The second – and third – year research areas had good irrigation, and it seemed that water problems were few.

Table 17. The average cost of input packages. Yogyakarta, Indonesia, 1974 – 75 to 1977.

Year	Package[a]	Cost (1003 Rp/ha)					
		Fertilizer		Insecticide		Weeding	Total
		Labor	Materials	Labor	Materials		
				Wet season			
1974 – 75	M_1	2.9	12	0	0	8.2	23.1
	M_2	2.2	12	3.8	2.7	8.2	28.9
	M_3	3.7	15	5.1	3.6	12.3	39.6
	M_4	5.2	21	6.3	4.5	16.3	53.3
	M_5	6.7	27	7.6	5.4	20.4	67.1
1975 – 76	M_1	4.5	25.1	1.5	1.4	14.7	47.2
	M_2	3.6	20	2.7	1.8	8	36.1
	M_3	5.0	28	3.6	3.6	12	52.2
	M_4	6.5	36	4.5	5.4	16	68.4
	M_5	8.6	48	4.5	5.4	20	86.5
1976 – 77	M_1	3.1	35.7	3.0	2.2		44
	M_2	1.5	17.5	5.3	4.8		29.1
	M_3	2.1	24.5	1.3	1.2		29.1
	M_4	2.7	31.5	5.4	13.8		53.4
	M_5	3.6	42	5.8	22.8		74.2
				Dry season			
1975	M_1	2.5	9	0	0	9	20.5
	M_2	2.5	9	1.6	1.8	9	23.8
	M_3	4.2	15	3.2	3.6	13.5	39.5
	M_4	5.9	21	6.4	7.6	18	58.9
	M_5	7.6	27	9.6	11.8	27	83
1976	M_1	1.8	8	2.4	2.7		14.9
	M_2	3.4	16	1.6	30		51
	M_3	6.3	32	5.7	16.3		60.3
	M_4	7.5	40	5.7	33.7		86.9
	M_5	9.6	48	6.3	35.4		99.3
1977	M_1	2.7	30	5.7	8		46.4
	M_2	1.4	14	2.5	2.5		20.4
	M_3	2.6	28	5.2	4.2		40
	M_4	3.3	38.5	3.1	2.8		47.7
	M_5	3.8	49	5.4	4.7		62.9

[a] M_1 = farmers' level, M_2 – M_4 intermediate levels, M_5 = high level.

Table 18. Economic comparison of four levels of input management packages in experiments on farmers' fields. Yogyakarta, Indonesia 1974 – 75 to 1977.

Input package level[a]	Year	Increase over farmers' level				
		Yield (kg/ha)	Gross return (1000 Rp/ha)	Cost[b] (1000 Rp/ha)	Owners' net return (1000 Rp/ha)	Share – tenants' (1000 Rp/ha)
			Wet season			
M_2	1974 – 75	– 226	– 13.7	2.7	– 14.7	– 9.0
M_3		497	29.7	16.7	9.3	– 3.3
M_4		542	32.3	30.0	– 1.7	– 16.0
M_5		1034	62.0	44.0	10.7	– 16.3
M_2	1975 – 76	– 992	– 64.5	– 11.0	– 47.0	– 18.0
M_3		– 668	– 43.4	0.7	– 39.7	– 20.2
M_4		315	20.5	21.3	– 2.8	– 12.5
M_5		330	21.4	39.4	– 20.1	– 29.8
M_2	1976 – 77	– 813	– 52.8	– 14.8	– 37.7	– 9.2
M_3		– 663	– 43.1	– 14.9	– 27.2	-4.8
M_4		25	1.6	9.5	– 8.7	– 8.8
M_5		138	9.0	30.3	– 35.6	– 26.5
			Dry season			
M_2	1975	377	30	3.3	238.0	10.3
M_3		875	70	19.0	44.0	12.5
M_4		1375	110	38.4	60.4	11.1
M_5		2688	21.5	62.5	131.0	34.3
M_2	1976[c]	435	30.5	36.2	– 8.8	– 25.2
M_3		1165	81.6	45.4	28.0	11.3
M_4		2895	202.7	72.1	110.4	16.5
M_5		3405	238.4	84.5	130.1	21.3
M_2	1976[d]	30	2.1	31.1	– 29.4	– 30.2
M_3		630	44.1	36.8	2.9	– 17.5
M_4		150	10.5	67.0	– 57.5	– 62.2
M_5		390	27.3	79.4	– 54.8	– 67.1
M_2	1977	400	36	– 26.4	50.4	42.2
M_3		250	22.5	– 6.4	18.7	16.5
M_4		1100	99	1.3	79.8	43.3
M_5		900	81	16.5	48.4	20.0

[a] $M_2 - M_4$ = intermediate levels, M_5 = high level.
[b] Does not include cost of harvest, so owners' net return is less than the difference between added return and cost.
[c] Data refer to trial with IR26.
[d] Data refer to trial with Pelita I/1.

Table 19. Farmers' costs, increased cost, and increased value of output from the high level of input compared with farmers' level. Yogyakarta, Indonesia, 1974–75 to 1977.

Item	Cost and value (1000 Rp/ha)						
	Wet season			Dry season,			
	1974–75	1975–76	1976–77	1975	1976 [a]	1976 [b]	1977
Fertilizer							
Cost of farmers' level	15.0	19.6	38.8	11.5	9.8	9.8	32.7
Increased cost	25.3	27.1	6.8	23.0	47.8	47.8	20.1
Increased value	43.1	-4.3	2.0	77.4	42.0	161.0	67.5
Insect control							
cost of farmers' level	0.0	2.9	5.2	0.0	10.1	5.1	13.7
Increased cost	13.0	7.0	23.4	21.4	31.6	36.7	-3.6
Increased value	-7.6	-6.5	-11.8	-21.9	28.0	45.5	13.5
Weed control							
cost of farmers' level	8.2	14.7		9-0			
Increased cost	12.3	5.3		18.0			
Increased value	-5.1	32.5		29.4			

[a] Pelita. [b] IR26.

Varieties

It was reasoned that farmers growing modern fertilizer–responsive varieties would use more pesticide and fertilizer than those growing traditional varieties. To examine this hypothesis, a cross tabulation of variety type and level of purchased inputs was constructed, and a c^2-test was calculated (Table 22). The significant c^2–value indicates that high levels of purchased inputs are indeed associated with modern varieties.

In Sleman and Bantul 1975–76 and 1976–77, only a few farmers grew local varieties. The planthopper problem became more important in choosing rice varieties, and most farmers used varieties with resistance to the insect.

Table 20. Comparison of inputs used per hectare and farm area in rice of the experimental farmers (EF) and average farmers (AF). Yogyakarta, Indonesia, 1974 – 75 to 1976 – 77.

	Urea (kg/ha)		TSP[a] (kg/ha)		Insecticide (kg/ha)		Farm size[b] (ha)	
	EF	AF	EF	AF	EF	AF	EF	AF
1974 – 75								
Pengasih	100	141	50	84	0	.52	2.25	.13
Sidomulyo	100	54	50	28	0	.11	7.24	.29
Sentolo	200	192	75	69	0	.0	2.18	.19
Av	133	129	58	60	0	.21	3.89	.20
1975 – 76								
Sidomulyo	295	270	35	30	0	.14		
Bantul	360	233	0	88	0	1.55		
Trimulyo	250	216	0	20	0	.32		
Av	302	240	12	46	0	.67		
Bantul 1976 – 77								
Complete factorial	122		0		0.0		.09	
Complete factorial	369		43		1.4		1.76	
Minifactorial	215		0		0.0		.37	
Minifactorial	429		61		3.3		.99	
Minifactorial	219		119		9.4		.16	
Minifactorial	200		23		1.8		.65	
Av	259	319	41	36	2.7	2.3	.67	.36
Sleman 1976 – 77								
Complete factorial	194		66		0.0		1.28	
Complete factorial	506		55		0.1		1.57	
Minifactorial	300		56		1.1		.09	
Minifactorial	132		0		2.1		.57	
Minifactorial	130		41		0.9		.46	
Minifactorial	380		0		2.4		.25	
Av	274	275	36	40	1.1	1.1	.70	.42

[a]TSP = triple superphosphate. [b]Rice area.

Table 21. Contingency table between water problem and level of purchased input. Yogyakarta, Indonesia, wet season 1974-75.

Purchased fertilizers (1000 Rp)	Water problem: Water shortage	Excess water	Neither	Total	x^2
	Modern varieties, Kulon Progo				
up to 10	2	11	8	21	
10 – 20	7	18	23	38	
20 or more	0	0	10	10	
Total	9	29	41	69	14.8**
	Local varieties, Kulon Progo				
up to 10	2	10	15	21	
10 – 20	4	1	11	16	
20 or more	1	1	6	8	
Total	7	12	32	51	7.3*
	Bantul and Sleman				
up to 20.7	0	0	41	41	
20.8 – 25.2	0	2	37	39	
25.3 or more	3	0	37	40	
Total	3	2	115	120	

** Significant at 1% level.

* Significant at 10% level.

Tenure. It was postulated that owner – operators would purchase more fertilizer than either share – farmers or cash – rent tenants. However, analysis of the frequencies indicates no differences between types of tenure (Table 23). An examination of the amounts of fertilizer used according to variety type for each tenure status showed that the cash – rent farmers growing modern varieties used more fertilizer than owner – operators and share – farmers, and that the share – farmers used more fertilizer on local varieties than owner – operators and cash – rent farmers. The cash – rent farmers appeared to be more commercially oriented in their farming practices, because they applied more fertilizer to the

Table 22. Contingency table between varieties and purchased inputs. Yogyakarta, Indonesia, 1974 – 75 wet season.

Purchased fertilizer ('000 Rp)	Modern varieties	National improved varieties	Local varie – ties	Total	χ^2
		Kulon Progo			
up to 10	6	19	25	50	
10 – 20	24	10	18	52	
20 or more	10	0	8	18	
Total	40	29	51	120	22.3**
		Bantul and Sleman			
up to 20.7	34		7	41	
20.8 – 25.2	38		1	39	
25.3 or more	39		1	40	
Total	111		9	120	

modern varieties, which are more responsive to added nutrients than local varieties. However, the number of cash – rent farmers in the sample was small.

Size of farm. To investigate a possible relationship between farm size and fertilizer purchased, a cross tabulation of farmers by these two factors was constructed. Farm size ranged from 0.1 ha to about 4 ha. An analysis of the frequencies indicated that farm size had no significant influence on the amount of fertilizer purchased. However, an examination of the effect of variety on fertilizer use showed that farmers with large holdings used more fertilizer, especially on the modern varieties (Table 24). Small landholders tended to use more fertilizer on local varieties.

Technical knowledge. A series of questions was used to determine how well farmers understood the rationale for good farming practices and modern rice technology. The maximum possible score was 48. The average score was 28 in Pengasih, 21 in Sidomulyo, and 24 in Sentolo. The differences between villages were not significant.

Table 23. Contingency table between purchased input used and tenure status of rice farmer. Yogyakarta, Indonesia, 1974 – 77 wet season.

Purchased fertilizer (1000 Rp)	Tenure status				
	Owner	Share	Cash rent	Total	c^2
Kulon Progo, 1974 – 75 wet season					
up to 10	38	10	2	50	
10 – 20	35	15	2	52	
20 or more	13	4	1	18	
Total	86	29	5	120	1.2^{ns}
Bantul and Sleman, 1975 – 76 wet season					
up to 20.7	24	17	0	41	
20.8 – 25.2	24	13	2	39	
25.3 or more	30	7	3	40	
Total	78	57	5	120	7.7^{*}
Bantul and Sleman, 1976 – 77 wet season					
up to 19	22	9	2	33	
19 – 27	24	6	4	34	
more than 27	28	5	1	34	
Total	74	20	7	101	4.0^{ns}

ns = not significant.
* = significant at 10% level.

A simple correlation between average scores of technical knowledge and average fertilizer levels for all farmers in the six hamlets gave a low positive value (r = .38). A contingency test on the cross tabulation of technical knowledge and fertilizer use was highly significant in Kulon Progo in the wet season of 1974 – 75 (Table 25).

In the second – year study in Bantul and Sleman, technical knowledge was also related to fertilizer use (at the 5% level). But in the third year, in the area closer to Yogyakarta City, the c^2– test showed a nonsignificant result.

Table 24. Fertilizer used on various varieties and farm size. Yogyakarta, Indonesia, 1974 – 75 wet season.

Farm size	Modern varieties		Local varieties		Av fertil-izer (kg/ha)
	Fertili-zer (kg/ha)	Farms (no.)	Fertili-zer (kg/ha)	Farms (no.)	
Large	194	6	63	3	151
Medium	133	44	29	32	90
Small	125	31	83	16	107
Av	136		48		90

Input availability. Farmers were asked if they were able to obtain the rice production inputs they wanted in the proper amounts and when needed. If they answered yes to both questions, the index of input availability was scored as high. If they answered yes to only one question, their index was scored as medium. If they answered no to both questions, they scored low. The input availability scores were cross tabulated with the level of fertilizer purchased.

As expected, the data for Kulon Progo 1974 – 75 showed a strong positive relationship between input availability and levels of fertilizer purchased (Table 26). The most frequent reason given by farmers who were unable to obtain adequate fertilizer was the lack of financing caused by the absence of the BIMAS program (in one area). Because of the remoteness of the hamlet and poor roads leading to it, input availability and, consequently, input use, were lower in the intermediate irrigation area.

During the next two years in the main rice – growingareas in Bantul and Sleman, there was not enough variation in input availability scores to permit a meaningful test.

Credit availability. Farmers were asked about credit availability, whether or not they borrowed, and how long it took them to complete arrangements for a loan. One week or less scored 2; between 1 and 2 weeks scored 1, and more than 2 weeks scored 0. If they thought sufficient credit was available to them they scored 1.

Table 25. Contingency table of technical knowledge and levels of purchased input. Yogyakarta, Indonesia, 1974-77 wet season.

Purchased fertilizer (1000 Rp)	Technical knowledge score Low	Medium	High	Total	c^2
Kulon Progo, 1974 – 75 wet season					
up to 10	19	25	6	50	
10 – 20	5	29	18	52	
20 or more	6	5	7	18	
Total	30	59	31	120	17.4^{**}
Bantul and Sleman, 1975 – 76 wet season					
up to 20.7	19	11	11	41	
20.8 – 25.2	8	17	14	39	
25.3 or more	9	11	20	40	
Total	36	39	45	120	10.7^{*}
Bantul and Sleman, 1976 – 77 wet season					
up to 19	8	14	11	33	
19 – 27	10	14	10	34	
More than 27	4	18	12	34	
Total	22	46	33	101	3.4^{ns}

**Significant at 1% level.
*Significant at 5% level.
^{ns}Not significant at 5% level.

The two scores were added. A cross tabulation of credit availability and level of fertilizer purchased was constructed.

A contingency test indicated that the lower scores tended to be associated with lower fertilizer levels and higher scores with higher fertilizer levels, although the relationship was not significant (Table 27).

In Bantul and Sleman there was not enough variation in the second and third years to permit meaningful testing.

Extension. Farmers were asked how often they were contacted by extension workers. Nearly 75% had no contact during the growing season. A contingency test between the number of visits by

Table 26. Contingency table between scores of input availability and purchased input level. Yogyakarta, Indonesia, 1974 – 76 wet season.

Purchased fertilizer level	Input availability			Total	c^2
	Low	Medium	High		
	Kulon Progo, 1974 – 75 wet season				
Low	27	15	8	50	
Medium	9	18	25	32	
High	1	6	11	18	
Total	37	39	44	120	26.3**
	Bantul and Sleman, 1975 – 76 wet season				
Low	4		37	41	
Medium	3		36	39	
High	0		40	40	
Total	7		113	101	

** Significant at .01% level.
ns Not enough variation.

agricultural extension agents and the level of purchased inputs indicated that the frequency of visits was independent of the level of inputs used in Kulon Progo in the 1974 – 75wet season (Table 28).

In Bantul and Sleman in the wet season of 1975 – 76, the c^2 test showed no significant relationship. In 1976 – 77a new set of questions and a new scoring were developed that covered not only the visits of extension agents but also several kinds of extension activities, such as training courses, demonstrations, and formal information. The two variables were still independent.

Traditional beliefs. We asked farmers whether they agreed with a set of four statements reflecting traditional ways of thinking about rice production. The statements included belief in the rice god, offerings to make it rain, and the effect of control measures on the population of pests. The scores ranged from –4 indicating strong disagreement with the traditional statements to +4 indicating agreement with the statements. Most farmers in Pengasih and Sidomulyo disagreed with the statements, but those in Sentolo usually had a score of 0, indicating a somewhat more traditional orientation.

Table 27. Contingency table between level of purchased inputs and credit availability. Yogyakarta, Indonesia, 1974 – 76 wet season.

Purchased fertilizer level	Index of credit availability 0 – 2	3	Total	χ^2
	Kulon Progo, 1974 – 75 wet season			
Low	10	5	15	
Medium	6	16	22	
High	4	7	11	
Total	20	28	48	5.86^{ns}
	Bantul and Sleman, 1975 – 76 wet season			
Low	6	23	29	
Medium	4	32	36	
High	5	34	39	
Total	15	89	104	1.32^{ns}

^{ns}Not significant at 5% level.

The χ^2-test showed a nonsignificant relationship between levels of purchased inputs and traditional beliefs (Table 29).

The regression analysis

A simultaneous analysis of the factors thought to be important in governing fertilizer use is necessary for obtaining an indication of the relative importance of each factor. For the simultaneous analysis, two multiple regression models were developed for the first-year experiment. The first model included nearly all factors of interest but on a smaller sample. The second model included all samples but fewer variables. The number of variables differed because not all samples had all of the information for each factor (e.g. credit availability scores existed only for farmers who used credit.)

Table 28. Contingency table showing the relationship between agricultural extension and the levels of purchased inputs. Yogyakarta, Indonesia, 1974-77 wet season.

Purchased fertilizer level	Agricultural extension score			Total	c^2
	Low	Medium	High		
	Kulon Progo, 1974-75 wet season				
Low	43	6	1	50	
Medium	34	14	4	52	
High	11	5	2	18	
Total	88	25	7	120	7.6^{ns}
	Bantul and Sleman, 1975-76 wet season				
Low	33		8	41	
Medium	30		9	39	
High	35		15	40	
Total	88		32	120	3.7^{ns}
	Bantul and Sleman, 1976-77 wet season				
Low	17	11	5	33	
Medium	15	10	9	34	
High	11	11	12	34	
Total	43	32	26	101	4.2^{ns}

^{ns} Not significant at 5% level.

Table 30 shows no significant F-statistic in the first model for any variation. The tests were relatively insensitive because of the low degrees of freedom associated with the residual mean square.

However, some individual factors when subjected to a t-test were significant in the area with good irrigation. The factors were water shortage, variety, and cash-rent tenancy.

Although the second model used a larger sample and fewer variables, the results were similar to those found in the first model (Table 31). Only technical knowledge in the area with moderate irrigation produced a significant t-statistic.

Table 29. Contingency table showing the relationship between traditional beliefs and levels of purchased inputs. Yogyakarta, Indonesia, 1974-77 wet season.

Purchased fertilizer level	Traditional beliefs score 0-4	negative	Total	x^2
	Kulon Progo, 1974-75 wet season			
Low	14	38	50	
Medium	24	28	52	
High	11	7	18	
Total	49	73	120	
	Bantul and Sleman, 1975-76 wet season			
Low	9	32	41	
Medium	13	26	39	
High	16	24	40	
Total	38	82	120	3.12^{ns}
	Bantul and Sleman, 1976-77 wet season			
Low	16	17	33	
Medium	18	16	34	
High	17	17	34	
Total	51	50	101	0.14^{ns}

^{ns} Not significant at 5% level.

Table 30. First-equation regression analysis of factors associated with fertilizer use. Yogyakarta, Indonesia, 1974-75 wet season.

Variable	Good irrigation	Moderate irrigation	Rainfed
Excess water	- 3.78	- 3.96	
	(-1.02)	(-0.00)	
Shortage of water	21.83		5.36
	(3.62)**		(0.57)
Variety	12.80	-9.95	
	(3.07)**	(-0.00)	
Share tenure	4.28	-1.88	- 8.53
	(1.29)	(-0.44)	(-0.94)
Cash rental	- 9.61		-21.46
	(-2.34)*		(-0.61)
Farm size	16.64	9.54	23.22
	(2.00)	(0.66)	(-0.35)
Technical knowledge	0.18	0.26	0.99
	(0.44)	(0.46)	(-1.04)
Credit	2.45	-0.91	-11.57
	(1.29)	(-0.23)	(-0.86)
Extension score	1.45	- 2.13	1.33
	(0.94)	(-0.00)	(0.38)
Traditional beliefs	- 1.46	- 0.43	7.93
	(-1.02)	(-0.28)	(1.58)
Input expenditure	- 0.24	- 0.88	
	(0.05)	(-0.23)	
F	2.99 ns	0.45 ns	3.59 ns
R^2	.80	.58	.83
n	20	13	15

Note: t-values in parentheses.

ns Not significant at 5% level.
* Significant at 5% level.
** Significant at 1% level or less.

Table 31. Second-equation regression analysis of factors associated with fertilizer use. Yogyakarta, Indonesia, 1974-75 wet season.

Variable	Good irrigation	Moderate irrigation	Rainfed
Excess water	-3.55	-2.00	-15.89
	(-1.12)	(-0.87)	(-2.04)
Share tenure	3.97	-0.74	-0.90
	(1.32)	(-0.28)	(-0.24)
Cash rental	-0.62	1.34	-9.61
	(-0.13)	(0.22)	(-0.78)
Farm size	6.78	-0.53	-12.36
	(0.67)	(-0.12)	(0.97)
Technical knowledge	0.42	0.44	-0.07
	(1.59)	(2.90)**	(-0.27)
F	1.2l^{ns}	2.34^{ns}	1.17^{ns}
R^2	.15	.26	.15
n	40	40	40

Note: t-values in parentheses.

^{ns}Not significant at 5% level.
**Significant at 1% level.

Several linear regression equation models were developed from the second-year data. They are shown in Table 32. Share-tenure and input availability significantly affected the purchased input level. Share-tenancy was highly significant in all equations, although the regression analysis did not explain most of the variation in the purchased input level, as reflected in the very small R^2s.

A third-year regression equation using the same variables had a nonsignificant F-value, although the t-tests on technical knowledge and village show that the two variables significantly affected the level of purchased inputs (Table 33). As with the second, year regression analysis, the unexplained variation was large.

Table 32. Regression analysis of factors affecting the level of purchased inputs. Yogyakarta, Indonesia, 1975 – 76.

Variable	Equation model					
	1	2	3	4	5	6
Variety	4.02					
	(1.35)					
Share tenure	– 3.66*	– 4.02	– 3.89	– 4.29	– 4.35	– 4.59
	(– 2.60)	(– 2.93**)	(– 2.82**)	(– 3.35**)	(– 3.41*)	(– 3.63**)
Cash rental	3.00	2.77	3.46	3.65	3.36	
	(1.06)	(1.02)	(1.22)	(1.27)	(1.20)	
Farm size	-0.30	0.12	– 1.16	– 1.48		
	(– 0.10)	(0.04)	(– 0.41)	(-0.54)		
Technical knowledge	0.09	0.11	0.19			
	(0.64)	(0.81)	(1.43)			
Credit availability	– 1.40	– 1.23	-0.68			
	(– 0.98)	(– 9.87)	(– 0.49)			
Traditional beliefs	– 0.01	– 0.01	0.34			
	(– 0.02)	(– 0.03)	(0.81)			
Input availability	6.67*	6.70*	6.68*			
	(2.35)	(2.36)	(2.34)			
Village 1	– 2.77	– 3.04				
	(-1.15)	(– 1.66)				
Village 2	– 0.44					
	(– 0.27)					
Intercept	10.27	12.91	8.97	25.49	25.14	25.38
F	2.80**	3.27**	3.29**	4.96**	7.35**	13.20**
R^2	.23	.21	.19	.13	.13	.11
n	105	105	105	105	105	105

Note: t-values in parentheses.

* Significant at 5% level.
** Significant at 1% level.

Table 33. Regression analysis of factors affecting the level of purchased inputs. Yogyakarta, Indonesia, 1976-77.

Variable	Regression coefficient
Variety	-0.15 (-0.04)
Share-tenancy	0.49 (0.17)
Cash-rent tenure	-1.06 (-0.25)
Farm size	-1.46 (-0.55)
Technical knowledge	1.46 (2.23)*
Extension	0.24 (0.27)
Traditional belief	9.69 (1.16)
Input availability	-1.14 (-0.41)
Village	-6.83 (-2.88)**
Intercept	2.46
F	1.49ns
R^2	.13
n	101

Note: t-values in parentheses.

ns Not significant at 5% level.
* Significant at 5% level.
** Significant at 1% level.

CONCLUDING REMARKS

Government efforts to solve the rice problem in Indonesia has long been reflected in production efforts and price and import policies to protect consumers and producers and to ensure economic stability. Up to the present, such efforts have traditionally been consumer-oriented, in accordance with economic stabilization and the promotion of higher rates of nonagricultural growth.

The rice intensification program in Java has been expanded, but the gap between potential and actual yields still exists. Three years of research in Yogyakarta indicated that the contribution of fertilizer to the gap was the greatest, but higher nitrogen fertilizer application tended to increase the crop's susceptibility to planthoppers.

In dry season experiments the highest inputs generally gave the highest yields; this was not so for the wet-season experiments. Some farmers in Bantul and Sleman in 1975-76 and 1976-77 used very high levels of inputs.

Water was one of the main physical field constraints in Kulon Progo in 1974-75. It did not seem to be a constraint in the main rice-growing area with good irrigation in Bantul and Sleman in 1975-76 and 1976-77. The major constraint among socioeconomic factors was technical knowledge. Input availability affected the level of purchased inputs in Kulon Progo in 1974-75. It did so too in Bantul and Sleman in 1975-76, but not in 1976-77. Credit availability seemed to be a problem only in Kulon Progo in 1974-75, but not in Bantul and Sleman in the following two years. It appears that rice variety was also a factor, but the recent problem of brown planthoppers encouraged farmers to obtain the planthopper-resistant varieties.

REFERENCES CITED

Gomez, K. A. 1977. On-farm assessment of yield constraints: methodological problems. Pages 1-16 in International Rice Research Institute. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Laguna, Philippines.

International Rice Research Institute. 1977. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Laguna, Philippines. 235 p.

Rice and Agriculture in the Philippines

Robert W. Herdt

RICE IN PHILIPPINE AGRICULTURE[1]

Seventy-four percent of Philippine cereal consumption is rice (Aviguetero et a1 1977). More than 30% of all agricultural land and more than 50% of the food cropland is planted to rice. Between 1960 and 1974 rice production increased at 2.4% annually, about as fast as the population. Yields increased from 1.19 t/ha in 1960-63 to 1.56 t/ha in 1972-75, to 1.83 t/ha in 1976-77 (Table 1).

Rice production inputs have increased sharply. Modern fertilizer-responsive varieties were introduced in 1965 and by 1977 were grown on more than 70% of the rice area. Fertilizer use per hectare of arable land in the Philippines increased from about 15 kg/ha on a nutrient basis in the early 1960s to about 25 kg/ha in 1971-72 (Herdt and Barker 1975). Irrigated riceland has been increased by about 1 million hectares since 1960, totaling more than 1.6 million in 1975 (Table 2).

Area and production of rice in the 9 agricultural regions of the Philippines are shown in Table 3. Central Luzon contains 13% of the nation's rice area and produces 17% of the total output. Southern Tagalog, Western Visayas, and South and West Mindanao each contribute 12 to 14% of the national rice area, while three other regions each have about 10%. Field research reported in the following four chapters was conducted in provinces in four important rice-producing regions: Nueva Ecija in Central Luzon, Laguna in Southern Tagalog, Camarines Sur in the Bicol region, and Iloilo in Western Visayas.

The lowland first crop or wet season crop area, grown between July and December, accounts for 56% of the total national harvested

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[1]Unless otherwise specified, data in this section were obtained from the publications of the Bureau of Agricultural Economics, Department of Agriculture, Republic of the Philippines.

Table 1. Production, area, yield, and imports of paddy rice, Philippines, 1960-78 (Apiraksirikul 1976).

Year	Production (1000 t)	Area (1000 ha)	Yield (t/ha)	Imports (1000 t)
1960	3,739	3,306	1.13	[a]
1961	3,704	3,198	1.16	186
1962	3,910	3,197	1.23	0
1963	3,967	3,161	1.25	256
1964	3,842	3,087	1.24	300
1965	3,993	3,199	1.25	569
1966	4,073	3,109	1.31	108
1967	4,094	3,096	1.32	291
1968	4,561	3,304	1.38	[a]
1969	4,445	3,332	1.33	[a]
1970	5,233	3,113	1.68	[a]
1971	5,343	3,113	1.72	367
1972	5,100	3,246	1.57	444
1973	4,414	3,112	1.42	311
1974	5,594	3,437	1.63	169
1975	5,660	3,539	1.60	145
1976	6,169	3,579	1.72	56
1977	6,456	3,548	1.82	30
1978	6,895	3,509	1.96	n.a.

[a] Negligible.

n.a. = not available.

rice land (Table 4). The area planted to second-crop lowland rice (mainly dry season) is 32% of the total, while upland rice, grown without standing water, makes up 12% of the area. In the four study areas, the first crop depends largely on monsoon rains. Much of it is grown under rainfed lowland conditions where the land is puddled before transplanting. Areas served by irrigation systems rely on the diversion of river flows and as a consequence are also highly dependent upon rainfall.

The irrigated area in the country has more than doubled since 1960. Much of the growth has been in government-assisted, gravity irrigation systems, but in recent years pump irrigation has increased rapidly. Most of the irrigated area is devoted to rice production. Modern semidwarf varieties have been increasingly planted on both irrigated and rainfed-lowland

Table 2. Irrigable areas in the Philippines by type of system for selected years (Hayami and Kikuchi 1975).

Type of system	1960		1965		1970		19 75	
	1000 ha	%	1000 ha	%	l000 ha	%	1000 ha	%
National canal systems	261	35	319	34	420	36	561	35
Communal systems:								
Government assisted	84	11	154	16	199	17	321	20
Private	334	45	374	40	418	36	468	29
Pump irrigation systems	33	4	60	6	89	8	225	14
Others[a]	28	4	29	3	30	3	31	2
Total[b]	740	100	934	100	1575	100	1607	100

[a] Includes Friar Land Irrigation Systems and Municipal Systems.
[b] Figures are rounded to nearest whole number and may not add to 100% in each column.

Table 3. Total rice area, area planted to first-crop rice, and total rice production by region, Philippines, average 1975 (Bureau of Agricultural Economics, Department of Agriculture).

Region	Total area (ha)	% of natl area	Area in 1st crop lowland (ha)	% of natl area	Total produc- (1000 t)	% of natl produc- tion
Ilocos	330,650	9.3	274,143	13.8	504	8.3
Cagayan Valley	422,037	11.9	170,950	8.6	756	12.4
Central Luzon	459,190	12.9	308,807	15.6	1,012	16.6
Southern Tagalog	454,747	12.8	200,607	10.1	771	12.7
Bicol	340,260	9.6	174,673	8.8	619	10.2
Western Visayas	453,937	12.8	281,456	14.2	785	12.9
Central Visayas	87,473	2.4	56,417	2.9	125	2.0
Eastern Visayas	181,257	5.1	69,420	3.5	225	3.7
Western Mindanao	140,443	3.9	87,027	4.4	292	4.8
Northern Mindanao	312,797	8.8	101,893	5.1	422	6.9
Southern Mindanao	372,430	10.5	256,030	12.9	581	9.5
Philippines	3,555,220	100.0	1,981,423	100.0	6,092	100.0

Table 4. Area planted to rice by type of crop and by region, Philippines, average 1975 – 77 (Bureau of Agricultural Economics, Department of Agriculture).

Region	Lowland				Upland		Total	% of total
	First crop		Second crop					
	(1000 ha)	(%)	(1000 ha)	(%)	(1000 ha)	(%)	(1000 ha)	
Ilocos	274	83	47	14	10	3	331	9.31
Cagayan Valley	171	41	229	54	22	5	422	11.87
Central Luzon	309	67	146	32	4	1	459	12.91
Southern Tagalog	201	44	136	30	118	26	455	12.80
Bicol	175	51	115	34	50	15	340	9.56
Western Visayas	281	62	148	33	25	5	454	12.77
Central Visayas	56	64	29	33	3	3	88	2.48
Eastern Visayas	69	38	96	53	16	9	181	5.09
Western Mindanao	87	62	25	18	28	20	140	3.94
Northern Mindanao	102	33	117	37	94	30	313	8.81
Southern Mindanao	256	69	72	19	44	12	372	10.46
Philippines	1,981	56	1,160	32	414	12	3,555	100.00

rice fields (Table 5). By 1974 the modern varieties were planted on 80% of the irrigated area and 64% of the rainfed lowland area. Virtually all of the upland area was planted to traditional varieties.

Despite these favorable trends and the rapid increase in area devoted to the new varieties, yields were low. The new varieties averaged only 13% more than other varieties on the irrigated land and only 9% more than other varieties under rainfed conditions (Table 6).

Three hypotheses can be advanced to explain the disappointing performance record of modern varieties in the Philippines:

1. modern varieties actually have little higher production potential than the old varieties;

2. farmers are not growing the modern varieties "properly"; that is, they are not using the required inputs;

3. modern varieties have only slightly higher yield potential under farmers' environments than the old varieties.

The data in Figure 1 show the effect of nitrogen on the yield of three varieties as measured in experiments and provide some tentative tests of the three hypotheses. Peta is typical of the

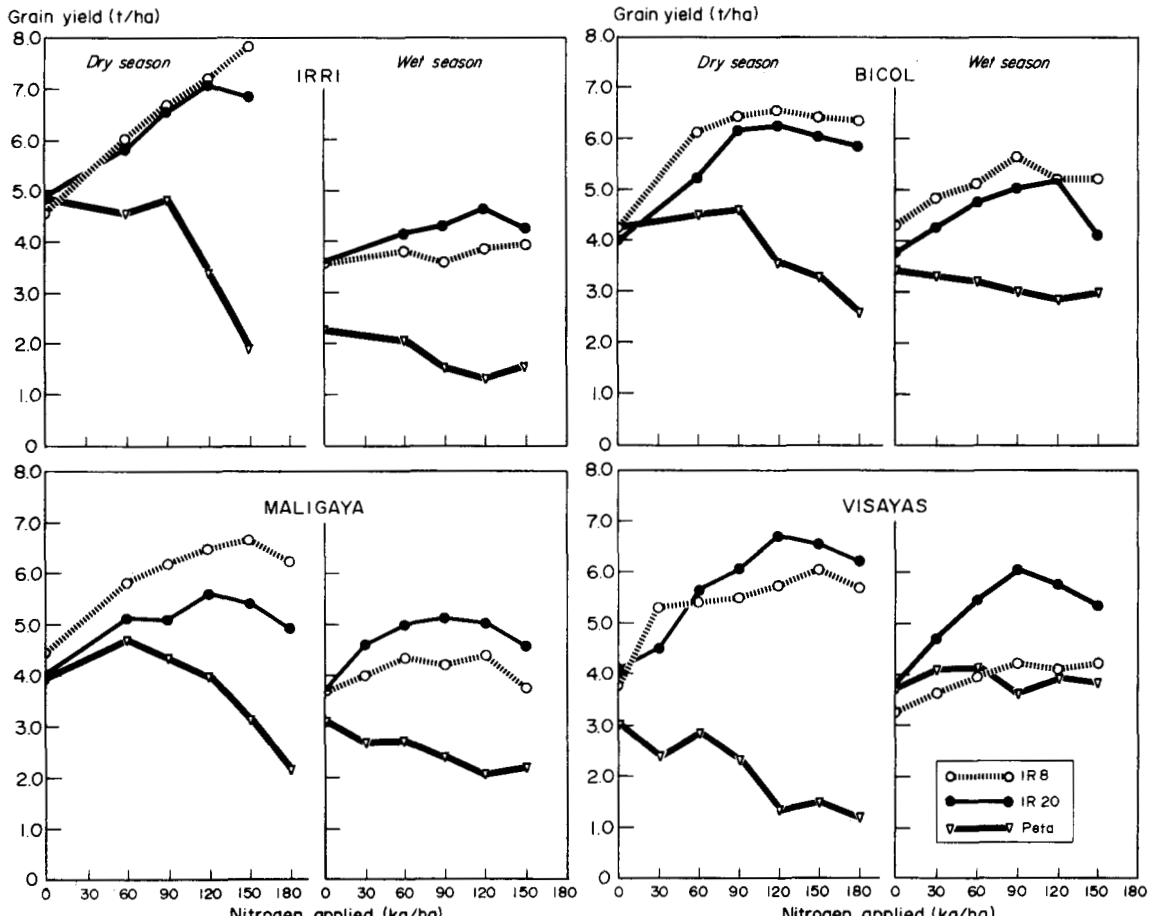
Crop Year	Irrigated		Rainfed			
			Lowland		Upland	
	Modern[a] varieties	Other varieties	Modern[a] varieties	Other varieties		Total
1967 – 68	447	862	254	1,260	481	3,304
1968 – 69	913	570	439	968	442	3,332
1969 – 70	827	519	527	828	412	3,113
1970 – 71	985	486	580	697	365	3,113
1971 – 72	977	355	850	698	366	3,246
1972 – 73	873	368	807	629	434	3,112
1973 – 74	1,195	299	982	551	409	3,437
1974 – 75	1,109	303	1,066	608	453	3,539
1975 – 76	1,207	287	1,092	602	390	3,579
1976 – 77	1,286	204	1,131	526	401	3,548

[a] Include IR-series, BPI-series and C-series.

Table 6. Palay yield (kg/ha), irrigated and rainfed, by varietal type. Philippines, 1968 – 1977 (Bureau of Agricultural Economics, Department of Agriculture).

Crop year	Irrigated		Rainfed			
			Lowland		Upland	
	Modern[a] varieties	Other varieties	Modern[a] varieties	Other varieties		Total
1967 – 68	1,968	1,614	1,307	1,239	825	1,380
1968 – 69	1,778	1,618	1,126	1,089	793	1,334
1969 – 70	2,156	1,886	1,488	1,527	1,026	1,681
1970 – 71	2,024	1,931	1,614	1,580	1,025	1,716
1971 – 72	2,053	1,723	1,443	1,350	855	1,571
1972 – 73	1,960	1,742	1,277	1,111	786	1,419
1973 – 74	2,051	1,888	1,531	1,252	940	1,628
1974 – 75	2,222	1,879	1,430	1,179	854	1,601
1975 – 76	2,317	1,994	1,509	1,329	872	1,721
1976 – 77	2,400	2,004	1,654	1,263	1,065	1,820

[a] Include IR-series, BPI-series and C-series.



1. Effects of nitrogen on grain yield of three varieties, 1968–1973. (Source: IRRI Agronomy Department).

best of the traditional varieties. IR8 is the prototype first-generation modern variety, giving high yields but with susceptibility to many insects and diseases. IR20 is a widely grown second-generation modern variety. It is resistant to several of the most damaging pests of rice. Maximum dry season yields of IR8 in these experiments at four Philippine stations averaged 6.8 t/ha over the six-year period, while at the same stations maximum yields of Peta averaged 4.4 t/ha. Wet season yields were 4.6 t/ha for IR8 and 3.1 t/ha for Peta. Average yields of IR20 were similar to those of IR8.

The data clearly show maximum yields about 50% higher for the modern varieties than for Peta. Hence, the first of the above hypotheses can be rejected. The advantage is real and appreciable. It is true that the yield advantage varies with location and season. At the Visayas experiment station, IR8 and Peta have about the same average yield during the wet season. This suggests that there may be some validity in the hypothesis that under different environmental conditions the yield advantage of the modern varieties is reduced. In almost all cases, the yields of the three varieties are nearly identical at the zero level of nitrogen input. This lends support to the second hypothesis that farmers' yields with modern varieties may be low because they use low levels of inputs.

These conclusions are highly tentative, because the evidence examined was designed to answer other questions, and the trials were conducted in the well-protected environments of experiment stations. Other experiment station evidence could be examined, but it has the same basic limitations. Experiments in farmers' fields overcome these limitations, which is one of the basic rationales for the constraints research project.

METHODOLOGY

Selecting study areas

The major criteria for selecting study areas were that rice must be an important crop for income and employment and that the areas must be accessible from IRRI or another research center. Background research on the development of methodology for use in the project had been conducted in Laguna province in 1972 and 1973 (IRRI 1974). Research information was available from the Maligaya Rice Research and Training Center (MRRTC) in Nueva Ecija Province (Central Luzon) and the Bicol Rice and Corn Experiment Station (BRCES) in Camarines Sur Province, Bicol Region. We decided to continue the research in Laguna, to begin research in Nueva Ecija in the wet season (July-November) of 1974, and to begin research in Camarines Sur in the dry season (December-May) of 1975. Iloilo

province was added in the dry season of 1976 in order to include an area with different characteristics. The next four chapters in this report summarize the results of work in all of the seasons, but with more detailed results provided for 1976 and 1977,

Table 7 shows the area of rice in each of the provinces included in the study. Nueva Ecija has the second largest rice area in the country. Iloilo has the fourth largest area, Camarines Sur the sixth, and Laguna is a relatively less important rice-producing province but it is where IRRI is located. Two-thirds of the national rice area was rainfed in 1971, but the study provinces have somewhat higher proportions of Irrigated land. The provinces of Laguna and Nueva Ecija have good access to Manila, but Iloilo and Camarines Sur are somewhat remote from that major market. In all provinces, the rainfed areas tended to be less accessible to the provincial towns than the irrigated areas. Yields in the study provinces were similar to yields in the rest of the country. Thus, the study provinces are fairly representative of Philippine rice-producing areas.

Laguna and Nueva Ecija were studied more intensively and over a longer period than the other two provinces. The chapters reporting results for Laguna and Nueva Ecija are more detailed than the chapter dealing with the other two.

Table 7. Total rice area and production of eight important rice-growing provinces in the Philippines, 1971 (National Census and Statistics Office).

Province	Total rice area				Total production		Av yield (t/ha)
	(ha)	(%)	Rainfed (ha)	Irrigated (ha)	(t)	(%)	
Cotabato	180,069	7.8	123,797	56,272	259,423	6.2	1.4
Nueva Ecija	154,992	7.2	71,693	93,299	354,266	8.5	2.1
Pangasinan	132,250	5.7	71,488	60,762	254,911	6.0	1.9
Iloilo	124,939	5.4	95,503	31,436	211,984	5.0	1.7
Isabela	103,092	4.5	49,127	53,965	253,297	6.0	2.4
Camarines Sur	90,692	3.9	54,328	36,364	137,762	3.3	1.5
Tarlac	85,100	3.7	40,057	45,042	191,274	4.6	2.2
Laguna	25,594	1.1	5,014	20,580	91,897	2.2	3.6
Philippines	2,305,301	100.0	1,436,534	868,767	4,185,909	100.0	1.8

REFERENCES CITED

Apiraksirikul, S. 1976. Rice trade policy as it relates to national objectives in the Philippines. M.A. thesis, School of Economics, University of the Philippines, Diliman, Quezon City, Philippines. 156 p.

Aviguetero, E.F., F. V. San Antonio, I. G. Serrano, H. A. del Castillo, and C. K. Cabilangan. 1977. Summary of 19 Economic Surveys of Food Consumption. Paper No. 77-9. Special Studies Division, Office of the Secretary of Agriculture, Philippines. March 1977.

De Datta, S.K., N. W. Obcemea, W. P. Abilay, M. T. Villa, B. S. Cia, and A. K. Chatterjee. 1976. Identifying farm yield constraints in tropical rice using a management package concept. Paper presented at the 7th Annual Meeting of the Crop Science Society of the Philippines, Davao City, May 10-12, 1976.

Gomez, K.A. 1976. The use of field plot technique in quantifying yield constraints in farmers' fields. Paper presented at the International Rice Research Conference, International Rice Research Institute, Los Baños, Philippines.

Gomez, K.A., D. Torres, and E. Go. 1973. Quantification of factors limiting rice yields in farmers' fields. Paper presented at IRRI Saturday Seminar, November 24, 1973, International Rice Research Institute, Los Baños, Philippines.

Hayami, Y., and M. Kikuchi. 1975. Investment inducements to public infrastructure: irrigation in the Philippines. Paper no. 75-15, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

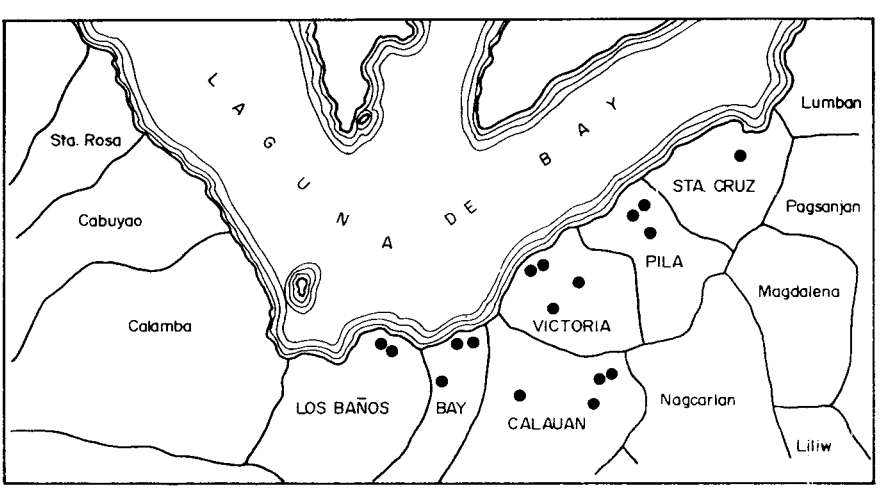
Herdt, R.W., and R. Barker. 1975. Possible effects of fertilizer shortages on rice production in Asian countries. In Impact of fertilizer shortage: focus on Asia. Asian Productivity Organization, Tokyo, Japan. pp. 205-240.

International Rice Research Institute. 1974. Annual report for 1973, Los Baños, Philippines, 266 p.

Constraints to High Rice Yields, Laguna, Philippines

K. A. Gomez, L. Lopez, M. J. Novenario, R. W. Herdt,
and V. P. Marciano

Constraints research techniques were first developed and applied on farmers' fields in six selected towns in the province of Laguna, Philippines (Fig. 1). Research was undertaken from the 1972 dry season through the 1977 wet season (no experiment was conducted in the 1973 dry season). The number of test sites for each crop season is shown in Table 1. At each site in each crop season, except in 1977, a standard 2^n complete factorial experiment was conducted, with n as the number of test factors, and with the two levels of each test factor at the farmer's practice and the improved or high level of practice. The farmer's practice refers to what each farmer was actually doing in the current crop season, and varied from one farm to another. The high level is the level expected to give maximum yield; it was fixed for all test sites in a given crop season. The high level consisted of 120 kg/ha N in the dry season and 90 kg/ha N in the wet season, as close to weed-free conditions as possible, and with maximum protection against insects and diseases through application of insecticides.



1. Areas where yield constraints experiments were conducted. Laguna, 1972–77.

Table 1. Number of yield constraints experiments conducted in Laguna province, Philippines. 1972-1977.

Year	Number of test sites	
	Wet season	Dry season
1972	3	4
1973	12	0
1974	10	6
1975	20	9
1976	13	12
1977	19	19
Total	77	50

In both crop seasons in 1977, there were 4 minifactorial trials and 12 supplemental trials (Gomez 1977, De Datta et al 1978) in addition to the complete factorial trials in three locations. For both complete factorial and minifactorial trials, two replications per site were used in all crop seasons, except in the 1976 wet season when treatments were not replicated within farms.

In 1972 there were five test factors: water management, insect control, fertilizer, weed control, and seed source and seedling management. In the 1973 wet season and the 1974 dry season, water management was excluded, and four factors were tested. From the 1974 wet season through the 1977 wet season, three factors - insect control, fertilizer, and weed control - were tested.

The farmer's level of each test factor was established in the designated experimental plots through the use of the comparable-paddy technique (De Datta et al 1978). During 1972-74, simulation of farmers' practices was done for all test factors. During 1974-75, the farmers' levels of weed control and fertilizer were simulated, an in 1976-77, only the level of fertilization was simulated by the researchers.

Aside from yield, data on weeds, insect and disease incidence, and rat damage were collected. A complete record of management and cultural practices from seedling preparation to harvest was kept for both the farmers' practice and the improved practice.

The yields obtained by using high and farmers' levels of test factors were subjected to cost-and-returns analysis for the 1975 to 1977 experiments. The actual prices paid and received by farmers in the study area were obtained through surveys of farmers with experiments and randomly chosen farmers in the same villages. The usual method of paying for harvesting and threshing in Laguna is a share of the crop; so in calculating net returns an amount equal to 1/7 of yield (the average share paid for these services) is deducted.

Information on credit and input availability, level of input use, perceived constraints, and other factors that might help in explaining farmers' behavior was obtained through the farm survey.

AGRONOMIC RESULTS

The relative frequency of varieties grown on the farms for each season and year is shown in Figure 2. Farmers in Laguna seemed to be "up to date" in their choice of varieties grown. IR8, the first IRRI variety released in 1966, was not seen after the 1972 dry season. IR1561-228-3 appeared in the cooperator farms in the 1973 wet season and was last planted in the 1975 wet season. IR26, released at the end of 1973, was first seen in the 1974 wet season and was planted in every season thereafter until the 1976 wet season. IR36, released in April of 1976, first appeared in the cooperator farms in the 1976 wet season and was still being grown in the 1977 wet season. IR42, released in April of 1977, appeared in more than 30% of the farms in the 1977 wet season.

Table 2 summarizes the average levels of test inputs used by farmers in the study area for each study season. Most farmers applied some form of nitrogen fertilizer, with an average rate of 76 kg/ha N in the dry season and 64 kg/ha N in the wet season. While the farmers' nitrogen rates in the wet season were, on the whole, slightly lower than in the dry season, this trend was not consistent over all farms. Very few farmers applied phosphorus and fewer still applied potassium. To control insect pests, most farmers used foliar sprays, averaging about two applications per crop season. A few farmers supplemented spraying with granular insecticides. The high level of insect protection included 2 applications of granular insecticide plus sprays as needed to minimize insect infestation. Weeds were generally controlled by one or two rotary weedings followed by one or two hand weedings. Very few farmers used herbicides in controlling weeds. The weed-free conditions of the high level of weed control were maintained by the use of both herbicides and hand weeding.

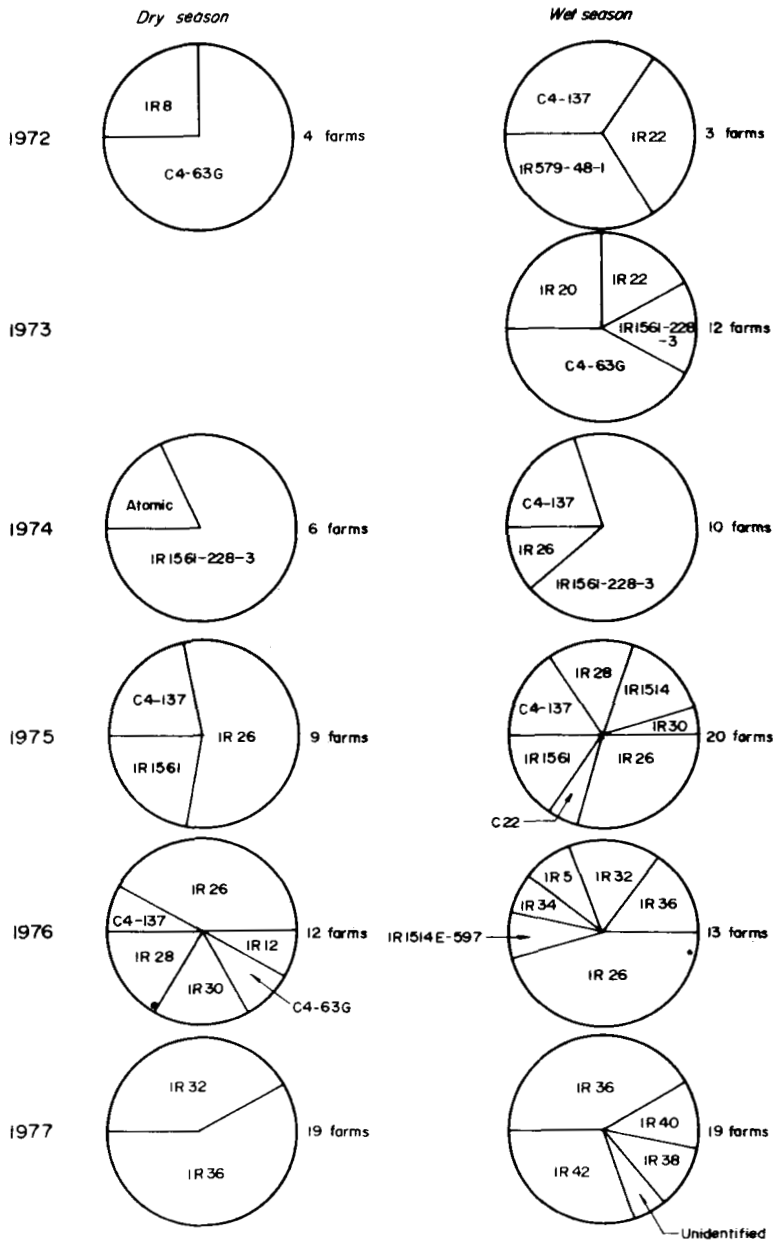
Table 2. Average levels of test inputs used by farmers in yield constraints project, Laguna, 1972–1977.

Year	Farms (no.)	Fertilizer (kg/ha)			Insect control [a]				Weed control [b]		
					Seedbed		Field				
		N	P_2O_5	K_2O	F	G		FG	RW	HW	C
					Wet season						
1972	3	65	1	0	0.0	0.0	1.7	0.7	0.3	1.7	0.3
1973	12	42	1	0	0.6	0.0	2.0	0.2	1.1	1.6	0.1
1974	10	37	2	0	1.1	0.0	1.7	0.2	1.1	1.1	0.1
1975	20	74	3	2	0.0	0.0	2.3	0.4	1.2	1.2	0.3
1976	13	77	7	2	0.5	0.1	3.3	0.4	1.5	1.0	0.8
1977	19	73	6	2	0.1	0.1	1.7	0.6	0.9	1.6	0.4
Av	77	64	4	1	0.3	0.0	2.2	0.4	1.1	1.3	0.4
					Dry season						
1972	4	88	0	0	0.0	0.0	1.0	0.0	1.0	1.0	0.2
1974	6	54	12	0	0.0	0.0	2.0	0.2	0.2	2.0	0.0
1975	9	63	5	1	1.7	0.0	2.3	0.2	0.9	1.0	0.0
1976	12	96	15	8	0.3	0.0	3.5	0.1	1.5	1.3	0.1
1977	19	73	4	3	0.1	0.0	1.5	0.4	1.6	0.7	0.2
Av	50	76	7	3	0.4	0.0	2.1	0.2	1.2	1.1	0.1

[a] Data show the average number of foliar (F) sprays or granular (G) applications.

[b] Data show the average number of rotary weedings (RW), hand weeding (HW), and chemical weedicide (C) applications.

The 1972 tests indicated that improved water management increased farmers' rice yields by about 1 t/ha in the dry season and not at all in the wet season (Table 3). However, the experimental procedure involving water management as a test factor was not satisfactory for assessing the contribution of improved water management to farmers' yields. The researchers maintained the desired improved water level in farmers' fields with great difficulty because water was not available at all times. Unless the procedure can be simplified, the use of water management as a test factor would not be feasible in a large-scaleyield-constraints test. Thus, while large water management contributions to yield increase in Laguna farms could be expected in dry seasons, this test factor was dropped from the tests in succeeding years.



2. Relative frequency of varieties grown in farmers' fields. Laguna, Philippines, 1972–77. No data were collected for the 1973 dry season.

Table 3. Average contribution of "water management" to increased rice yields in farmers' fields, measured experimentally. Laguna, 1972.

Season	Farms (no.)	Actual farm yield (t/ha)	Total yield gap[a] (t/ha)	Contribution of water management (t/ha)
Wet	3	4.4	0.6	-0.1
Dry	4	3.9	3.4	0.9

[a]From 5 test inputs: insect control, fertilizer, weed control, water management, and seed management.

Table 4. Average contribution of "seed source and seedling management" to increased rice yields in farmers' fields, measured experimentally. Laguna, 1972-1974.

Year	Season	Farms (no.)	Farmers' yields (t/ha)	Total yield gap[a] (t/ha)	Contribution of seed management (t/ha)
1972	Wet	3	4.4	0.6	-0.2
	Dry	4	3.9	3.4	0.3
1973	Wet	12	3.0	1.9	0.2
1974	Dry	3	3.2	3.6	0.4

[a]From 5 test inputs: insect control, fertilizer, weed control, water management, and seed management in 1972; and from 4 test inputs (excluding water management) in 1973 and 1974.

In four seasons of tests in 1972-74, improved seed source and seedling management contributed an average of 0.2 t/ha to increased rice yields in the Laguna farms (Table 4). Since Laguna farmers consistently grow improved varieties soon after they are released, the use of mixed or impure seeds is not common. Availability of improved seed and seedling management were not found to be major constraints to high yields in Laguna farms.

Yields and yield gap

Results on actual farm yield, potential farm yield, yield gap, and contributions of the remaining three test factors (insect control, fertilizer, and weed control) to the yield gap as revealed by the studies conducted beginning in the 1973 wet season through the 1977 wet season will be described.

In the dry season, average actual farm yields across the years ranged from 4.1 t/ha in 1975 to 4.8 t/ha in 1977, with a 4-year average of 4.5 t/ha (Table 5). In the wet season, actual farm yields ranged from 2.9 t/ha in 1973 to 4.5 t/ha in 1977, with a 5-year average of 3.8 t/ha. With high levels of test inputs, average farm yields increased from the farmer's level of 4.5 t/ha to 6.4 t/ha in the dry season and from the farmer's level of 3.8 t/ha to 5.5 t/ha in the wet season. While the actual farm yields and potential farm yields were consistently lower in the wet season than in the dry season, there was no such consistent trend for the yield gap. The relatively large yield gap in the 1976

Table 5. Average actual farm yield, potential farm yield, and yield gap measured in yield constraints experiments in farmers' fields. Laguna, 1973-1977.

Year	Farms (no.)	Actual farm yield (t/ha)	Potential farm yield (t/ha)	Yield gap (t/ha)
		Wet season		
1973	12	2.93	4.59	1.66
1974	10	3.78	5.85	2.07
1975	20	3.63	5.34	1.71
1976	13	3.56	5.82	2.26
1977	19	4.49	5.70	1.21
Av	(74)	(3.75)	(5.46)	(1.71)
		Dry season		
1974	6	4.18	6.76	2.58
1975	9	4.13	6.65	2.52
1976	12	4.36	6.12	1.76
1977	19	4.78	6.46	1.68
Av	(46)	(4.46)	(6.45)	(1.99)

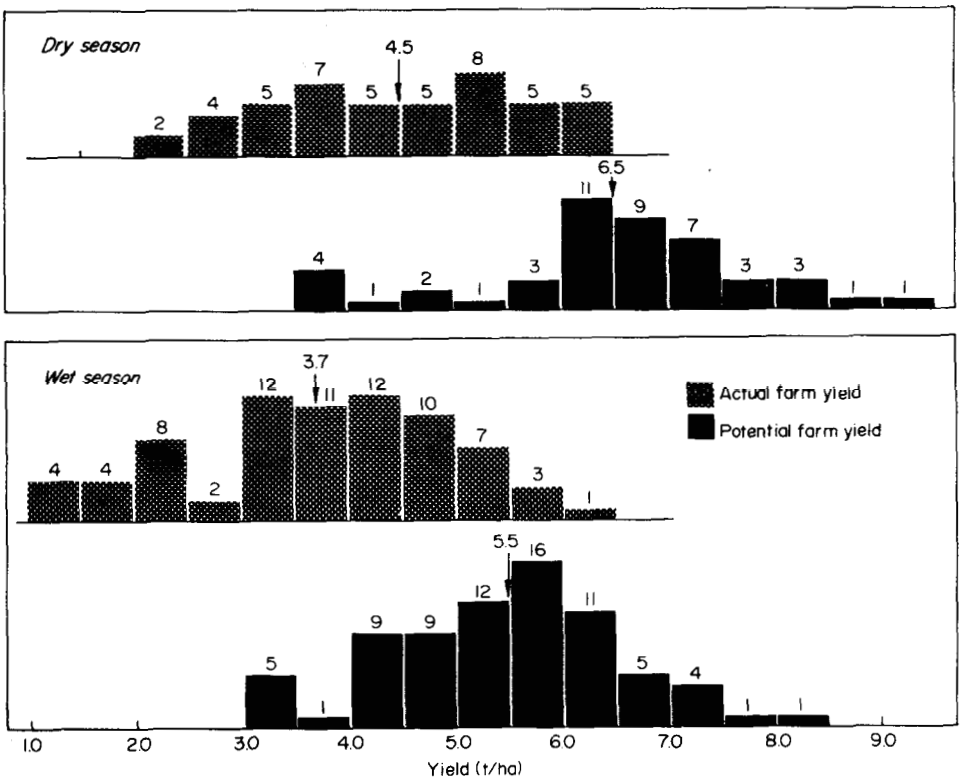
wet season, for instance, was primarily the result of severe brown planthopper attack on some farms. The yield gap averaged 2.0 t/ha in the dry season and 1.7 t/ha in the wet season.

Potential farm yield correlated positively with actual farm yield ($r = 0.66^{**}$, $n = 127$) indicating that farms which already had relatively higher farm yields also had higher potential yields. On the other hand, the yield gap correlated positively with the potential farm yield ($r = 0.43^{**}$) and correlated negatively with the actual farm yield ($r = -0.39^{**}$). These results indicate that while yield gaps could be expected to be greater on farms with relatively low actual farm yields than on farms with already high farm yields, some yield gap could be expected on all farms, regardless of their present yield levels.

While the average yield and yield-gap levels seemed quite stable over the years (Table 5), large variations between farms were observed. Actual yields per farm ranged from 2.0 t/ha to 6.5 t/ha in the dry season and from 1.0 t/ha to 5.5 t/ha in the wet season (Fig. 3). The potential farm yield ranged from 3.5 t/ha to 9.5 t/ha in the dry season and from 3.0 t/ha to 8.5 t/ha in the wet season. It was estimated that 87% of the total variation in actual farm yield was attributable to variation among farms within year and season, and only 13% to variation between dry and wet seasons (Table 6). Seventy-one percent of the total interfarm variation in the potential farm yield was attributable to variation among farms within year and season and 26% to between-season variation. Ninety-one percent of the total interfarm variation in the yield gap (Fig. 4) was attributable to variation among farms within year and season, while 4% was attributable to between-season variation. For all three characters, a very negligible portion of the total variation was due to year-to-year variation. In effect, estimates of actual and potential farm yields and of the yield gap were highly stable over years, relatively less stable over seasons, and highly variable over farms within the same year and season.

Contribution of test factors to the yield gap

Information on interactions among test factors was obtained with data for the complete factorial trials. Knowledge of the existence and size of interaction effects among test factors is essential in the assessment of the contributions of individual test factors. In Laguna, significant interactions were observed in only a few cases, with the interaction between insect control and fertilizer (I x F) being most notable (Table 7). Although about the same number of farms showed a significant I x F interaction in the dry and wet seasons, only in the dry season were the results consistent and of appreciable size (Table 8).



3. Frequency distribution of actual farm yields and potential farm yields (based on three test factors: insect control, fertilizer, and weed control) in farmers' fields (46 tests in the dry season and 74 tests in the wet season). Yield constraints study, Laguna, 1973–1977.

However, since only a few farms gave significant interactions in each season and year, the estimated contributions to yield increase from each test factor, averaged over all farms, did not differ appreciably whether or not the computations were made based on the average over the farmer's level and high level of other inputs (i.e., main effects), or based on either one of the two levels (i.e., simple effects). We therefore present our results simply based on the main effects for all years and seasons, except for the 1977 dry and wet seasons, where simple effects (based on the farmer's level of other inputs) were used. Results are shown in Table 9.

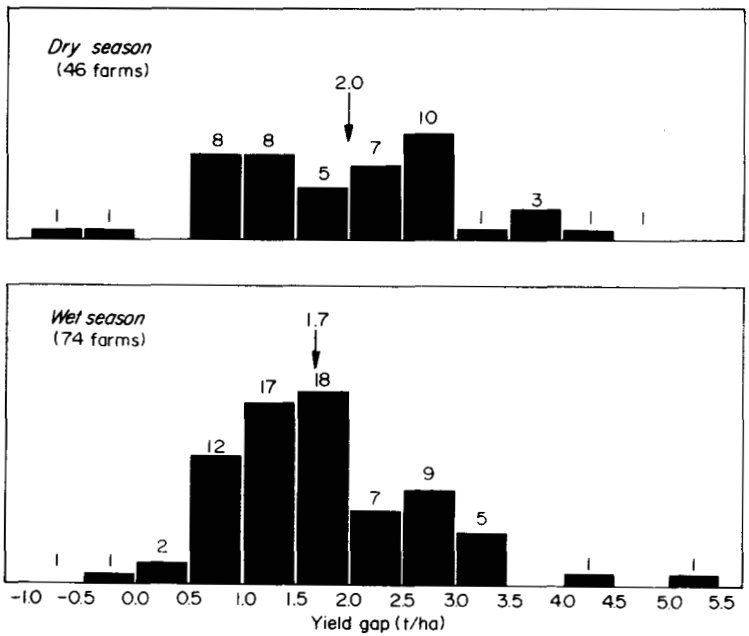
Table 6. Variation between seasons (V_s), among years within seasons (V_y), and among farms within years and seasons (V_f) in actual farm yield, potential farm yield, yield gap, and the contribution of three test factors. Laguna, 1973–1977.

	Actual farm yield	Potential farm yield	Yield gap	Contribution from Insect control	Contribution from Fertilizer	Contribution from Weed control
Mean (t/ha)	3.75	5.75	2.00	0.94	0.79	0.26
Between seasons						
V_s	0.22	0.53	0.04	0.00	0.08	0.00
cv (%)	12.4	12.6	9.5	0.0	34.7	0.0
% of total[a]	13	26	4	0	19	0
Among years within season						
V_y	0.00	0.07	0.06	0.09	0.06	0.00
cv (%)	0.0	4.5	11.8	32.1	29.9	0.0
% of total	0	3	5	18	14	0
Among farms within year and season						
V_f	1.39	1.48	0.92	0.43	0.26	0.05
cv (%)	31.5	21.1	48.0	69.3	65.0	88.2
% of total	87	71	91	82	67	100

[a] Total = $V_s + V_y + V_f$.

In the dry season, of the 2.1 t/ha average yield gap, 0.9 t/ha was contributed by improved insect control, 1.0 t/ha by improved fertilization, and 0.2 t/ha by improved weed control. In the wet season, of the 1.8 t/ha yield gap, 1.0 t/ha was from improved insect control, 0.6 t/ha from improved fertilization, and only 0.2 t/ha was from improved weed control.

On the whole, about 90% of the 2 t/ha yield gap found in Laguna farms was contributed by the effects of improved insect control and improved fertilization. The contribution of improved insect control seemed to be quite stable over the dry and wet seasons, but the contribution of improved fertilization was larger in the dry season than in the wet season. This result is further confirmed by estimates of the relative variance components shown in Table 6: the portion of the total variation attributable to crop season was estimated at 19% for the contribution of fertilizer and 0% for the contribution of insect control.



4. Frequency distribution of yield gaps contributed by improved insect control, fertilizer, and weed control by season. Laguna, 1973–1977.

In both seasons and over all years, improved weed control did not appreciably increase yields in Laguna farms, indicating that the farmers in the study area generally used adequate weed control. These farmers averaged more than one rotary weeding plus one hand weeding each (Table 2). In contrast, their average levels of fertilizer application and insect control (Table 2) were considerably below the tested high level.

ECONOMIC ANALYSIS

Table 10 summarizes the results of the economic analysis, comparing the farmers' input levels with the high levels tested in the experiments between 1975 and 1977. In the dry season, farmers spent an average of ₱595/ha on fertilizer, weed control, and insect control, while the high inputs cost ₱1985/ha. On the average, yields increased from 4.4 t/ha at the farmer's level to 6.5 t/ha at the high level. This resulted in an average increase of ₱464/ha in net returns. Thus, profits to farmers would be marginally increased in the dry season by spending three times as much as they had for inputs, a prospect that does not appear to be very attractive. Wet season results were

Table 7. Frequency of farms showing one or more significant interactions among the test factors.[a] Yield constraints study, Laguna, 1973 – 1977.

Year	Farms (no.)	No. of farms with significant interaction			
		I x F	I x W	W x F	I x W x F
			Wet season		
1973	12	1	1	1	-
1974	10	2	-	-	-
1975	4	3	1	1	1
1977	3	-	-	-	-
			Dry season		
1974	6	1	-	-	-
1975	9	3	2	2	1
1976	7	2	-	-	-
1977	3	1	-	-	-
Total	54	13	4	4	2

[a]Three test factors: Insect control (I), Fertilizer (F), and Weed control (W).

Table 8. Average size of insect control x fertilizer interaction effects obtained in yield constraints experiments in farmers' fields.[a] Laguna, 1973 – 1977.

Season	Farms (no.)	Actual farm yield (t/ha)	Contribution of insect control (t/ha)		Contribution of fertilizer (t/ha)		Inter – action effect (t/ha)
			Farmer's ferti – lizer	High ferti – lizer	Farmer's insect control	High insect control	
Wet	6	3.20	0.71	0.88	0.77	0.94	0.17
Dry	7	3.90	0.63	1.73	0.88	1.98	1.10

[a]Only those farms with "significant" interaction were considered.

Table 9. Average contribution of insect control, fertilizer, and weed control to increased rice yields in farmers' fields. Laguna, 1973 – 1977.

Year	Farms (no.)	Yield (t/ha) Farmers' inputs	High inputs	Gap	Contribution (t/ha) of Insect control	Ferti-lizer	Weed control	Residual
				Wet season				
1973	12	2.93	4.59	1.66	1.22	0.19	0.30	– 0.05
1974	10	3.78	5.85	2.07	0.72	1.08	0.23	0.04
1975	20	3.63	5.34	1.71	0.66	0.73	0.27	0.05
1976	13	3.56	5.82	2.26	1.37	0.66	0.23	0.00
1977	6	4.54	5.64	1.10	0.91	0.21	0.16	-0.18
Av	61	3.59	5.41	1.82	0.96	0.62	0.25	-0.01
				Dry season				
1974	6	4.18	6.76	2.58	1.47	0.89	0.29	– 0.07
1975	9	4.13	6.65	2.52	1.00	1.20	0.25	0.07
1976	12	4.36	6.12	1.76	0.58	1.04	0.19	– 0.05
1977	6	4.87	6.67	1.80	0.90	0.94	– 0.23	0.19
Av	33	4.36	6.48	2.12	0.91	1.04	0.15	0.02

similar. Profits would have increased by ₱353/ha with three times as much cash input. Tables 11 through 13 examine the costs and returns associated with the three separate inputs tested in the experiments.

Weed control showed the smallest contribution to the yield gap, averaging about 200 kg/ha. On the average by using chemical weed control, net returns could be increased by over P100/ha in the dry season and by over P150/ha in the wet season (Table 11). These data show rather high returns from modest additional costs for weed control, so one must ask why Laguna farmers do not make the investment. The answer appears to lie in the institutional arrangement called "gama", under which hand – weeding operations are conducted by the individual who harvests the plot, with the payment for weeding included as part of the crop share received for harvesting. The availability of laborers willing to carry out such activities makes the use of chemical weed control (included in the high level in Table 11) less attractive than it otherwise would be.

Table 10. Comparison of anticipated maximum yield levels of inputs with farmers' levels in constraints experiments. Laguna, 1975-1977.

Year	Sites (no.)	Cost of inputs (₱/ha)		Yield (t/ha)		Net returns (₱/ha)	
		Farmers'	High	Farmers'	High	Farmers'	High
				Wet season			
1975	20	618	2257	3.6	5.3	2482	2243
1976	14	720	1684	3.6	5.8	2248	3722
1977	7	632	1830	4.5	5.6	3168	2970
All	41	654	1984	3.7	5.5	2520	2873
				Dry season			
1975	9	382	2668	4.1	6.7	3218	3132
1976	12	706	1360	4.4	6.1	3360	4202
1977	7	691	2154	4.9	7.0	3929	4446
All	28	595	1985	4.4	6.5	3457	3921

Table 12 shows the economic comparisons of the tested high level of insect control. In the dry season farmers spent an average of ₱59/ha on insect control, while the high level cost ₱130l/ha -- more than 20 times as much. The value of the increased yield generated by the high level of protection was much less than the cost, giving a B:C ratio on increased input cost of about 0.6. Farmers spent somewhat more on their inputs in the wet season, but the high input cost was still seven times as much as farmers spent and resulted in a reduction in net returns, although yields were increased by less than 1.0 t/ha. It is clear that the high level of insect control would not be economically attractive to the farmers.

The economic comparisons of high levels and farmers' levels of fertilizer shown in Table 13 present quite a contrast to the weed and insect control data. Farmers spent about twice as much on fertilizer as on either insect or weed control. The high levels in the experiments are about 30-50% above farmers' levels, but both yields and net returns were consistently and substantially increased through the use of the high fertilizer levels in both seasons. Net yield increases averaged 0.9 t/ha in the dry season and 0.5 tlha in the wet season, while profits increased by ₱826/ha and ₱429/ha. This indicates considerable opportunity for improving performance through higher fertilizer levels.

Table 11. Economic comparisons of the tested maximum yield level of weed control and the farmers' levels in constraints experiments. Laguna, 1975 – 1977.

Year	Sites (no.)	Input cost (₱/ha)		Increase resulting from high inputs			B – C ratio of increased inputs
		Farmers'	High	Yield[a] (t/ha)	Output value (₱/ha)	Net return (₱/ha)	
				Wet season			
1975	20	147	250	0.26	260	157	2.5
1976	14	132	118	0.17	180	194	0.0
1977	7	235	279	0.17	170	126	2.9
All	41	154	206	0.21	217	165	4.2
				Dry season			
1975	9	110	198	0.23	230	142	2.6
1976	12	206	118	0.20	214	302	0.0
1977	7	272	353	-0.17	– 187	– 268	– 3.3
All	28	191	206	0.09	119	104	7.9

[a] One – seventh of added yield was subtracted to allow for harvesting and threshing costs.

Table 12. Economic comparisons of the tested maximum yield level of insect control and farmers' levels in constraints experiments. Laguna, 1975 – 1977.

Year	Sites (no.)	Input cost (P/ha)		Increase resulting from high inputs			B – C ratio of increased inputs
		Farmers'	High	Yield[a] (t/ha)	Output value (P/ha)	Net return (P/ha)	
				Wet season			
1975	20	162	1492	0.60	600	-730	0.45
1976	14	257	2113	1.37	1452	496	1.51
1977	7	81	1220	0.77	770	– 369	0.68
All	41	184	1352	0.86	920	– 248	0.79

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Table 12 continued

				Dry season			
1975	9	22	2080	0.86	860	-1198	0.42
1976	12	74	757	0.51	546	-137	0.80
1977	7	81	1227	0.69	759	-387	0.66
All	28	59	1301	0.69	700	-542	0.56

[a]One-seventh of additional yield was subtracted to allow for harvesting and threshing costs.

Table 13. Economic comparisons of the tested maximum yield level of fertilizer and farmers' levels in constraints experiments. Laguna, 1975 – 1977.

Year	Sites (no.)	Input cost (₱/ha)		Increase resulting from high inputs			B-C ratio of increased inputs
		Farmers'	High	Yield[a] (t/ha)	Output value (₱/ha)	Net return (₱/ha)	
				Wet season			
1975	20	309	515	0.60	600	394	2.9
1976	14	331	353	0.60	636	614	28.9
1977	7	316	331	0.17	170	155	11.3
All	41	316	426	0.51	539	429	4.9
				Dry season			
1975	9	250	390	1.11	1110	970	7.9
1976	12	426	485	0.86	912	853	15.5
1977	7	338	573	0.77	847	612	3.6
All	28	345	478	0.94	959	826	7.2

[a] One – seventh of additional yield was subtracted to allow for harvesting and threshing costs.

Table 14. Fertilizer expenditures and responses by farmers[a] surveyed to the question of why they were unwilling to apply higher fertilizer levels. Laguna, 1976 – 1977.

Reasons for not using higher fertilizer level	% of sample giving reason				Expenditures on fertilizer (₱/ha)			
	Wet 1976	Wet 1977	Dry 1976	Dry 1977	Wet 1976	Wet 1977	Dry 1976	Dry 1977
Lack of capital	11	10	14	27	333	495	352	325
Used high enough rate	21	37	12	26	438	561	398	406
Plants may lodge	12	12	2	4	370	535	194	335
Lack of water	0	0	1	2	0	0	238	239
Other	6	2	4	0	239	123	350	0
No response	0	0	16	1	0	0	300	280

[a] The numbers of sample farmers were 49, 60, 50, and 61 in dry 1976, dry 1977, wet 1976, and wet 1977, respectively.

Farmers were questioned as to why they were not using higher rates of fertilizer application. The most frequent reasons given were that they believed they were using enough or that they lacked the cash to apply higher rates (Table 14). Lack of cash seemed implausible because there was very little difference in the input levels used between farmers who gave the above – mentionedreasons. Hence, we concluded that in reality farmers believe that they are using optimal levels of fertilizer.

SUMMARY

Results from tests conducted in 11 planting seasons in Laguna farms indicate that:

- Improved water management gives a yield increase of about 1 t/ha in the dry season and no increase in the wet season.
- Farm yields average 4.5 t/ha in the dry season and 3. 8 t/ha in the wet season. The yield gaps from the combined effects of insect control, fertilizer use, and weed control average 2.0 t/ha in the dry season and 1.7 t/ha in the wet season. About 90% of the yield gap is attributable to the combined effects of improved insect control and fertilizer use, with negligible contribution from improved weed control.

- Some yield gaps could be expected in most farms regardless of the farm-yield level, but these tend to be larger on farms with relatively low actual farm yields.

- The farm-to-farm variation in yields and yield constraints is much larger than seasonal variation and year-to-year variation.

- The increased costs of high levels of insect control are larger than the value of the rice they produced, compared to farmers' levels.

- Chemical weed control produces a modest increase in profit but is not attractive to farmers because of institutional arrangements favoring hand weeding.

- High fertilizer levels are much more profitable than farmers' present levels in both the wet and the dry seasons, but farmers believed they were using optimal fertilizer levels.

REFERENCES CITED

De Datta, S. K., K. A. Gomez, R. W. Herdt, and R. Barker. 1978. Handbook for an integrated experiment-survey yield constraints methodology. International Rice Research Institute, Los Baños, Philippines.

Gomez, K. A. 1977. On-farm assessment of yield constraints: methodological problems. in International Rice Research Institute. Constraints to high yields on Asian rice farms: an interim report, Los Baños, Philippines.

International Rice Research Institute. 1974. Annual report for 1973. Los Baños, Philippines.

International Rice Research Institute. 1975. Annual report for 1974. Los Baños, Philippines.

International Rice Research Institute. 1976. Annual report for 1975. Los Baños, Philippines.

International Rice Research Institute. 1977. Annual report for 1976. Los Baños, Philippines.

Rahim, K. 1978. A technique to identify constraints to high rice yields in farmers' fields. Unpublished M.S. thesis, University of the Philippines, Los Baños, Philippines.

Constraints to High Rice Yields, Nueva Ecija, Philippines

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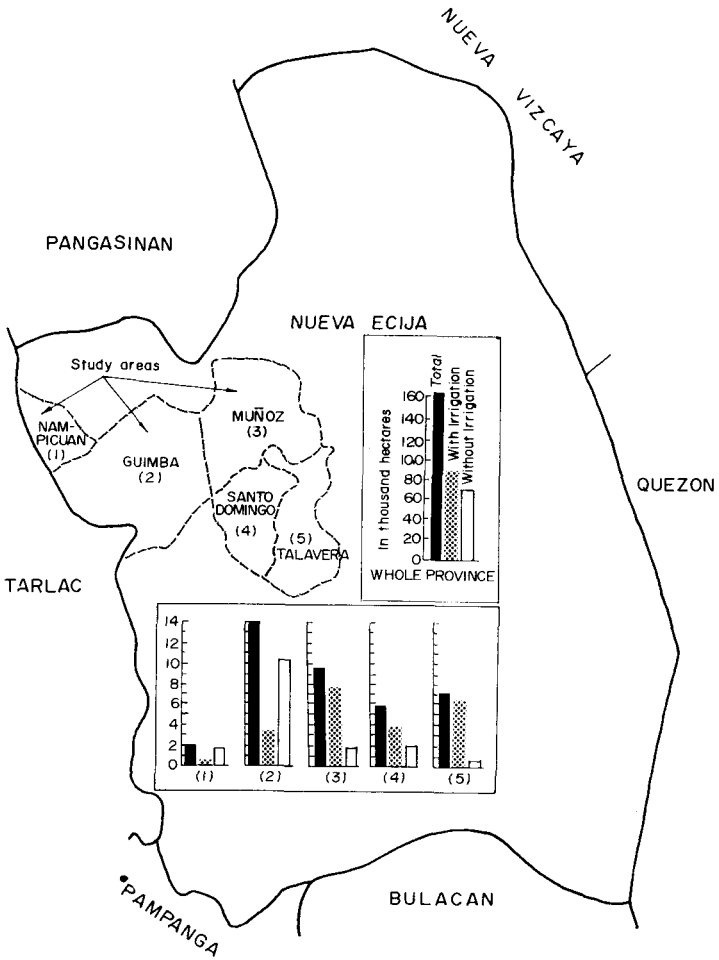
Nueva Ecija has the second largest area of land in rice among the Philippine provinces and the largest production, contributing 8.5% of the national rice production. In 1971, Nueva Ecija with 57% of its area irrigated had the highest percentage of irrigated rice lands among the seven leading rice provinces.

Figure 1 shows the location of the municipalities of Muñoz, Talavera, Sto. Domingo, Guimba, and Nampicuan, where the yield constraints experiments were conducted from the 1974 wet season to the 1977 wet season. These municipalities constitute about one-fourth of the total rice area of the province. Of the five municipalities, Guimba and Nampicuan are predominantly rainfed, while over 60% of the rice area in the other three municipalities is irrigated. The annual rice production of Nueva Ecija was 400,000 t during the study period, about 25% of which was produced in the 5 municipalities included in the project. Average yields in the province were 2.1 t/ha, while average yields in the five municipalities varied from 2.0 t/ha to 2.5 t/ha. Yields in the predominantly rainfed municipalities (Guimba and Nampicuan) were similar to yields in the more highly irrigated municipalities.

METHODOLOGY

The constraints project was started in the 1974 wet season with complete factorial experiments combined with management packages. In these trials all factors except the test factors were held at the farmers' levels. In addition, three management package project trials were conducted in which all nontest factors were held at the level that was anticipated to be needed for maximum yields. This pattern was followed in 1975 (Table 1). In 1976 and 1977 the experimental designs were modified.

Equal numbers of experimental farms were selected from low-, medium-, and high-yielding groups based on information collected during a preliminary survey. In the wet season, rainfed farms were included in the trials in addition to irrigated farms.



1. Municipalities in Nueva Ecija with constraints studies, and area planted to rice on farms with and without irrigation facilities, by municipality (1971 Census of Agriculture, National Census and Statistics Office).

Table 1. Number of farms on which each type of experiment was conducted. Nueva Ecija, 1974 – 77.

Year	Two – level factorial with mgt. packages	Multi – level factorial	Mini – fac- torial	Supple – mental	Management package with other factors high
			Wet season		
1974	10	0	0	0	3
1975	11	0	0	0	11
1976	0	9	0	0	1
1977	0	10	14	13	2
All	21	19	14	13	17
			Dry season		
1975	3	0	0	0	3
1976	0	9	0	0	2
1977	0	7	9	12	1
All	3	16	9	12	6

Factorial experiments

In the 1976 dry and wet seasons, a multilevel factorial experiment comparing the level of inputs anticipated to give maximum yield (high level) with the farmers' and intermediate levels was conducted in selected farmers' fields. Fertilizer was applied at two intermediate levels below the high level, and insect control was carried out at one intermediate level. Weed control was tested at the farmers' and the high levels. Insect control was used as the main plot factor and fertilizer, weed control, and cultural practices for the subplots.

The high fertilizer level varied during the first three years as methodology and weather affected research decisions (Table 2). It was fixed in 1976 and 1977. During the wet season, nitrogen was applied in two equal split doses, basal, and 5 to 7 days before the panicle initiation stage. The high level of insect control in the 1976 and 1977 wet seasons consisted of two granular insecticide applications in the seedbed, with three granular treatments plus one foliar spray applied to the main crop. The intermediate insect control level had one granular insecticide application in the seedbed and at least two granular insecticide applications on the main crop. Additional foliar spraying with

Table 2. High levels and farmers' levels of inputs in farmers' fields. Nueva Ecija, Philippines, 1974 – 77.

Input level	Sites (no.)	Year	Fertilizer (kg/ha) N	P_2O_5	K_2O	Weed control[a] M	C	Insect control[b] F	G
				Wet season					
Farmers'	10	1974	37	21	0	0.4	0.3	1.1	0.4
High			120	60	60	1.0	1.0	5.0	3.0
Farmers'	11	1975	79	22	2	0.3	0.4	0.9	0.4
High			75	30	20	0.0	1.0	3.0	2.0
Farmers'	9	1976	57	13	0	0.2	0.3	1.9	0.4
High			100	40	30	1.0	1.0	1.0	3.0
Farmers'	37	1977	64	30	8	0.4	0.4	2.3	0.7
High			100	40	30	1.0	1.0	2.3	3.0
				Dry season					
Farmers'	3	1975	118	52	0	0.7	0.3	1.0	1.0
High			120	30	30	0.0	1.0	3.0	2.0
Farmers'	9	1976	76	34	1	0.9	0.4	1.6	0.4
High			150	40	30	1.0	1.0	1.0	4.0
Farmers'	28	1977	93	41	4	0.8	0.5	1.9	0.6
High			150	40	30	1.0	1.0	1.0	4.0

[a] Data show average number of mechanical weeding operations (M) -- either by hand or by rotary weeder -- or chemical weedicide (C) applications.

[b] Data show average number of foliar (F) sprays - Hytox, Azodrin, Brodan, Parapest, etc. -- or of granular (G) applications - Lindane, Furadan, Diazinon, etc. -- to paddy water.

insecticide was included as needed. The high level of weed control included an application of granular herbicide at 4 days after transplanting and one hand weeding at 20 – 30 days after transplanting Levels and methods of applications of each test input used by the farmers in the "comparable paddy" were carefully simulated as the farmers! levels in the experiment.

During the 1977 dry season, nitrogen was applied in three equal split doses; basal (broadcast and incorporated), topdressings at 20 – 30 days after transplanting and 5–7 days before the panicle initiation stage. The high level of insect control included two foliar insecticide applications in the seedbed and four granular

treatments plus one foliar spray on the main crop. The intermediate level of insect control was somewhat flexible; insecticide was applied only when the incidence of a certain insect species had reached a certain critical level. The high level of weed control was the same as in the wet season.

In the complete factorial experiments, the farmer's variety was compared to a test variety at three levels of inputs and at the farmers' and the high levels of cultural practices. In these trials seed source, seedling age, spacing, and method of transplanting were held at what was expected to give maximum yield at the high level of cultural practices.

In 1977, minifactorial and supplemental trials were conducted in the sane study area, in order to identify the yield gap and contribution of various factors to the yield gap from a larger sample of farms. A description of each experiment follows.

Minifactorial trials. Each trial had the number of treatments equal to two more than the number of factors being tested: one treatment with all factors at high level; one with all factors at farmers' level, and others with each having all but one factor at the high level. One intermediate treatment consisting of fertilizer at the second intermediate level, weed control at the high level, and insect control at the intermediate level was included in this experiment.

Supplemental trials. Each trial had a minimum of one plot with all factors at the high level. Farmers' yields were measured by crop-cutting the farmers' fields or sampling plot yield from a comparable paddy chosen at the same farm.

Management package experiments. A separate management package experiment was also conducted in sane experimental sites to compare the performance of the farmers' variety with the latest released improved variety under five management packages. In this experiment, all cultural practices were at a presumed maximum yield level, and inputs varied from the farmers' level to the maximum yield level.

Surveys. A number of farmers in the same areas were surveyed in addition to farmers where experiments had been placed in order to learn more about the levels and variability in farmers' use of the factors studied in the experiment. The survey also showed differences between and similarities among farms with experiments and a larger sample of farms.

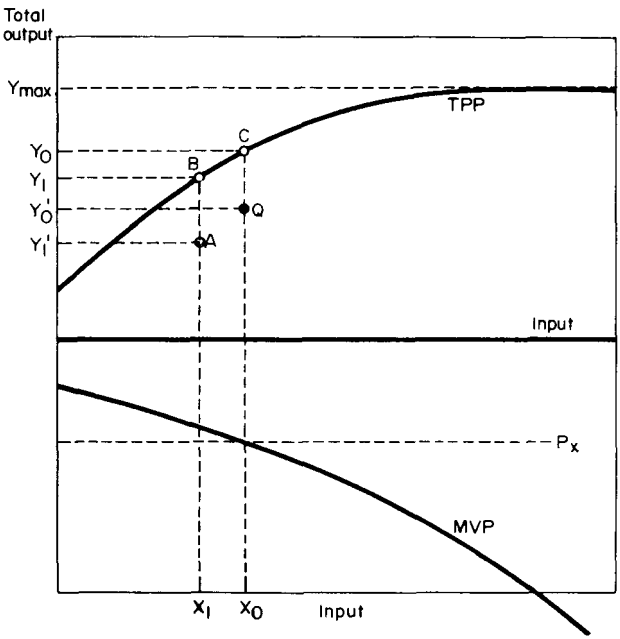
Aside from the experimental cooperators, the sample farmers were randomly selected from among all farmers in the barrios where experiments were located and from the neighboring barrios. One parcel of each farmer's land was studied. For those farmers who had more than one parcel, their largest parcel or the largest area planted to one variety was selected as the "intensive data parcel" for which input and output data were obtained through interview. This was done in order to save time and resources and to have data specific to one parcel. The yield and practices on the experimental farms and those of the randomly selected farmers were compared.

Economic analysis

Costs and returns analyses were conducted on the main test factors in the experiment: fertilizer, insect control, and weed control. The yields, costs and levels of test inputs at the farmer's level were compared to the results of the high input levels. Average prices of inputs actually paid by farmers in the region were used to calculate the costs of inputs on a per hectare basis. In Nueva Ecija, all farmers interviewed were paying fixed rents; so tenure was not a factor affecting optimal input levels. Farmers pay 5% of their output for threshing; so this amount is deducted in evaluating the economics of input use. Labor inputs used by farmers in applying fertilizer, insect control, and weed control were not included in the cost and returns calculation since they were assumed to come from the farm family. Thus, *net returns* in the analysis is the value of output minus the cost of test factors. To determine the economic benefit of each experimental treatment, the output value and the input cost of the farmer's input level were compared to the output value and the input cost of the treatment.

Efficiency analysis. The experimental data were used to estimate a complex production function relating yield to a number of site-specific environmental factors and input levels applied in the trials. A dummy variable involving the simulation of the farmers' practices was included for each treatment. The dummy variable provided a measure of the efficiency of each farmer's input use relative to that achieved by researchers in the trial on his farm.

Figure 2 shows the basic model used to conceptualize the constraints imposed on rice production by technical and allocative inefficiencies in the simple one-inputcase (Mandac and Herdt 1978). Given the production function (TPP), market prices of inputs and outputs, no restriction on input use, profit-maximizingbehavior, and competitive markets, economic theory shows that producers will



2. Basic model used to measure constraints imposed by technical and allocative inefficiencies.

choose to utilize X_0 level of input where its marginal value product (MVP) equals its marginal cost and produce Y_0 level of output. At point C in Figure 2, the farm is both technically and allocatively efficient.

The farm at point Q is technically inefficient in the use of X_0, because its output, Y_0, is lower than Y_0. This farmer is operating below the technically efficient production function. In general, a farmer's actual output, given his actual input levels, would equal potential output only if he operated on the production function. The technical efficiency score is the ratio of his actual output to efficient output, Y'_0/Y_0. All farms have a technical efficiency ranking of 100 or less on this basis, with the lower limit being zero if the farm uses inputs but produces no output.

On the other hand, a farm is allocatively or price efficient if it uses its inputs so as to maximize its profits. In Figure 2, allocative inefficiency occurs with the use of input levels differentfrom X_0 , say the X_1 level of input, which if used in the technically efficient way will produce Y_1(point B). The degree of price inefficiency measured along the technically

efficient function is the ratio $(X_0 - X_1)/X_1$ or $(Y_0 - Y_1)/Y_1$. One may alternatively define price inefficiency along the farmer's present technically inefficient production function, but the more conventional approach is followed.

These concepts can be generalized into the multi-input case as illustrated by Timmer (1970). They have the advantage, as illustrated, of separating the technical from the allocative decision, something that ordinary cost comparisons cannot do. The model also allows estimation of the yield gap as $(Y_{max} - Y_1')$ in Figure 2. With the devised measures above, the yield gap can then be attributed to three factors: economizing behavior, i.e. the desire of farmers to maximize profits rather than yields $(Y_{max} - Y_0)$: allocative inefficiency $(Y_0 - Y_1)$; and technical inefficiency $(Y_1 - Y_1')$. Depending on which of these components is most important, corrective action can be suggested. If artificially distorted prices can be shown to significantly increase the portion of the yield gap due to economizing behavior, it may be possible to recommend that the government remove such distortions. Also, improving our knowledge of what factors are responsible for technical inefficiencies will improve the possibility of their removal.

RESULTS OF AGRONOMIC TRIALS

Farmers' input levels. Results of the 1974 and 1975 trials are discussed in the *Interim report.* In the 1976 wet season, farmers applied, on the average, 57 kg N/ha and 13 kg P_2O_5/ha. Weed control was minimal. Insect control usually consisted of two foliar applications of insecticides and an additional dose of granular insecticides.

In the 1977 wet season, farmers averaged 64 kg N/ha, 30 kg P_2O_5/ha, and 8 kg K_2O/ha of fertilizer. Twenty-five farmers used either handweeding or chemical weed control. All but one of the 37 farmers controlled. Insects by foliar insecticides, averaging 2.3 applications.

Farmers' inputs levels were higher during the 1977 dry season. The average level of fertilizer applied was 93 kg N/ha, 41 kg P_2O_5/ha, and 4 kg K_2O/ha. Insecticide applications averaged two foliar sprays. About half of the farmers supplemented foliar sprays with granular insecticides. They controlled weeds by hand pulling or rotary weeding, or by a combination of chemicals and hand weeding

Yields and yield gap

A severe outbreak of tungro (transmitted by green leafhoppers) prevented farmers from getting high yields in the 1976 wet season.

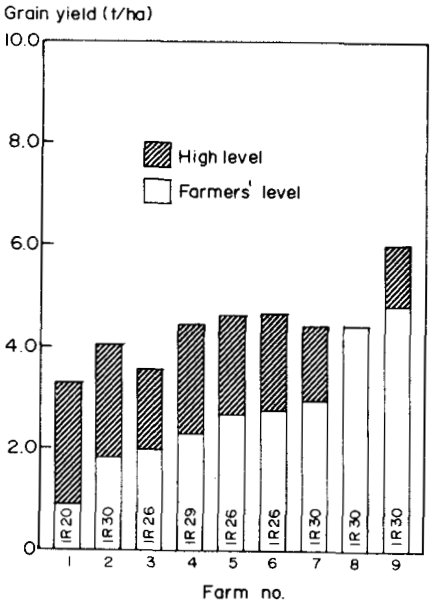
Table 3. Yields at farmers' and high levels of inputs in farmers' fields. Nueva Ecija, Philippines, 1974 – 77.

Year	Sites (no.)		Grain yield (t/ha)		
	Irrigated	Rainfed	Farmers' inputs	High inputs	Yield gap
			Wet season		
1974	7	3	1.8	2.3	0.5
1975	6	5	3.2	3.9	0.7
1976	6	3	2.8	4.4	1.6
1977	28	9	4.0	5.3	1.3
All	47	20	3.4	4.5	1.1
			Dry season		
1975	3	0	4.3	5.2	0.5
1976	9	0	4.0	6.5	2.5
1977	28	0	4.8	7.0	2.2
All	40	0	4.6	6.8	2.2

Insect infestation was observed in some farms as early as the seedling stage. Even varieties such as IR26 and IR30, which were originally thought to be resistant to the tungro virus, were seriously infected. Grain yields at the farmers' levels of inputs were therefore generally low (Table 3). Yields ranged from less than 2 t/ha to 4.8 t/ha, averaging 2.8 t/ha (Fig. 3). The high level of inputs produced yields ranging from 3.3 t/ha to 6 t/ha, with an average of 4.4 t/ha. Yield gaps ranged from zero to 2.4 t/ha, averaging 1.6 t/ha.

In the 1977 wet season, farmers' yields varied from 2.4 t/ha to 6.0 t/ha (Fig. 4), averaging 4.0 t/ha (Table 3). In the complete factorial experiment, the lowest farmer's yield of 2.8 t/ha was obtained on a rainfed farm (farm 5) which suffered from drought, while the same yield in irrigated farm 4 was largely due to typhoon damage before harvesting. With high inputs, yields ranged from 3.2 t/ha to 6.9 t/ha, averaging 5.3 t/ha. The variability in yields at the high input level was caused by typhoon damage in 14 farms, brown planthopper infestation in two farms, and moisture stress at the reproductive stage in three rainfed farms. The average yield gap was 1.3 t/ha.

Yields at the farmers' level of inputs were more variable during the 1977 dry season. They ranged from 3.2 t/ha to 8.6 t/ha (Fig. 5) and averaged 4.8 t/ha (Table 3). One of the two low – yielding



3. Variations in yield gap between farmers' fields. Nueva Ecija, Philippines, 1976 wet season.

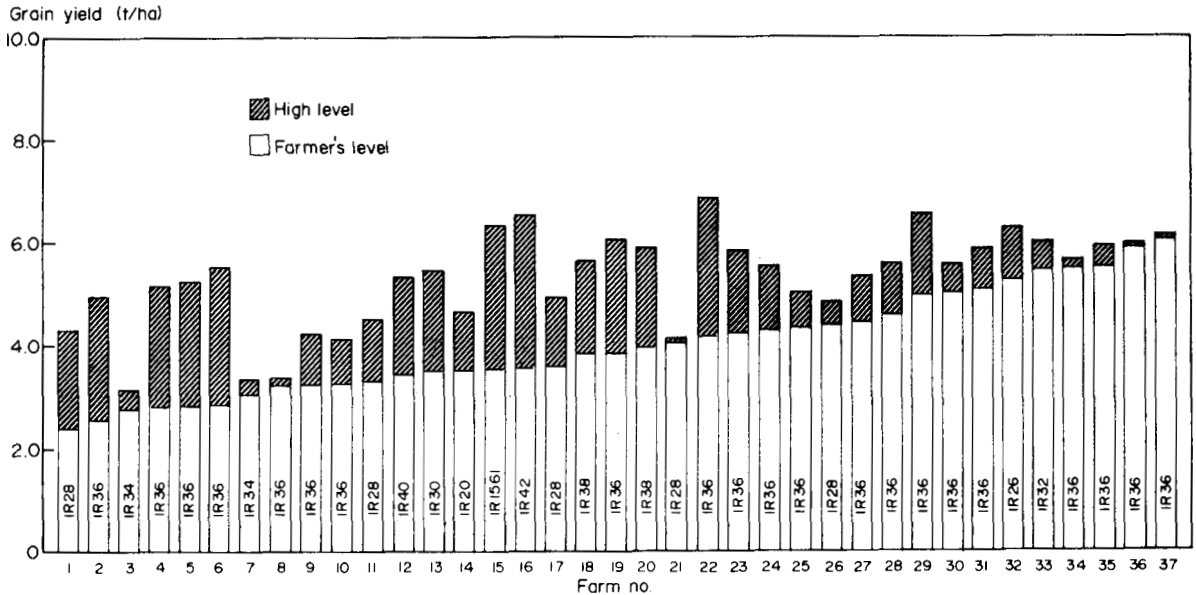
farmers had a high level of stem rot damage at the ripening stage. The highest farmer's yield was recorded on a farm which received 164 kg/ha of fertilizer more than the high test level. Yields with high inputs on the other hand, ranged from 4.7 to 8.9 t/ha, and averaged 7.0 t/ha. The two farms with the lowest yields at high inputs (4.7 t/ha and 5.1 t/ha) also suffered from stem rot at the ripening stage. The average yield gap of 2.2 t/ha was similar to the 2.5 t/ha average yield gap obtained from 9 farms during the 1976 dry season.

Contribution of test factors to the gap

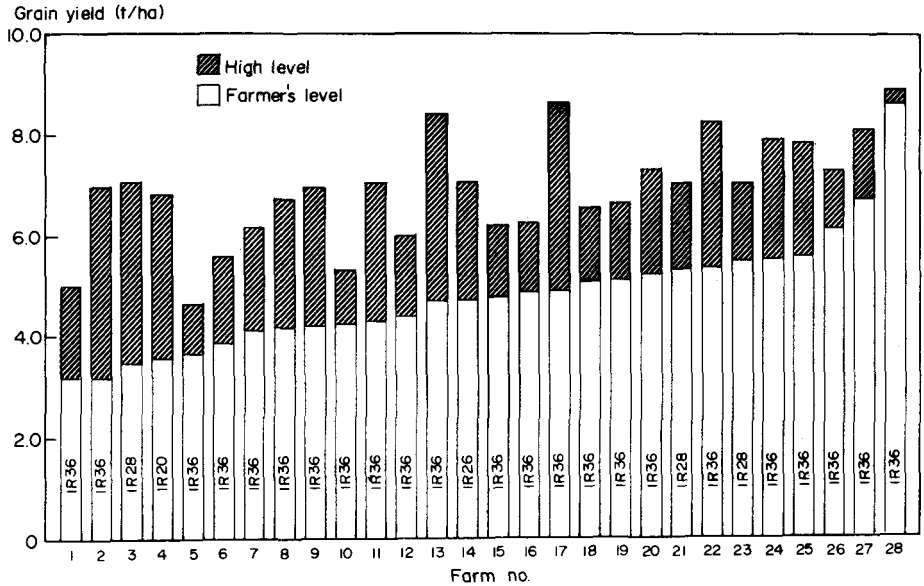
The relative contribution of each test input to the yield gap is given in Table 4. Over four wet seasons, the average yield gap was 1.5 t/ha. Insect control contributed about half, fertilizer about one-third, and weed control less than 10%.

In the 1976 wet season, insect control contributed 62% to the gap and fertilizer contributed the other 38%.

The high level of insect control produced significantly higher yields than the farmers' levels on seven out of nine farms. Yields with intermediate insect control were significantly higher



4. Variations in yield gap between farmers' fields. Nueva Ecija, Philippines, 1977 wet season.



5. Variations in yield gap between farmers' fields. Nueva Ecija, Philippines, 1977 dry season.

than the farmers' levels in five farms. Low farmers' yields in general, were largely due to inadequate protection against insects, particularly the green leafhopper.

Farmers' yields during the 1977 wet season in the complete and minifactorial experiments varied from 2.4 t/ha to 6.0 t/ha, averaging 4.2 t/ha (Table 4). The high level of inputs increased yield by an average of 1.1 t/ha. As in the 1977 dry season, insect control made the greatest contribution to the yield gap - 56% (0.5 t/ha). Fertilizer accounted for 44% (0.4 t/ha), and weed control made no contribution. Weed control practices of the cooperating farmers are therefore considered to have been adequate, but observations indicate that this cultural requirement is still a major constraint to high yield of rice in many farms in the study area.

High insect control outyielded the farmers' and intermediate levels by 0.6 t/ha. Whorl maggots and stem borers during the early growth stages, and leaf rollers, leaf folders, and stem borers from maximum tillering to heading stages, accounted for the yield losses at farmers' and intermediate levels of insect control.

Table 4. Relative contribution of three inputs (insect control, fertilizer, and weed control) towards the improvement of rice yields in farmers' fields. Nueva Ecija, Philippines, 1974–77.

Year	Sites (no.)		Grain yield (t/ha)			Contribution[a] (t/ha)			
	Irrigated	Rainfed	Farmers' inputs	High inputs	Yield gap	Fertilizer	Weed control	Insect control	Residual
				Wet season					
1974	7	3	1.8	2.3	0.5	−0.1	0.2	0.5	−0.1
1975	6	5	3.2	3.9	0.7	0.3	0.1	0.2	0.1
1976	6	3	2.8	4.4	1.6	0.6	0.0	0.9	0.1
1977	18	6[b]	4.2	5.3	1.1	0.4	0.0	0.5	0.2
All	37	17	4.8	6.3	1.5	0.5	0.1	0.7	0.2
				Dry season					
1975	3	0	4.3	5.2	0.9	0.2	0.5	0.2	0.0
1976	9	0	4.0	6.5	2.5	1.4	0.3	0.8	0.0
1977	16	0[b]	5.2	7.3	2.1	0.9	0.2	1.0	0.0
All	28	0	4.7	6.8	2.1	1.0	0.3	0.9	0.0

[a] Measured as yield decrease from high input due to a reduction from high to farmers' levels of each input.

[b] Includes only complete factorials and minifactorials, so number of sites differs from Table 3.

Results from 3 dry seasons show that fertilizer accounted for about one-halfof the average yield gap of 2.1 t/ha. Insect control contributed about 40%, and weed control contributed about 10% to the yield gap.

1977 dry season yields at farmers' levels of inputs in the complete and minifactorial experiments ranged from 3.2 t/ha to 8.6 t/ha, averaging 5.2 t/ha. The high level produced yields ranging from 5.4 to 8.9 t/ha, averaging 7.3 t/ha. The average yield gap was 2.1 t/ha (Table 4). Improved insect control contributed 48% (1.0 t/ha) to the yield gap, while fertilizer accounted for 43% (0.9 t/ha). The lower yield gain from fertilizer compared with the previous dry season was due to a higher level of nitrogen (106 kg N/ha) application by the cooperating farmers. Improved weed control did not appreciably increase yield, contributing only 9% (0.2 t/ha) to the yield gap.

Table 5. Farmers' levels and intermediate levels of fertilizer. Nueva Ecija, Philippines, 1976–77.

Sites (no.)		Fertilizer (kg/ha)								
		Farmers'			Intermediate I			Intermediate II		
Irrigated	Rainfed	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
				1976 wet season						
6	3	57	13	0	40	20	10	70	30	20
				1977 wet season						
8	2	82	35	10	40	20	10	70	30	20
				1976 dry season						
9	0	76	34	1	50	20	10	100	30	20
				1977 dry season						
7	0	125	36	0	50	20	10	100	30	20

Due to heavy stem borer damage with farmers' insect control practices on most farms, the high level of insect control produced significantly higher grain yields than the farmers' and intermediate levels. Grain yields were similar between farmers' and intermediate levels of insect control. Rat damage occurred in only two out of seven farms.

Fertilizer efficiency at intermediate levels

In 1976 and 1977, the first intermediate fertilizer levels were lower than the levels many farmers applied (Table 5) . This gave an opportunity to compare the efficiency of farmers' fertilizer application techniques with the researchers' techniques and lower quantities.

Averaged across all levels of other factors, increasing fertilizer generally resulted in higher yields (Table 6). The 1976 wet season yields responded only modestly to increasing fertilizer levels, but there was an average of 0.5 t/ha yield increase from the farmers' to the second intermediate levels. Although the farmers' average level of fertilizer N was higher than the first

Table 6. Grain yield with different levels of fertilizer. Nueva Ecija, Philippines, 1976 – 77.

Year	Sites (no.)		Grain yield[a] (t/ha)			
			Fertilizer			
	Irrigated	Rainfed	F	I-1	1 – 2	H
			Wet season			
1976	6	3	3.3	3.5	3.8	3.9
1977	8	2	4.8	4.9	5.2	5.2
			Dry season			
1976	9	0	4.5	4.6	5.5	5.8
1977	7	0	5.8	5.5	6.4	6.7

[a]F = farmers' level, I = intermediate level, H = high level.

intermediate level (I-l), an increase in grain yield of 0.2 t/ha was obtained by researchers, apparently because fertilizer application was more efficient. Weed and insect control at farmers' yields with farmers' levels of nitrogen compared with the intermediate and high nitrogen levels substantiates the conclusion. On the average, I-1 with 40 kg of N yielded 0.7 t/ha more than the two farmers who applied 50 kg/ha of N (Table 7). Appendix Tables 1 through 4 give the individual farm data (by season) that show this kind of inefficiency.

In the 1977 wet season, yields with farmers' fertilizer and first intermediate fertilizer levels were similar, despite farmers using 20 kg/ha more fertilizer (Table 7). The farmers' fertilizer levels on 5 farms were about 40 kg/ha higher than the second intermediate level, an increase of 0.7 t/ha was still obtained by the researchers. Similar results hold for comparisons at high levels of weed and insect control (Table 7).

Four farmers in the 1976 dry season applied more than the I-1 rate and less than the 1 – 2rate of fertilizer, hut the researchers still got slightly higher yields. Two farmers applied more than the I – 2 level but had yields 0.8 t/ha lower than the researchers.

In the 1977 dry season, five farmers used a higher level of fertilizer than the 1 – 2 level, but a yield advantage of 0.3 t/ha

Table 7. Comparisons of farmers' and intermediate fertilizer levels showing relative efficiency of fertilizer use. Nueva Ecija, Philippines, 1976–77.

Year	Level of insect and weed control	Performance of farmers' and test plots where farmers' fertilizer was: Higher than I-1, lower than 1 – 2					Higher — than1 – 2				
		Farms (no.)	N (kg/ha)		Yield (t/ha)		Farms (no.)	N (kg/ha)		Yield (t/ha)	
			Farmers'	I-1	Farmers'	I-1		Farmers'	I – 2	Farmers'	I – 2
						Wet season					
1976	Farmers'	2	50	40	2.9	3.6	4	96	70	3.5	3.7
	High		50	40	4.1	4.1		96	70	4.1	4.4
1977	Farmers'	4	60	40	5.1	5.0	5	109	70	4.1	4.8
	High		60	40	5.4	5.7		109	70	4.9	5.3
						Dry season					
1976	Farmers'	4	74	50	3.4	3.6	2	126	100	5.0	5.8
	High		74	50	4.7	5.0		126	100	5.9	7.2
1977	Farmers'	1	81	50	4.9	4.8	5	152	100	6.0	6.3
	High		81	50	6.6	6.0		152	100	6.4	7.4

was obtained with the researchers' method. This is an indication of poor method and timing of fertilizer nitrogen application used by the cooperating farmers.

Effect of cultural practices and variety

Table 8 shows the yield differences between the high and the farmers' cultural practices. On the average, the farmers' cultural practices outyielded the high cultural practices by 0.1 t/ha in the 1976 wet season.

On one farm, there was a significant difference of 0.6 t/ha in the 1976 wet season because the farmer's variety, IR30, when grown under high cultural practices with farmer's insect control, suffered seriously from tungro infection. The same variety with all cultural practices held at the farmer's level showed a surprisingly high degree of resistance to tungro.

Table 8. Yields with cultural practices at a high level compared with the farmers' levels for input packages in farmers' fields. Nueva Ecija, Philippines, 1976–77.

Sites (no.)		Level of cultural practices	Grain yield [a] (t/ha)			
Irrigated	Rainfed		Farmers'	Intermediate	High	Av
			1976 wet season			
6	3	Farmers'	3.4	4.3	5.1	4.3
6	3	High	3.6	4.2	4.8	4.2
			1977 wet season			
8	1	Farmers'	4.5	4.5	5.6	4.8
8	1	High	4.2	4.3	5.3	4.6
			1976 dry season			
9	0	Farmers'	4.2	4.6	6.5	5.1
9	0	High	4.0	4.5	6.3	4.9
			1977 dry season			
7	0	Farmers'	5.4	5.2	8.1	6.2
7	0	High	5.3	4.8	7.2	5.8

[a]Data are averages of test and farmers' varieties.

Farmers' cultural practices during the 1977 wet season gave a yield advantage of 0.2 - 0.3 t/ha Over the high cultural practices. In the dry season, however, the yield advantage with farmers' practices was much higher (0.4 t/ha). Lower yields with high cultural practice will be due to rat damage and bird damage, since these plots were harvested much later than the plots with farmers' cultural practices. It is also hypothesized that the farmers' closer spacing than the recommended 20 x 20 cm spacing contributed to sane degree to the yield difference between cultural practices.

Varietal differences were tested at all farms by comparing the yield performance of the farmers' variety with that of a test variety. Four farmers grew IR30, three used IR26, one grew IR20, and another. grew a glutinous variety, IR29. The test variety was IR36 in all farms. As shown in Table 9, the test variety outyielded the farmers varieties across all management levels in the 1976 wet season. The superior performance of IR36 over the farmers' varieties was primarily due to its high – yielding characteristic and excellent resistance to tungro.

In the 1977 wet season, eight farmers grew IR36, and one farmer used IR32. The test variety was IR42. On the average, farmers' varieties outyielded the test variety by 0.4 t/ha. Serious grain losses of IR42 were caused by typhoon damage, although in some cases, rats were a problem when the test variety was the only crop left in field.

There was no yield difference, on the average, between farmers' and test varieties in the 1977 dry season. However, in two farms the test variety IR26 produced significantly higher yields than the farmers' variety IR36.

Management package project (MPP)

An additional series of experiments was conducted to evaluate intermediate levels between farmers' sets of practices and the improved or recommended set of practices. The incremental steps between treatments usually involved a simultaneous change in more than one input. Input levels are shown in Table 10. Subsoil placement of insecticide was tried at M_3 and M_4 levels. Detailed methodology is described elsewhere (De Datta et al 1976).

In the 1976 wet season, average grain yield for five management packages for the test variety IR36 was 0.5 t/ha higher than the average grain yields for the farmer's variety IR30 (Table 11). Comparing the yield performance of both varieties in each management package level, the test variety gave higher yields only at the M_1 and M_2 levels.

Table 9. Yields of farmers' varieties compared with test varieties for input packages grown at high and farmers' levels of cultural practices. Nueva Ecija, Philippines, 1976–77.

Sites (no.)			Grain yield (t/ha)			
Irrigated	Rainfed	Variety[a]	Farmers'	Inter-mediate	High	Av
		1976 wet season				
6	3	Farmers'[b]	3.0	3.6	4.4	3.7
6	3	Test	4.1	4.8	5.5	4.8
		1977 wet season				
8	1	Farmers'[c]	4.6	4.6	5.6	4.9
8	1	Test	4.1	4.1	5.3	4.5
		1976 dry season				
9	0	Farmers'[d]	4.0	4.5	6.3	4.9
9	0	Test	4.1	5.0	6.3	5.1
		1977 dry season				
7	0	Farmers'[e]	5.3	5.0	7.6	6.0
7	0	Test	5.4	5.0	7.7	6.0

[a] Test varieties: IR36 in 1976 wet and dry seasons; IR42 in 1977 wet season; IR26 in 1977 dry season.
[b] Refers to IR20, IR26, IR29 and IR30.
[c] Refers to IR36 and IR32.
[d] Refers to IR1561, IR30, and IR26.
[e] Refers to IR36.

In the 1977 wet season, the management package experiment was conducted on two irrigated farms. The farmers' average levels of fertilizer were about the M_2 level for N, the M_4 level of P_2O_5, and about half of the M_3 level for K_2O (Table 10). Average levels of farmers' insect and weed control were at the M_2 level. The farmers used IR36, and the test variety was IR42, at that time the latest released variety in the Philippines.

Average yields of farmers' and test varieties rose steadily from M_2 to M_5 package levels (Table 11). On farm 1 the test variety significantly outyielded the farmers' variety at all managanent

Table 10. Average levels of farmers' inputs and four input management packages. Nueva Ecija, Philippines, 1976 – 77.

Sites (no.)		Package level[a]	Fertilizer (kg/ha)			Insect control[b]					Weed control[c]	
						Seedbed		Field				
Irri-gated	Rain-fed		N	P_2O_5	K_2O	F	G	R	F	G	M	C
					1976 wet season							
1	0	M_1	49	29	0	1	0	0	2	1	0	0
		M_2	40	10	0	0	0	0	2	0	1	0
		M_3	60	20	20	0	1	1	0	0	0	1
		M_4	80	30	30	2	0	1	0	1	1	1
		M_5	100	40	40	0	2	0	1	4	1	1
					1977 wet season							
2	0	M_1	43	27	11	0	0	0	3	0	1	0
		M_2	40	10	0	0	0	0	3	0	1	0
		M_3	60	20	20	0	1	1	0.5	0	0	1
		M_4	80	30	30	0	2	1	1	1	0	1
		M_5	100	40	40	0	2	0	2.5	4	1	1
					1976 dry season							
2	0	M_1	83	36	3.5	0.5	0	0	0.5	0.5	1	0.5
		M_2	40	10	0	0	0	0	20		1	0
		M_3	80	20	20	1	0	0	21		0	1
		M_4	120	30	30	2	0	0	22		0	1
		M_5	160	40	40	2	1	0	14		1	1
					1977 dry season							
1	0	M_1	132	27	0	0	0	0	3	0	1	0
		M_2	40	10	0	0	0	0	2	0	1	0
		M_3	80	20	20	0	1	1	0	0	0	1
		M_4	120	30	30	1	1	1	1	0	0	1
		M_5	160	40	40	0	2	0	1	4	1	1

[a] M_1 = farmers' level of application of the three inputs. $M_2 - M_5$ = levels of fertilizer, insect control, and weed control as listed in this table

[b] Data show average number of applications. F = foliar, G = granular, R – root zone placement of liquid carbofuran.

Data show average number of applications. M = mechanical weeding, either by hand or rotary weeder; C = chemical weedicide.

Table 11. Average grain yield of farmers' varieties and test varieties compared at farmers' and four input management packages and grown under high levels of cultural practices. Nueva Ecija, Philippines, 1976 – 77.

Sites (no.)			Grain yield[b] (t/ha)					
Irrigated	Rainfed	Varietya	M_1	M_2	M_3	M_4	M_5	Av.
		1976 wet season						
1	0	Farmers'[c]	3.8	3.1	4.8	4.8	4.8	4.3
1	0	Test	5.0	5.2	4.5	4.4	4.9	4.8
		1977 wet season						
2	0	Farmers'[d]	4.6	4.3	5.1	5.3	5.4	4.9
2	0	Test	4.8	4.8	5.2	5.6	6.3	5.3
		1976 dry season						
2	0	Farmers'[e]	4.3	4.6	5.2	5.6	6.5	5.2
2	0	Test	4.8	5.0	5.6	6.0	6.7	5.6
		1977 dry season						
1	0	Farmers'[d]	5.4	4.4	5.7	6.1	7.8	5.9
1	0	Test	5.6	4.2	5.7	6.4	7.3	5.9

[a] Test varieties: IR36 in 1976 wet and dry seasons; IR42 in 1977 wet season; IR26 in 1977 dry season.

[b] M_1 = farmers' level; M_2 - M_5 = management package levels of fertilizer, insect control and weed control as shown in Table 10.

[c] Refers to IR30.

[d] Refers to IR36.

[e] Refers to IR30 and IRl561.

levels. The yields of the test variety were comparable at M_1 and M_2, but as the package level was raised to M_5, a yield benefit was obtained with the test variety. On the other farm, however, the farmers' variety (IR36) gave higher yields than the test variety (IR42), which suffered serious grain losses from a typhoon, while the farmers' variety was harvested before the typhoon.

During the 1977 dry season, the same management experiment was conducted on one pump – irrigated farm. The farmer used a higher nitrogen level than the M_4 level and about the same rate of

phosphate as the M_4. Insect and weed control measures of the farmer were about the M_2 level.

Yields of farmers' (IR36) and test (IR26) varieties rose steadily from the M_2 level to the M_5 level. Average yield at the farmers' level (M_1) was not significantly different from that at M_3 despite the higher amounts of N and P fertilizer used by the farmer. This indicates that the farmer did not apply fertilizer properly. Farmers' insect control measures were inadequate because of stemborer incidence at heading. No varietal differences were noted except at M_5, where IR36 gave significantly higher yields than IR26.

ECONOMIC ANALYSIS

Table 12 shows comparison of the economic performance of the high input level and the farmers' input levels for seven seasons. Farmers used roughly one-third the maximum input level in the wet season. Both farmers and researchers used lower input levels in the wet season than in the dry. Aside from this, there were year-to-year differences in the inputs used by farmers that reflect changes in farmers and their practices, and differences in the

Table 12. Canparison of anticipated maximum yield level of inputs with farmers' levels. Nueva Ecija, Philippines, 1974-77.

Year	Sites (no.)	Cost of inputs (₱/ha)		Yields (t/ha)		Net returns[a] (₱/ha)	
		Farmers'	Maximum	Farmers'	Maximum	Farmers'	Maximum
				Wet season			
1974	10	309	1654	1.8	2.3	1401	531
1975	11	412	1191	3.2	3.9	2628	2514
1976	9	485	1308	2.8	4.4	2414	3248
1977	24	676	1455	4.2	5.3	2314	3580
All	54	485	1386	3.3	4.3	2670	2743
				Dry season			
1975	3	867	1764	4.3	5.2	3218	3176
1976	9	720	1683	4.0	6.5	3764	5604
1977	16	862	1969	5.2	7.3	5066	6353
All	28	817	1854	4.7	6.8	4450	5772

[a] Exchange rate used: US$l.00 = ₱7.35.

Table 13. Prices of inputs reported by farmers. Nueva Ecija, Philippines, 1974 – 77.

Input	Unit	Price per unit (P)						
		Wet				Dry		
		1974	1975	1976	1977	1975	1976	1977
Fertilizer								
Urea	50 kg	70.00	90.50	91.00	82.50	82.70	90.00	82.50
14 – 14 – 14	50 kg	61.90	67.50	71.00	67.20	60.20	66.00	67.20
16 – 20 – 0	50 kg	63.00	72.35	71.00	72.20	64.95	72.00	72.20
Insecticide								
Furadan 3G	16.7 kg	85.00	91.10	105.00	110.00	89.90	86.50	111.30
Hytox	0.5 kg	25.45	30.00	25.00	-	25.45	27.00	25.00
Lindane 6G	25 kg	76.00	103.00	93.00	72.00	90.00	81.00	85.00
Weed control								
Hand weeding	1 ha	87.50	87.50	90.00	129.00	87.50	87.50	174.00
Rotary weeding	1 ha	30.00	30.00	42.00	-	30.00	30.00	80.00
2,4 D (G)	25 kg	67.50	61.00	60.00	60.00	64.50	61.00	66.00
Saturn D	15 kg	67.80	63.50	-	-	67.80	65.00	75.00
Agroxone	1 liter	27.00	30.70	-	-	-	30.70	27.00
Palay	1 kg	1.00	1.00	1.09	1.00	1.00	1.18	1.20

maximum yield input cost that reflect changes in researchers' judgments as to what inputs would give maximum yields. Input prices were relatively constant over the seasons shown. Thus, prices cannot account for much of the cost variability (Table 13).

Average net returns of farmers' and high inputs were nearly identical when averaged over four wet seasons. Thus, despite generally increased yields and increased net returns during some seasons, it would not pay farmers to utilize the high levels of inputs during the wet season. In the dry season there was an average increase of ₱1322/ha in net returns, suggesting that at least part of the 2.2 t/ha yield gap could be recovered economically.

A disaggregation of the three technological components -- weed control, insect control, and fertilizer -- provide sane insights into why the high input levels are more profitable in the dry than in the wet season.

Weed control. In the wet season, the anticipated maximum yield level of weed control had only a modest impact on yields with rather low benefit–costratios (Table 14). In Over 50% of the cases, net returns were lower with high weed control than with farmers' weed control. In the dry season, the high weed control increased costs and net yields by an average of ₱81/ha and 0.25 t/ha, respectively, and gave an average benefit–costratio of 3.6. However, absolute increases in net returns were small, exceeding 10% of farmers' levels in only 11% of the cases. In both wet and dry seasons, over one–third of the cases showed lower net returns with the high input, compared with the farmers' inputs. Thus, it appears that there is relatively little economic incentive for farmers to use the high level of weed control.

Insect control. The anticipated maximum yield level of insect control was set very high in 1974, the first wet season of research. This proved to be too costly to give a profitable return, and so it was subsequently reduced (Table 15). Results in the 1975 wet season were very similar to the first season, even though input levels were reduced. In over 80% of the cases

Table 14. Economic comparison of the tested maximum yield level of weed control and farmers' levels. Nueva Ecija, Philippines, 1974–77.

Year	Sites (no.)	Input cost (₱/ha)		Increase resulting from high inputs			B–C ratio of increased inputs
		Farmers'	High	Yield[a] (t/ha)	Output value (₱/ha)	Net returns (₱/ha)	
				Wet season			
1974	10	29	110	0.19	190	109	2.35
1975	11	29	103	0.09	90	16	1.22
1976	9	58	154	0.00	0	–96	0.00
1977	24	85	191	0.00	0	–106	0.00
All	54	59	152	0.09	76	–17	0.82
				Dry season			
1975	3	125	169	0.47	470	426	10.68
1976	9	81	147	0.29	342	276	5.18
1977	16	138	235	0.19	228	131	2.35
All	28	118	199	0.25	291	210	3.59

[a] The share paid to the thresher has been deducted (5% of the total harvest).

Table 15. Economic comparisons of the tested maximum yield level of insect control and farmers' levels. Nueva Ecija, Philippines, 1974 – 77.

Year	Sites (no.)	Input cost (₱/ha) Farmers'	Input cost (₱/ha) High	Increase resulting from high inputs: Yield[a] (t/ha)	Output value (₱/ha)	Net returns (₱/ha)	B – C ratio of increase inputs
				Wet season			
1974	10	74	1007	0.48	480	– 453	0.51
1975	11	96	632	0.19	190	– 346	0.35
1976	9	140	537	0.86	937	540	2.36
1977	24	219	669	0.48	480	30	1.07
All	54	154	702	0.48	497	– 51	0.91
				Dry season			
1975	3	125	809	0.19	190	– 494	0.28
1976	9	195	735	0.76	897	353	1.65
1977	16	157	948	0.95	1140	349	1.44
All	28	165	864	0.81	960	261	1.37

[a] The share paid to the thresher has been deducted (5% of the total harvest).

in the two seasons, net returns were lower with high insect control inputs than with low insect control inputs, even though average yields had been increased. In 1976, the situation was reversed. The benefit – cost ratio rose to 2.5 and net returns increased by more than 10% in two – thirds of the cases.

In the dry season, although yield increases averaged 0.8 t/ha from the high insect control levels, the costs of achieving those increases were such that benefit – cost ratios averaged less than 1.7 in each season. The average chance of increasing net returns by more than 10% was somewhat less than the average chance of decreasing net returns.

Intermediate levels of insect control with a lower cost than the maximum levels tested in the experiments, but with greater protection than farmers were applying, were tested in 1976 and 1977. These intermediate levels had little effect in the dry season (Table 16). In the wet season of 1976 the intermediate insect control saved 0.6 t/ha, with a benefit – cost ratio of 9.4. The 1977 wet season produced an opposite result. The average yield

Table 16. Economic comparisons of the tested intermediate level of insect control and farmers' levels. Nueva Ecija, Philippines, 1976–77.

Year	Sites (no.)	Input cost (₱/ha)		Increase resulting from intermediate inputs			B–C ratio of increased inputs
		Farmers'	Intermediate	Yield[a] (t/ha)	Output value (₱/ha)	Net returns (₱/ha)	
				Wet season			
1976	9	140	206	0.57	621	555	9.4
1977	9	184	184	–0.38	–380	–380	neg[b]
All	18	162	195	0.09	121	88	3.67
				Dry season			
1976	9	191	176	0.09	106	121	n.a.[c]
1977	7	191	331	–0.09	–108	–248	neg
All	16	191	243	0.01	12	–40	0.23

[a]The share paid to the thresher has been deducted (5% of the total harvest).

[b]neg = negative.

[c]Intermediate level is lower than the farmers' level so concept is not applicable.

using farmers' input level was greater than the intermediate levels, resulting in a negative benefit–costratio. Thus, neither the high nor the intermediate level of insect control gave a consistent economic advantage.

Fertilizer. The seven typhoons that passed over the experimental area during the 1974 wet season caused lodging in the plots with high fertilizer; so farmers' input plots had higher yields than the high–input plots in that season (Table 17). The high level of fertilizer was reduced somewhat the next year but was raised even higher than originally in 1976 and 1977. The high fertilizer level was marginally profitable in the 1975 and 1977 wet seasons but raised net returns by more than 10% in only one–third of the cases and reduced net returns just as frequently. Overall, the average increase in net returns was only ₱27/ha. The high level of fertilizer is just as likely to reduce yields as it is to significantly increase them in the wet season.

Table 17. Economic comparison of the anticipated maximum yield level of fertilizer and farmers' levels. Nueva Ecija, Philippines, 1974 – 77.

Year	Sites (no.)	Input cost (₱/ha)		Increase resulting from high inputs			B – C ratio of increased inputs
		Farmers'	High	Yield[a] (t/ha)	Output value (₱/ha)	Net returns (₱/ha)	
				Wet season			
1974	10	206	537	– 0.09	-90	-421	neg[b]
1975	11	287	456	0.29	290	121	1.72
1976	9	287	617	0.57	621	291	1.88
1977	24	372	595	0.38	380	157	1.70
All	54	272	560	0.31	315	27	1.09
				Dry season			
1975	3	617	786	0.19	190	21	1.12
1976	9	448	801	1.33	1569	1216	4.44
1977	16	567	786	0.86	1032	813	4.71
All	28	534	791	0.95	1114	857	4.33

[a] The share paid to the thresher has been deducted (5% of the total harvest).

[b] neg = negative.

The lower of the two intermediate levels included in the 1976 and 1977 experiments cost approximately the same as farmers' levels. The economics of the higher intermediate level is analyzed in Table 18. In the 1976 wet season the intermediate level raised yield considerably and generally increased returns, although in one – third of the cases returns decreased. In 1977 the cost of fertilizer used in the higher intermediate level was less than the average farmers' level, and there was an increase in profit. In 33% of the sites profits were lower with intermediate fertilizer than with farmers' level.

In each of the three dry seasons, on the other hand, average yields and net returns were increased over farmers' levels by applying both the intermediate and high levels of fertilizer. With the high level, there was a 50% chance of increasing net returns by more than l0%, an average benefit – costratio of 4.3, and only a 10% chance of experiencing losses.

Table 18. Economic comparison of one tested intermediate level of fertilizer and farmers' levels. Nueva Ecija, Philippines, 1976-77.

Year	Sites (no.)	Input cost (P/ha)		Increase resulting from intermediate inputs			B-C ratio of increase inputs
		Farmers'	Inter-mediate	Yield[a] (t/ha)	Output value (P/ha)	Net returns (P/ha)	
				Wet season			
1976	9	287	441	0.48	523	369	3.40
1977	9	485	419	0.38	380	446	n.a.[b]
All	18	386	430	0.43	452	408	10.27
				Dry season			
1976	9	456	551	0.95	1121	1026	11.8
1977	7	544	537	0.57	684	691	n.a.
All	16	492	544	0.76	930	878	17.88

[a]The share paid to the thresher has been deducted (5% of the total harvest).

[b]Intermediate level is lower than the farmers' level so concept is not applicable.

Thus, in the wet season, only the intermediate level of fertilizer was more profitable than farmers' practices, while in the dry season the high level was more profitable.

Economically recoverable gap

Table 19 summarizes the results of the economic analysis of the data from three years. Using cost and returns analysis discussed above, the particular canbination of test factors that *ex post* was most often economically superior to the farmers' levels was identified. For the wet season, these levels were the farmers' weed control, the intermediate insect control, and the higher of the two intermediate fertilizer levels. In the dry season, the economically superior levels were: farmers' weed control, intermediate insect control, and high fertilizer. In 1975 the experimental design was somewhat different; other combinations of inputs were tested as described in the IRRI Annual Report for 1975. The economically superior level identified in those trials

Table 19. Total gap and economically recoverable gap (ERG) as determined from three years of experiments[a] in farmers' fields. Nueva Ecija, Philippines, 1975–77.

Year	Sites (no.)	Yield (t/ha) Farmers'	High	Yield gap	Intermediate[b]	Economically recoverable gap (ERG) (t/ha)	ERG as % of total gap
				Wet season			
1975	11	3.2	4.4	1.2	3.7	0.5	42
1976	9	2.8	4.4	1.6	3.9	1.1	69
1977	9	4.6	5.7	1.1	5.0	0.4	36
All	29	3.5	4.8	1.3	4.2	0.7	50
				Dry season			
1975	3	4.4	7.0	2.6	5.6	1.6	62
1976	9	4.0	6.5	2.5	5.6	1.5	63
1977	7	5.4	7.9	2.5	6.0	0.6	25
All	19	4.6	7.1	2.5	5.7	1.1	44

[a]Experiments conducted by IRRI Agronomy Department.

[b]For 1976 and 1977 defined as farmers' weed control level, intermediate insect control level and, in the wet season the higher intermediate level, in the dry season the maximum fertilizer level. In 1975, management package level M_3 in wet season and M_4 in dry season (IRRI Annual report 1975, p. 312).

is shown in Table 19. In the wet season the total yield gap was about 1.3 t/ha, and the economically recoverable portion was 0.7 t/ha. In the dry season, the total gap was 2.5 t/ha and the economically recoverable portion was 1.1 t/ha. Thus, the economically recoverable gap was nearly twice as large in the dry season as in the wet season.

Variability in performance

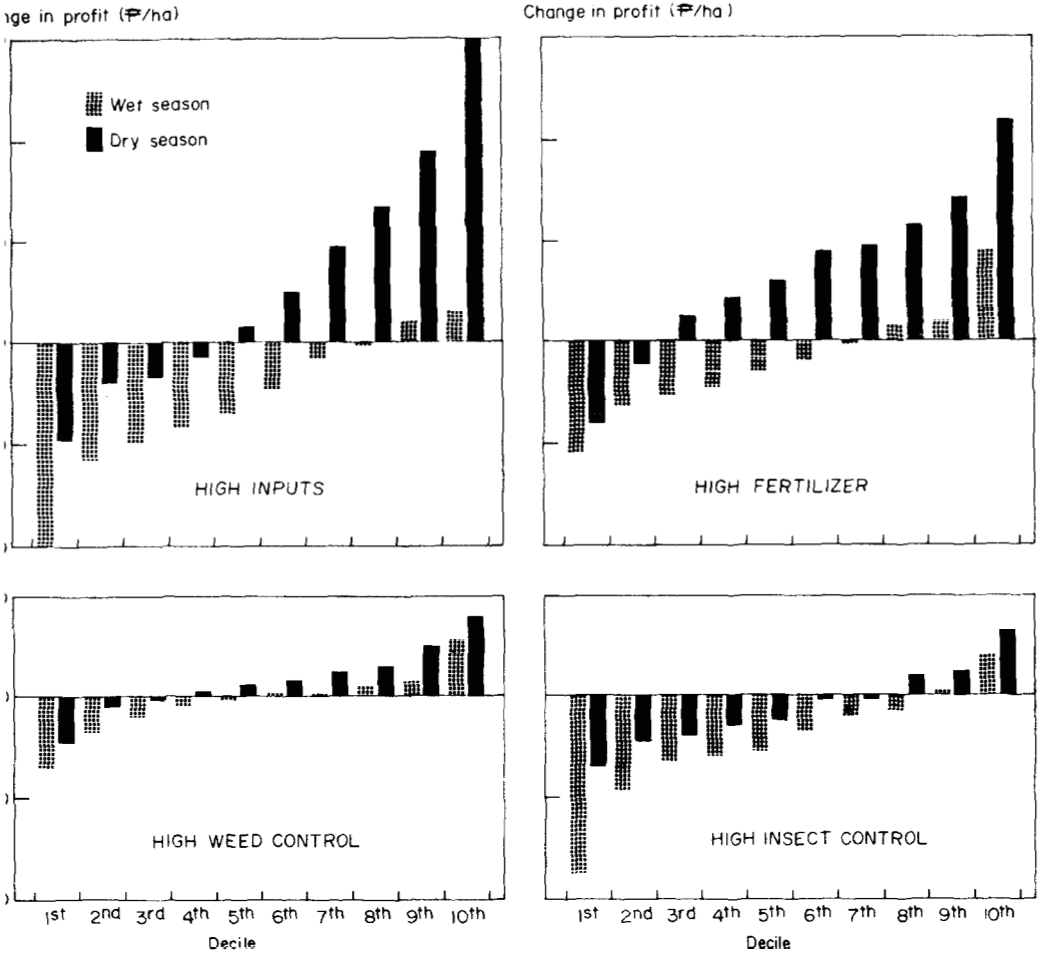
Experiments conducted over the four years have shown considerable year-to-year variability in results. It is hypothesized that inconsistency in yield performance may be one factor keeping farmers from using technologies that appear to be profitable in a single year.

There are clear indications that the maximum yield level of inputs is more risky in the wet season than in the dry season. Although the high inputs increased profits at most sites in the 1976 wet season, in 60% of the experiments the maximum input level gave lower profits than the farmers' inputs (Table 20). In only 25% were net returns increased by at least 25% above farmers' returns (not shown in the table). In contrast, the high input level gave higher yields than the farmers' inputs in 74% of the dry season experiments.

Figure 6 illustrates the substantial difference in the reliability of the high-input technology between the dry and wet seasons. The figure shows the average difference in net returns for each decile grouping of experiments arrayed by the difference in net returns between farmers' and high levels. In this figure the disastrous 1974 wet season was eliminated. Even then, during the other wet seasons in the poorest 10% of experiments, profits were about ₱1400/ha lower with the high input technology than with farmers' technology. The change in profit for the second, third, fourth, and fifth deciles were all negative during the wet season, In contrast, only the poorest 30% of trials in the

Table 20. The proportion of sites in which application of the high level of inputs led to decreased net returns. Nueva Ecija, Philippines, 1974-77.

Year	% of sites where specified level increased net returns compared to farmers'					
	High all inputs	High weed control	High insect control	Inter-mediate insect control	High fertilizer	Intermediate fertilizer
				Wet season		
1974	0	60	20	-	0	-
1975	27	44	18	-	55	-
1976	88	22	89	89	56	44
1977	56	22	56	22	56	67
All	39	44	44	56	41	55
				Dry season		
1975	67	67	0	-	67	-
1976	67	67	67	56	89	89
1977	86	43	71	14	86	86
All	74	58	58	38	a4	88



6. Changes in profit (₱/ha) obtained from high inputs compared with farmers' inputs in 29 wet season and 19 dry season trials. Nueva Ecija, Philippines, 1975–77. Average results grouped by deciles (Experiments conducted by IRRI Agronomy Department).

dry season resulted in profit reductions, and in the other 70% of trials the profit increases were much higher than in the wet season.

The high level of insect control is clearly more risky in the dry season than in the wet and is more risky than weed control in either season. The high level of weed control offers relatively

low added profit, even in the most profitable situations. Maximum fertilizer levels in the dry season, on the other hand, add substantially to profit in all but 10% of the cases.

Perceived constraints

The analysis suggests that there is significant potential for profitably increasing yields in the areas represented by the experiments in Nueva Ecija by properly applying higher rates of fertilizer in the dry season. Farmers were asked why they were not using higher fertilizer rates in 1975–76 and 1976–77 (Table 21). Several reasons were given for not using higher levels in the wet season, but the analysis shows that higher rates would not be profitable. In the dry season, the farmers gave two main, reasons; one group indicated lack of capital; a second group indicated that they believed they were using enough fertilizer.

The input levels and yields reported by the two groups were compared (Table 22). In both the wet and the dry seasons, the difference in input levels was small, but in the expected direction.

Table 21. Responses given by surveyed farmers to the question of why they were unwilling to apply higher fertilizer rates. Nueva Ecija, Philippines, 1975–77.

Reason	Wet season				Dry season			
	1975		1976		1976		1977	
	No	%	No	%	No	%	No	%
Lack of capital	43	61	31	62	53	75	26	43
Used high enough rate[a]	14	20	5	10	16	23	28	47
Plants may lodge[b]	3	4	7	14	0	0	0	0
Plants infected by tungro	0	0	6	12	0	0	0	0
Varieties don't require more	1	2	1	2	0	0	0	0
No response	2	3	0	0	1	1	5	8
Others[c]	7	10	0	0	1	1	1	2
Total	70	100	50	100	71	100	60	100

[a] Or used rate recommended by the technicians.

[b] Or soil is still fertile; additional fertilizer will encourage vegetative growth.

[c] Includes nonavailability of fertilizer.

Table 22. Average levels of fertilizer and expenditures on inputs of farmers claiming to have used enough (UE) or having a lack of capital (LC). Nueva Ecija, Philippines, 1975–76.

Average	Wet 'season				Dry season			
	1975		1976		1976		1977	
	UE	LC	UE	LC	UE	LC	UE	LC
Number of respondents	14	43	5	31	16	53	28	26
Nitrogen kg/ha	53	34	64	39	88*	55	124	104
Phosphorus kg/ha	24	16	28	18	44*	28	52	33
Potash kg/ha	2	4	0	1	8	4	2	5
Fertilizer cost (₱/ha)	301**	191	375	228	544*	353	654*	500
Insect control cost (₱/ha)	139*	49	66	117	81**	44	154	132
Weed control cost (₱/ha)	44*	7	139	59	59*	22	125	110
Total cost (₱/ha)	484	247	580	404	684	419	933	742
Yield t/ha	2.5	2.0	1.9	1.3	3.0	2.6	4.2	3.5

** Mean of those who reported they "used enough" was significantly different at the 1% level from mean of those who reported insufficient capital using t-test.

* Significantly different at the 5% level.

The difference was slightly larger, but not statistically significant, in the dry season. Yields also differed in the expected direction, but not significantly. Total input cost of those claiming to have used enough was substantially lower than the cost of the maximum input package (Table 12), and lower than the cost of the intermediate package (Tables 16 and 18). In the dry season, yields reported by those stating they used enough inputs averaged 2.0 t/ha less than the experimentally established economically superior package yield (Table 19). Since there was little difference in the cost of the economically superior package (₱911/ha) and the farmer who believed they used enough (₱838/ha), it appears that farmers just do not know how to effectively utilize the inputs being applied.

Technical inefficiency

Analysis of the experimental and survey data presents a dilemma -- farmers apparently think they are using enough fertilizer in the dry season, but the analysis shows a profitable opportunity to use more. This prompted us to further investigate the apparent inefficient use of fertilizer by farmers (Table 7).

Data show that in the dry season of 1976 the average expenditure for purchased inputs by 10 farmers was ₱147/ha higher than an intermediate package, while their average return over input cost was ₱820/ha less than what the researchers obtained. The opposite had been noted in isolated cases earlier; farmers spent less than the researchers' intermediate package but obtained higher profits.

We examined the experiments for inefficient cases, where "inefficiency" means a situation with a higher cost and a lower return than another comparable situation. Table 23 shows that in one-third of the experiments conducted in Nueva Ecija over seven seasons farmers spent an average of ₱218/ha more than the lowest intermediate package and had ₱826/ha less profit. The largest number of cases of inefficiency occurred in the 1975 wet season, 1976 dry season, and 1977 dry season, when nearly half the farmers' packages were inefficient. At the same time, in 15% of the cases the researchers'

Table 23. Frequency with which inefficiency of farmers' practices compared with an intermediate test package or the opposite was noted in constraints experiments[a] on farmers' fields. Nueva Ecija, Philippines, 1974–77.

Year	Trials (no.)	Inefficient farmers[b]			Inefficient researcher		
		no.	Difference in cost	Difference in profit	no.	Difference in cost	Difference in profit
			Wet season				
1974	10	3	165	–498	3	149	–313
1975	11	5	120	–463	1	50	–1345
1976	9	2	163	–522	1	390	–311
1977	9	3	291	–1036	1	177	–134
			Dry season				
1975	3	0	-	-	0	-	-
1976	10	5	268	–1250	2	54	–680
1977	7	3	314	–1044	1	31	–1178
All	59	21	218	–826	9	133	–585

[a]Experiments conducted by IRRI Agronomy Department.

[b]Defined as trials in which the farmer's practice cost more than a test package but gave a lower net return.

[c]Defined as trials in which the test package cost more than the farmer's package but gave a lower net return.

intermediate test package was technically inefficient compared with the farmer's package. Except for wet season 1974, when seven typhoons before harvest led to reduced yields with the high inputs, the intermediate package inefficiency occurred on only one or two farms each season.

It would be possible to estimate a production function like that illustrated in Figure 1 for each farm on which the full set of experimental treatments was placed. However, examination of the experimental data shows much farm-to-farm variability in response to inputs. The reasons for such variability apparently lies in characteristics of the physical or biological environment of each farm. Since careful records of many of the physical and biological characteristics were kept, it is possible to explain sane of the observed farm-to-farm variability. Thus, by including the environmental measurements of each farm in the analysis, we derive a generalized production function that can be made specific to the environment of each farm.

The model assumes that all rice farmers in the study area have the same technology but are modified by differences in physical factors. It therefore incorporates farm inputs, environmental variables, and efficiency parameters:

$$Y = f\ (X_1, X_2, \ldots, X_k, Z_1, Z_2, \ldots, Z_n, E_1, E_2, \ldots, E_n, U)$$

where

- Y is rice yield
- X_i are inputs, i = 1, 2, ... n
- Z_i are environmental variables
- E_i are zero-one variables used to reflect efficiency
- U is an error term.

The environmental factors considered are solar radiation, typhoons, water stress, and soil, plus two others which are strongly influenced by them: insect damage and disease. The latter two could he considered environmental variables subject to sane degree of management, while the former four are largely beyond the control of farmers. Three soil characteristics - organic matter, texture, and extractable P, measured at each site - were included in the estimating equation. Another variable was the age of seedlings for each experiment. This makes a total of seven variables measured for each experiment, or site, referred to subsequently as site variables. The input factors were controlled at specific levels for each plot, and these, along with insect and disease incidence, are referred to as plot variables.

The variables included in the regression analysis were specified as follows. Applied fertilizer (F) is the total amount of nutrients (N + P + K) in kg/ha. Insect and weed control were expressed as

expenditures in pesos per hectare. Age of seedlings was the number of days from sowing to the time of transplanting. Damage from insects and disease was expressed numerically, using a scale from zero to nine. Stress days were counted as the number of days after the first three that it took for the soil surface to dry up. Soil organic matter and texture were expressed as percentages, and extractable P was expressed in ppm. Solar radiation was expressed as the total energy received during the 45 days immediately before harvest. Typhoons were expressed as a dummy variable.

Regression analysis. Some previous experience with measuring the effects of production inputs to rice growth among a diverse set of locations has previously been reported (Mandac 1974, Rosegrant 1977). These equations have typically been based on a quadratic. response to fertilizer, modified by a relatively large number of other variables and interaction terms. In the analysis, yield was regressed on all 32 independent variables (Table 24). The 32 regression coefficients in the full model were tested for significance; 11 of these were found to be significant at the 5% level. Water stress (which reduces yields significantly in field observations) was not statistically significant. Soil texture, which was not expected to have much influence on yields, had a highly significant regression coefficient.

The coefficient of DFF indicates that when fertilizer was applied following farmers ' techniques, the yield response was approximately 2 kg of palay *less* per kg of fertilizer nutrient than when the input was applied using the researchers' technique. The coefficienl of DII shows that a peso worth of insect control resulted in 0.48 kg *less* palay when applied following farmers' techniques as compared to when it was applied following researchers' techniques. The coefficient of DWW shows that a peso worth of weed control (herbicide or hand weeding) applied following farmers' practices resulted in 1.5 kg *less* palay than when applied following researchers' techniques The value of the environmental site variables specific to each farm were substituted into the estimated production function, providing a function specific to the environmental faced by each farmer. This function corresponds conceptually to the TPP curve in Figure 1. Using this and prevailing prices, the measures of efficiency can be determined.

The degree of technical efficiency at the farm level of the three factors of production can be judged from the following. Less than half (48%) of the farmers studied had measured efficiencies within 10% of the efficient function. The least technically efficient farmer is more than 20% away from the efficient function. Similarly, there is a low degree of allocative efficiency, with less than half (45%) of the farmers within 10% of the economic optimum. The least allocatively efficient farmer is 50% away from

Table 24. Production function estimated from all sites combined. Nueva Ecija, 1974 wet season to 1977 dry season.

Independent variables	Symbol	Regression coefficient	Standard error	Beta coefficient
Constant		2422		
Applied fertilizer (linear)	F	−5.189	5.335	−0.207
Applied fertilizer (quadratic)	F^2	−0.030*	0.016	−0.351
Insect control cost (linear)	I	−1.689***	0.613	−0.372
Insect control cost (quadratic)	I^2	0.002**	0.001	0.601
I x F	IF	0.007	0.003	0.309
I^2 x F	I^2F	a	b	−0.451
Weed control cost (linear),	W	0.858	1.289	0.029
Weed control cost (quadratic)	W^2	0.013*	0.005	0.096
W x F	WF	−0.009***	0.006	−0.054
Age of seedlings	A	−15.617	5.957	−0.072
A x F	AF	0.090**	0.043	0.126
Pest damage index	P	1.475	3.115	0.011
P x F	PF	-0.132***	0.026	−0.130
Disease incidence index	D	−27.337***	6.470	−0.114
D x F	DF	−0.266***	0.053	−0.133
Soil organic matter (linear)	OM	3111.284***	649.665	1.190
Soil organic matter (quadratic)	OM^2	−657.808***	157.172	−0.765
OM x F	OMF	0.223	2.128	0.022
OM x F^2	CMF^2	0.001	0.008	0.039
Soil texture (linear)	T	−106.291***	16.504	−1.299
Soil texture (quadratic)	T^2	0.717***	0.111	0.876
Soil extractable P	EP	5.680***	0.992	0.283
EP x F	EPF	−0.018**	0.007	−0.105
Late water stress	SL	−44.196	32.379	−0.135
SL x F	SLF	0.044	0.077	0.017
Solar radiation	SR	89.357***	12.925	0.206
SR x F	SRF	0.928	0.928	0.824
SR x SL	SRSL	1.175	1.718	0.066
Dummy variable for typhoons	DT	−471.319***	44.869	−0.143
Slope dummy for fertilizer treatment	DFF	−1.974***	0.349	−0.070
Slope dummy for insect control treatment	DII	−0.475**	0.216	−0.028
Slope dummy for weed control treatment	DWW	-1.563**	0.653	−0.068

R^2 = 0.661 $\bar{R}^2$ = 0.653 F = 179.087

[a]Value is −.0000033. [b]Value is .000000l.

* significant at the 10% level (t = 1.645)

** significant at the 5% level (t = 1.960)

*** significant at the 1% level (t = 2.576)

the previous years. Three farms applied no fertilizer, and six farms applied only nitrogen.

Four out of 27 farms used no hand or rotary weeding, while the rest averaged one weeding. Nearly 50% of the farmers practiced chemical weeding, either by spraying or applying 2,4-D granules, supplemented by rotary weeding and spot hand weeding to achieve good weed control. All farms used foliar sprays, and 4 applied granular insecticides in addition.

During the 1977 dry season, complete factorial experiments were conducted on 6 farms, minifactorial experiments were conducted on 6 farms, and supplemental trials were conducted on 8 farms. All sites were irrigated, either by pump or with canal water. Dry season input levels were very slightly higher than the wet season levels, but the most striking observation was the gradual increase in farmers' levels of nitrogen use over the three years.

The average level of fertilizer applied by the farmer – cooperators in the 1977 dry season was slightly higher than in the previous years (Table 1). None of the farmers applied insecticides, although nearly all used foliar sprays, averaging three applications. Weeds were controlled using a combination of hand or rotary weeding and by the use of either granular or liquid herbicides.

Table 2. Yields at farmers' levels and high level of inputs. Camarines Sur, Philippines, 1975-1977.

Year	No. of trials		Grain yield (t/ha)		
	Irrigated	Rainfed	Farmers' inputs	High inputs	Yield gap
			Wet season		
1975	4	2	3.6	4.6	1.0
1976	5	1	2.7	3.4	0.7
1977	18	9	4.2	4.7	0.5
All	27	12	3.9	4.5	0.6
			Dry season		
1975	3	0	3.9	5.6	1.7
1976	5	0	3.3	4.9	1.6
1977	20	0	4.2	6.1	1.9
All	28	0	4.0	5.8	1.8

yield gap, and only 38% is explained by technical inefficiency. The contribution of economic behavior is rather small at 14% and 6%, respectively, for the wet and dry seasons. This analysis provides an explanation of the apparent ability of farmers to recover the yield from high fertilizer in the dry season. Many farmers are unable to attain as high yields as the researchers, even when they use as high or higher input levels. The reasons for this are being investigated and appear to be traceable to time and method of fertilizer application.

SUMMARY AND CONCLUSIONS

Results demonstrate that rice yields can be increased by 2 t/ha in the dry season and 1 t/ha in the wet season over the levels farmers are currently achieving. These increases would require farmers to use higher levels and better management of fertilizer (particularly nitrogen fertilizer) in the dry season and to increase the level and quality of insect control during the wet season.

Net returns were about the same for the farmers' and the maximum levels of inputs in the wet season but were 22% higher with the maximum input level in the dry season. The maximum-yield inputs increased profits in 40% of the wet season experiments and did likewise in 75% of the dry season cases.

A yield increase of about 0.5 t/ha in the wet season and 0.8 t/ha in the dry season was attributable to a high level of insect control compared to farmers' levels, but a higher yield level was unprofitable during the wet season. Dry season results indicated a small average increase in net returns from high insect control. An intermediate level of insect control was highly profitable in the wet and dry seasons of 1976 but decreased profits in both seasons of 1977. Weed control levels of farmers were generally adequate.

The maximum yield level of fertilizer was profitable in the dry season but not in the wet season. Intermediate fertilizer levels were more profitable than the farmers' levels in both seasons, but there was a much larger relative advantage in the dry season. There appears to be substantial potential for increasing yield and improving farmers' profits by using higher fertilizer levels in the dry season.

Farmers either believed they were using enough fertilizer or did not have enough capital to apply more. The farmers who reported using "enough" fertilizer applied more than the rate used at the intermediate levels of the experiment in the wet season and less

than the maximum level in the dry season. Since the intermediate level is optimal in the experiments, it seems that the farmer's judgment in the wet season was correct. Even so, farmers were not generally able to obtain as high yields with their fertilizer inputs as the researchers obtained.

Appendix Table 1. Grain yields under farmers' level and test levels of fertilizer under farmers' and high levels of weed and insect control in farmers' fields. Nueva Ecija, Philippines, 1976 dry season.

Farmer	Weed and insect control level	Nitrogen applied (Farmers' level)		Grain yield[b] (t/ha)			
		Rate (kg/ha)	Timing (DT)[a]	Farmers'	I-1	I-2	H
Pagaduan	Farmers'	74	18, 50	3.8	4.5	6.0	6.6
	High			6.1	5.8	7.3	8.0
Mercado	Farmers'	120	5, 26	6.1	5.8	6.7	7.0
	High			7.5	7.2	8.3	8.5
G. Eligado	Farmers'	46	20	4.5	4.4	5.1	5.5
	High			5.0	4.4	4.8	5.4
F. Eligado	Farmers'	132	0, 27, 50	3.8	3.7	4.8	5.7
	High			4.2	4.6	6.1	6.2
Villa	Farmers'	61	49	2.6	2.8	4.0	3.9
	High			4.0	5.6	5.5	5.9
Geranta	Farnrers'	43	8, 34	4.2	3.9	5.2	6.5
	High			5.8	6.9	7.6	8.6
Sirot	Farmers'	46	13	3.9	3.9	4.9	5.6
	High			4.3	5.1	5.7	6.1
Flores	Farmers'	71	17, 48	3.9	3.4	4.2	4.8
	High			4.4	4.0	5.0	4.4
Lopez	Farmers'	92	13, 52, 68	3.5	3.8	4.6	4.6
	High			4.4	4.7	5.2	5.2
Av	Farmers'	76		4.0	4.0	5.1	5.6
	High			5.1	5.4	6.2	6.5

[a] DT = days after transplanting.

[b] Test rates of nitrogen: Intermediate levels: I-1 =50 kg N/ha, 1–2 = 100 kg N/ha. High level (H): 150 kg N/ha. Time of N application = basal and 5–7 days before panicle initiation.

Appendix Table 2. Grain yields under farmers' levels and test levels of fertilizer under farmers' and high levels of weed and insect control measures in farmers' fields. Nueva Ecija, Philippines, 1976 wet season.

Farmer	Variety	Weed and insect control level	Nitrogen applied (Farmers' level) Rate (kg/ha)	Nitrogen applied (Farmers' level) Timing (DT)[a]	Grain yield[b] (t/ha) Farmers'	I-1	I – 2	H
Lopez	IR20	Farmers'	0	-	0.9	0.8	1.2	1.2
		High			2.8	3.2	3.4	3.4
Sirot	IR30	Farmers'	0	-	1.8	2.7	3.0	3.0
		High			3.1	2.9	3.5	4.1
A. Aquino[c]	IR26	Farmers'	98	14, 37	2.0	2.3	2.4	2.4
		High			2.5	3.2	3.3	3.6
E. Ramos	IR29	Farmers'	31	10	2.3	2.9	3.6	3.9
		High			3.4	4.2	4.2	4.5
P. Aquino[c]	IR26	Farmers'	78	31	2.7	4.1	3.0	3.8
		High			4.1	3.9	3.9	4.1
Pagaduan	IR26	Farmers'	51	28, 45	2.8	3.8	3.6	3.5
		High			4.3	4.3	4.9	4.1
R. Santos	IR30	Farmers'	49	3, 31	3.0	3.4	3.4	4.0
		High			3.8	3.9	4.1	4.4
Geranta	IR30	Farmers'	130	10	4.4	4.2	4.2	4.2
		High			3.9	4.3	4.3	4.4
Antonio[c]	IR30	Farmers'	78	18	4.8	4.7	5.0	5.2
		High			5.8	5.2	6.1	6.0
Av		Farmers'	57		2.8	3.2	3.3	3.5
		High			3.7	3.9	4.2	4.4

[a] DT = days after transplanting.

[b] Test rates of nitrogen: Intermediate level: I-1 = 40 kg N/ha, I – 2 = 70 kg N/ha. High level (H): 100 kg N/ha. Time of N application = basal and 5 – 7 days before panicle initiation.

[c] Rainfed farm.

Appendix Table 3. Grain yields under farmers' levels and test levels of fertilizer under farmers' and high levels of weed and insect control measures in farmers' fields. Nueva Ecija, Philippines, 1977 dry season.

Farmer	Variety	Weed and insect control level	Nitrogen applied (Farmers' level)		Grain yield[b] (t/ha)			
			Rate (kg/ha)	Timing (DT)[a]	Farmers'	I-1	1-2	H
Mejia	IR36	Farmers'	143	18,24,39,43	4.8	5.5	6.2	6.4
		High			6.6	6.9	7.6	8.4
Gamboa	IR36	Farmers'	81	22, 36	4.9	4.8	5.2	6.3
		High			6.6	6.0	6.9	8.6
Pagaduan	IR36	Farmers'	132	14, 44	5.3	4.6	4.5	5.3
		High			5.9	5.4	6.9	7.4
Geranta	IR36	Farmers'	164	14,32,37,40	8.6	5.7	7.6	8.2
		High			8.2	6.8	8.0	8.9
R. Santos	IR36	Farmers'	125	8,35,40	6.8	5.7	7.3	6.2
		High			8.1	7.6	8.1	8.1
Bartolome	IR36	Farmers'	194	12, 34	4.3	5.5	6.0	6.2
		High			6.8	5.8	6.4	7.0
R. Umagat	IR36	Farmers'	34	27	3.2	4.3	5.2	6.6
		High			4.0	5.1	6.2	7.0
Av		Farmers'	125		5.4	5.2	6.0	6.4
		High			6.6	6.2	7.2	7.9

[a]DT = days after transplanting.

[b]Test rates of nitrogen: Intermediate levels: I-1 = 50 kg N/ha, 1-2 = 10 kg N/ha. High level (H): 150 kg N/ha. Time of N application = basal, 20-30 days after transplanting and 5-7 days before panicle initiation.

Appendix Table 4. Grain yields under farmers' levels and test levels of fertilizer under farmers' and high levels of weed and insect control measures in farmers' fields. Nueva Ecija, Philippines, 1977 wet season.

Farmer	Variety	Weed and insect control level	Nitrogen applied (Farmers' level) Rate (kg/ha)	Timing (DT)[a]	Grain yield[b] (t/ha) Farmers'	I-1	I – 2	H
MRRTC	IR36	Farmers'	57	12, 35	4.3	4.6	5.1	5.4
		High			4.9	5.4	5.8	5.8
Saludez	IR36	Farmers'	36	19, 34	5.1	5.1	5.6	5.7
		High			5.6	5.5	5.7	5.9
Geranta	IR36	Farmers'	177	10, 41	4.3	5.3	5.3	4.0
		High			5.0	5.9	5.4	5.0
R. Santos	IR36	Farmers'	65	9, 42	5.0	5.3	4.9	5.2
		High			5.8	5.9	6.2	5.6
G. Umagat	IR36	Farmers'	110	14, 37	2.8	2.0	2.2	2.9
		High			4.8	3.5	4.1	5.2
Imperial	IR36	Farmers'	66	28	5.5	5.0	5.0	5.2
		High			5.3	5.8	6.0	5.9
Garcia	IR32	Farmers'	101	17, 31	5.4	5.6	6.1	6.2
		High			4.9	5.5	5.6	6.0
Mejia	IR36	Farmers'	51	19, 34	5.5	5.3	5.8	5.2
		High			5.5	5.8	5.9	5.7
Sanahez[c]	IR36	Farmers'	85	6	2.8	3.6	4.4	4.1
		High			4.2	4.8	5.0	5.2
I. Antonio[c]	IR36	Farmers'	73	16	5.0	5.1	5.9	6.0
		High			5.8	5.4	6.3	6.5
Av		Farmers'	82		4.6	4.7	5.0	5.0
		High			5.2	5.4	5.6	5.7

[a]DT = days after transplanting.

[b]Test rates of nitrogen: Intermediate levels: I-1 = 40 kg N/ha, I – 2 = 70 kg N/ha. High level (H): 100 kg N/ha. Time of N application = basal and 5 – 7 days before panicle intiation.

[c]Rainfed farm.

REFERENCES CITED

De Datta, S. K., K. A. Gomez, R. W. Herdt, and R. Barker. 1978. A handbook on the methodology for an integrated experiment survey on rice yield constraints. International Rice Research Institute, Los Baños, Laguna, Philippines.

International Rice Research Institute (IRRI). 1975. Annual report. Los Baños, Philippines.

International Rice Research Institute (IRRI). 1977. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Philippines.

Mandac, A. 1974. An economic analysis of factors affecting yield of rice in 1973–74 Central Luzon farmers' field experiments. IRRI Saturday Seminar, 7 December 1974.

Mandac, A. and R. W. Herdt. 1978. Economic inefficiency as a constraint to high rice yields in Nueva Ecija, Philippines. IRRI Saturday Seminar, 16 September 1978.

National Census and Statistics Office. 1971. Census of Agriculture Manila, Philippines.

Rosegrant, M. 1977. Risk and farmer decision-making: a model for policy analysis. IRRI Saturday Seminar, 23 April 1977.

Timmer, C. P. 1970. On measuring technical efficiency. Food Research Inst. Studies. 9:99–171.

Constraints to High Rice Yields, Camarines Sur, Philippines

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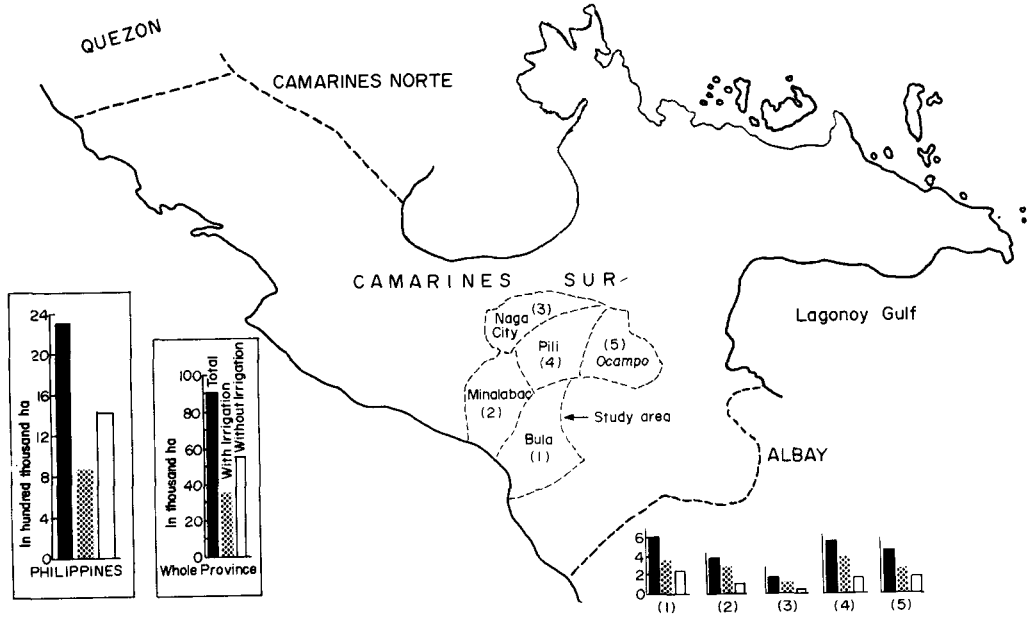
Camarines Sur, in the Bicol area of the country, is the sixth most important rice-producing province in the Philippines, with 3.9% of the total physical rice area of the country (1971 Census). Of the 90,692 hectares of rice lands in Camarines Sur, 60% were rainfed and 40% were irrigated in 1971. The high proportion of rainfed rice partly explains the low average yield (1.5 t/ha) in that province.

The five municipalities in Camarines Sur in which the yield constraints studies were conducted represent more than 24% of the total rice area in the province (Fig. 1). Of this area, 33% is rainfed and 67% is irrigated. These five municipalities produce 34% of the total rice in the province, with an average yield of 2.1 t/ha. Irrigation water canes either from streams by natural flow, by canals, or pumps.

METHODOLOGY

Constraints research was first undertaken in Camarines Sur in the dry season of 1975. In that year, experiments included the two-level constraints factorial design on 3 dry season farms and 6 wet season farms. In addition, management package project experiments were conducted on the same farms. In 1976, a multi-level factorial design with 3 test levels of fertilizer, 2 test levels of insect control, and 1 test level of weed control, was conducted on 5 farms in the dry season and 6 farms in the wet season. In 1977, the supplemental and minifactorial trials described in the Nueva Ecija chapter were added to the multi-level factorial trials. Management package trials were conducted on one farm in the dry and 3 farms in the wet season. Methodology and analytical procedures are essentially as described in the Nueva Ecija chapter. The results discussed in detail in this paper cover the 1976 wet season and the 1977 dry and wet seasons. Previous results are reported in the *Interim report.*



1. Physical crop area planted to rice on farms with and without irrigation facilities in the study area. Camarines Sur, Southern Luzon, Philippines (Camarines Sur - 1971 Census of Agriculture. National Census and Statistics Office).

RESULTS AND DISCUSSION

Farmers' input use. During the 1976 wet season, experiments were conducted on one rainfed and five irrigated farms. The average levels of inputs used by the cooperating farmers are shown in Table 1. Two farms applied no fertilizer, while one farm applied only nitrogen. Farmers' levels of insect control averaged about 3 foliar sprays, and one farm used an application of granular insecticide. All farms except the rainfed farm used hand or rotary weeding or both, while 3 farms used granular herbicides to control weeds.

During the 1977 wet season, experiments were conducted on a total of 27 farms — 18 irrigated by canal or pump, and 9 rainfed. The farmers applied somewhat higher fertilizer levels than during

Table 1. High level and farmers' levels of inputs. Camarines Sur, Philippines, 1975–77.

Input levels[a]	Year	No. of trials: Irrigated	No. of trials: Rainfed	Fertilizer (kg/ha): N	Fertilizer (kg/ha): P_2O_5	Fertilizer (kg/ha): K_2O	Weed control[b]: M	Weed control[b]: C	Insect control[c]: F	Insect control[c]: G
				Wet season						
F	1975	4	2	28	15	8	0.5	1.0	3.3	0.0
H				75	30	20	0.0	1.0	3.0	2.0
F	1976	5	1	34	8	6	1.3	0.5	3.0	0.2
H				100	40	30	1.0	1.0	1.0	3.0
F	1977	18	9	54	13	12	0.9	0.5	2.8	0.2
H				100	40	30	1.0	1.0	1.0	3.0
				Dry season						
F	1975	3	0	36	14	14	1.0	0.3	1.3	0.0
H				120	30	30	0.0	1.0	3.0	2.0
F	1976	5	0	43	25	10	0.8	0.8	4.0	0.2
H				150	40	30	1.0	1.0	1.0	4.0
F	1977	20	0	54	6	5	0.8	0.6	2.5	0.0
H				150	40	30	1.0	1.0	1.0	4.0

[a] F = average level of inputs used by farmers on whose fields the trials were conducted; H = high level of inputs.

[b] Data show average number of weeding operations. (M) indicates weeding by hand or by rotary weeder, and (C) chemical herbicide application.

[c] Data show average number of foliar (F) sprays or granular (G) application of insecticide to paddy water.

the optimum. Considering our overall measure of efficiency, there is not one farm within 10% of the efficient function and the economic optimum. The most economically efficient farmer is 11% away while the least economically efficient is more than 50% away.

To summarize the measures of efficiency, the magnitude of the yield gap is presented in Table 25. The yield gap is attributed to three factors -- economizing behavior, allocative inefficiency, and technical inefficiency. The average yield gap is shown as calculated directly from experiments and from the efficient production function for the average of all wet and dry season experiments. For purposes of estimating the farmers' yields using the function, the farmers' input levels with farmers' efficiency is used. The maximum yield was estimated without regard for input costs and with researchers' efficiency.

The yield gap during the wet season is small compared with the gap during the dry season. Of the 0.7 t/ha yield difference, about 0.5 t, or 71%, can be attributed to technical inefficiency. In the dry season, allocative inefficiency explains 56% of the

Table 25. Estimated yield gap and contribution of economic behavior, allocative and technical inefficiencies. Nueva Ecija, Philippines, 1974 wet season to 1977 dry season.

Source	Grain yield (t/ha)			Av contribution' (t/ha)		
	Farmers' behavior[a]	High input and efficiency[b]	Yield gap	Economic behavior	Allocative inefficiency	Technical in efficiency
			Wet season			
Experiments	2.4	3.3	0.9	-	-	-
Function	2.2	2.9	0.7	0.1 (14)	0.1 (14)	0.5 (71)
			Dry season			
Experiments	4.4	6.4	2.0	-	-	-
Function	4.8	6.4	1.6	(6)	(56)	(38)

[a] For the experiments, the farmers' input plots. For the function, farmers' input level with farmers' efficiency.

[b] Maximum yield, disregarding input costs, and with researchers' efficiency.

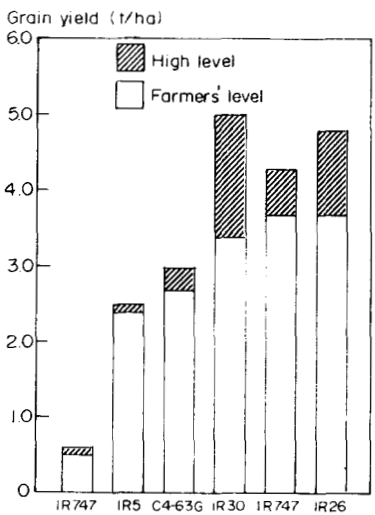
[c] Figures in parentheses are percentage contributions.

Yield gap and its variation

The wet season yield gap averaged across all the experiments was 0.6 t/ha, while in the dry season it averaged 1.8 t/ha (Table 2). The size of the gap was more consistent in the dry season, ranging from 1.6 to 1.9 t/ha.

In the 1976 wet season the yield gap varied as shown in Figure 2. Grain yields at farmers' input levels were below 3 t/ha on 3 farms and slightly over 3 t/ha on 3 other farms. The rainfed farm gave the lowest yield because of irregular rainfall and poor weed control. Average yield with farmers' inputs was 2.7 t/ha. With high inputs, yields ranged from 0.7 t/ha on the rainfed farm to 5 t/ha on the irrigated farms. The average yield gap, at 0.7 t/ha, was slightly lower than in 1975 (Table 2). The yield gap was small on 3 farms but large on two.

In the 1977 wet season farmers' yields varied from 2.2 t/ha to 6.2 t/ha (Fig. 3), averaging 4.2 t/ha (Table 2). The lowest yield of 2.2 t/ha was obtained on the farm growing the traditional variety Masjava. Low yields were also obtained in 3 rainfed farms, where the rainfall distribution was irregular. The irrigated sites of the complete factorial experiment gave yields higher than the rainfed farms even though there was a severe typhoon during harvest time.



2. Yield gap between potential and farmers' yields in farm yield constraints studies. Camarines Sur, Philippines, 1976 wet season.

The yields obtained on 5 farms, under high input levels were lower than yields under the farmers' levels because the crops lodged and grains sprouted due to inadequate drainage during the typhoon Farmers' crops using a lower rate of fertilizer did not lodge. Those trials harvested before the typhoon gave a higher yield gap between the farmers' levels and the high input level.

Yields from high inputs ranged from 2.1 t/ha to 6.9 t/ha, averaging 4.7 t/ha, and showed a yield gap of 0.5 t/ha.

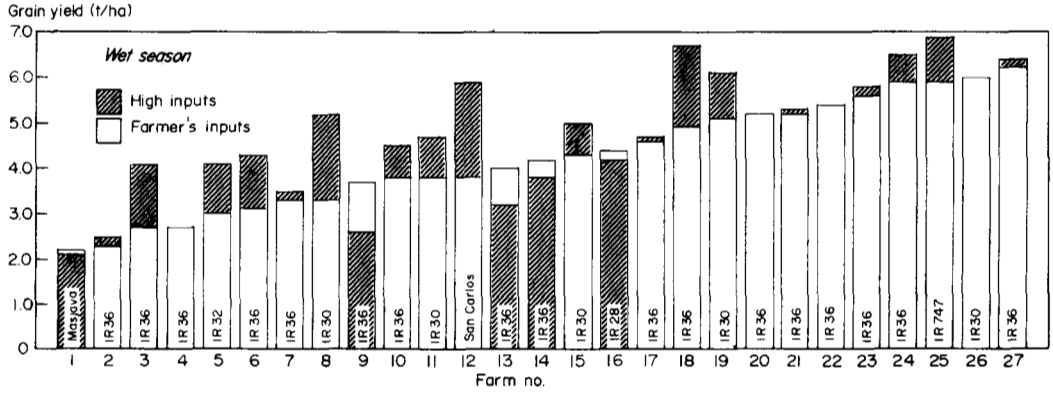
In the 1977 dry season yields at the farmers' levels of inputs were quite variable (Figure 3), ranging from 1.0 t/ha to 5.8 t/ha and averaging 4.2 t/ha (Table 2). Two sites had water shortages that caused serious weed problems and low yields. One farm grew a non-recommended obsolete line (IR1006). In supplemental trials on 2 farms, yields of over 5.0 t/ha were obtained from the farmers' intensive management levels in the comparable paddy. This resulted in yields in comparable paddy higher than the average of all other paddies belonging to the same farm.

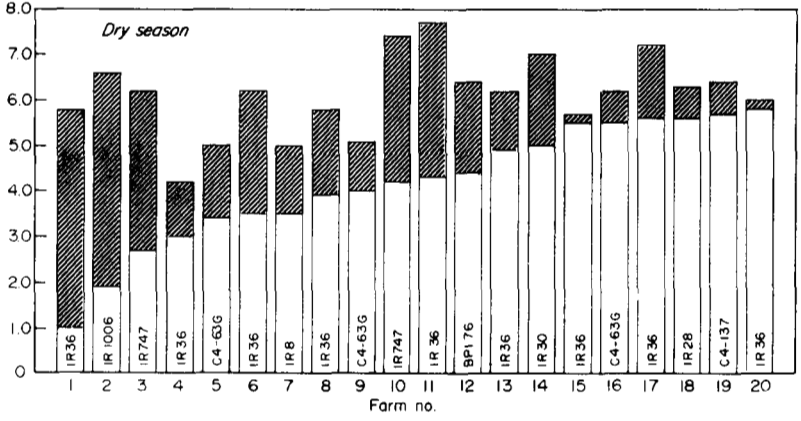
Yields at the high level of inputs ranged from 4.2 t/ha to 7.7 t/ha (Figure 3), averaging 6.1 t/ha (Table 2). On 19 out of 20 farms, yields higher than 5.0 t/ha were obtained with high inputs. The highest yield (7.7 t/ha) was obtained in the minifactorial experiment on a farm where excellent water and weed management practices were followed.

Contributions of test factors

The relative contribution of each test input to the yield gap is given in Table 3. The results of the 1975 and 1976 wet seasons were quite similar. In the 1977 wet season the yield gap was smaller . Fertilizer, weed, and insect control contributions were negative. There was a substantial difference in 1977 between the gap measured in the complete factors of trials and the minifactorials and the gap measured in the supplemental trials because the latter were harvested earlier. In the dry season, the contribution of fertilizer was dominant, exceeding 1 t/ha each year. The contributions of weed and insect control were more erratic.

In the 1976 wet season fertilizer accounted for 67% (0.4 t/ha) of the yield gap and insect control accounted for the rest. High weed control did not increase yields above farmers' levels, indicating that farmers' weed control practices were adequate. In the 1977 wet season no positive contribution of the test factors was measurable when the data were averaged over all farms. However, on some farms the test factors made positive contributions to the yield gap. On 6 farms high fertilizer application increased





3. Variations in yield gap between farmers' fields in farm yield constraints studies. Camarines Sur, Philippines, 1977 dry and wet seasons.

Table 3. Contribution of insect control, fertilizer, and weed control above farmers' levels towards the improvement of rice yields in farmers' fields. Camarines Sur, Philippines, 1975–77.

Year	Trials (no.)	Grain yield (t/ha)[a] Farmers' inputs	High inputs	Gap	Contribution[b] (t/ha) Fertilizer	Weed control	Insect control	Residual
			Wet season					
1975	6	3.6	4.6	1.0	0.4	0.1	0.6	-0.1
1976	6	2.7	3.4	0.7	0.4	0.0	0.2	0.1
1977	15	3.6	3.8	0.2	-0.1	-0.1	-0.2	0.6
All	27	3.7	3.9	0.5	0.1	0.0	0.1	0.3
1975/76	12	3.2	4.0	0.8	0.4	0.1	0.4	0.0
			Dry season					
1975[c]	3	3.9	5.6	1.7	1.1	0.1	0.4	0.0
1976	5	3.3	4.9	1.6	1.3	0.2	0.2	-0.1
1977	12	3.5	5.9	2.4	1.2	0.3	1.0	-0.1
All	20	3.5	5.6	2.1	1.2	0.2	0.7	0.0

[a] May differ from yields in Table 2 because that table contains data from single-plot supplemental trials while this table contains only mini and complete factorials.

[b] Measured as yield decrease from high inputs due to a reduction from high to farmers' levels of each input.

[c] Land preparation was included in these experiments and contributed 0.1 t/ha to the yield gap.

yield by nearly 0.5 t/ha. Weed control practices using 2,4–D granules at 4 days after transplanting and supplemental hand weeding added to the yield oyer farmers' levels on 7 out of 15 farms. Insect control at the high level increased grain yield on only 4 farms, where the farmers' levels of insect control were less than adequate.

In the 1977 dry season fertilizer accounted for 48% of the gap, weed control accounted for 12% of the gap, and insect control accounted for 40% of the gap. Unlike earlier dry seasons, where fertilizer dominated in 1977, the contributions of fertilizer and insect control were similar.

Input efficiency at intermediate levels

The lower intermediate fertilizer level was similar to the average farmer levels (Table 4). In the wet seasons the increasing level of fertilizer application from I-1 to 1 – 2, and then to high, resulted in only a slight yield increase in 1976 and a slight yield decrease in 1977 (Table 5). The intermediate insect control level also increased yields very little above the farmers' level.

In the 1976 wet season the intermediate levels of fertilizer generally increased yields with farmers' insect and weed control practices and increased yields on at least half of the farms with high insect and weed control practices (Appendix Table 1).

On 4 out of 6 farms, yield increases were recorded with farmers' levels of weed and insect management and on 5 out of 6 farms under high levels of weed and insect control practices (Appendix Table 1). An increase of 0.2 t/ha using the first intermediate level and 0.5 t/ha using the second intermediate level of fertilizer was obtained over the farmers' levels under high levels of weed and insect control. This indicates that high levels of weed and insect control increased fertilizer efficiency.

To investigate the possible difference in efficiency of fertilizer use by farmers and researchers, farms were grouped into those where the farmers' level was between I-1 and I – 2and those where the farmers' level was greater than I – 2 (Table 6). Farmers' yields were then compared with the I-1 and I – 2yields with farmers' and high levels of weed and insect control.

In the 1976 wet season researchers applying lower levels of fertilizer than the farmers were able to obtain higher yields on 3 farms (Table 6).

In the 1977 wet season the second intermediate level of fertilizer (70 kg N/ha) gave higher yields on 5 out of 8 farms under farmers' levels of weed and insect control measures as well as under high weed and insect control practices. Unlike the previous years, farmers in general had higher yields at comparable fertilizer levels than the researchers (Table 6).

In the 1977 dry season the first intermediate level of fertilizer (I – 1) increased yield on 3 farms with high levels of weed and insect management (Appendix Table 2). Using the second intermediate level of fertilizer, higher yields were obtained in all six farms under farmers' levels of weed and insect control and in 5 out of 6 farms under high levels of weed and insect control. The high level of fertilizer (150 kg N/ha) increased yields on 4 out of 6 farms under both farmers' and high levels of weed and insect control.

Table 4. Farmers' levels and intermediate levels of fertilizer and insect control.[a] Camarines Sur, Philippines, 1976 – 77.

	Wet season		Dry season	
	1976	1977	1976	1977
Trials (no.)	6	8	5	6
	Fertilizer (kg/ha)			
Farmers'				
N	34	37	43	63
P_2O_5	8	6	25	6
K_2O	6	2	10	3
Intermediate I				
N	40	40	50	50
P_2O_5	20	20	20	20
K_2O	10	10	10	10
Intermediate II				
N	70	70	100	100
P_2O_5	30	30	20	30
K_2O	20	20	20	20
	Insect control[b]			
Farmers'				
F	3.0	2.1	4.0	3.5
G	0.2	0.2	0.2	0
Intermediate				
F	0	0	0	0
G	2.0	2.0	2.0	2.0

[a] Complete factorial experiment.

[b] Average number of applications. F = foliar application, G = granular application.

Table 5. Grain yield under different levels of inputs. [a] Camarines Sur, Philippines, 1976–77.

Year	Trials (no.)	Grain yield [b] (t/ha)						
		Fertilizer				Insect control		
		F	I-1	1–2	H	F	I	H
				Wet season				
1976	6	2.8	3.0	3.2	3.2	3.0	3.0	3.2
1977	8	3.2	3.6	3.5	3.4	3.4	3.5	3.4
A11	14	3.0	3.3	3.4	3.3	3.2	3.3	3.3
				Dry season				
1976	5	3.4	3.6	4.2	4.7	3.9	4.0	4.1
1977	6	4.1	4.5	5.4	5.3	4.4	4.8	5.3
A11	11	3.8	4.1	4.8	5.0	4.2	4.4	4.7

[a] Complete factorial experiment.

[b] F = farmers' level, I = intermediate level, H = high level.

Two out of 6 farmers applied more fertilizer than I-1 and obtained lower yields (at their own weed and insect control levels). But at the high weed and insect control levels, farmers' yields were higher.

Variety and cultural practices

Table 7 shows that increased yields Over the farmers' levels were obtained with both farmers' and high levels of cultural practices using intermediate and high management package levels in the 1976 wet season. However, high cultural practices showed no significant advantage over the farmers' practices on any management package level. Table 8 shows that the test variety gave only an average of 0.2 t/ha yield advantage over the farmers' varieties because all farmers used high–yieldingvarieties.

In the 1977 wet season with the farmers' levels of management package, the farmers' cultural practices (method of planting, age of seedling, etc.) yielded 3.0 t/ha on 8 farms, while the average yield with optimal cultural practices was 2.8 t/ha (Table 7). It was observed that under the low fertilizer

Table 6. Comparison of yields with researchers' and farmers' fertilizer application methods and rates. Camarines Sur, Philippines, 1976–77.

Year	Level of insect and weed control	Performance in trials where farmers' fertilizer level was greater than I-1, less than I–2					Performance in trials where farmers' fertilizer level was greater than 1–2				
		Farms (no.)	N (kg/ha)		Yield (t/ha)		Fans (no.)	N (kg/ha)		Yield (t/ha)	
			Farmers'	I-1	Farmers'	I-1		Farmers'	I–2	Farmers'	I–2
					Wet season						
1976	Low	2	47	40	3.7	4.1	1	71	70	2.4	2.4
	High				3.9	4.1				2.7	2.6
1977	Low	3	47	40	3.9	3.5	2	83	70	3.7	3.1
	High				3.3	3.7				3.3	3.2
					Dry season						
1976	Low	2	64	50	2.6	2.8	0	-	-	-	-
	High				3.0	3.2					
1977	Low	3	77	50	4.1	5.1	0	-	-	-	-
	High				5.3	5.8					

Table 7. Yields with cultural practices at a high level and at the farmers' levels at different input levels.[a] Camarines Sur, Philippines, 1976–77.

Trials (no.)	Level of cultural practices[b]	Grain yield (t/ha) at input level			
		Farmers'	Intermediate	High	Average
		1976 wet season			
6	F	2.8	3.1	3.4	3.1
	H	2.7	3.1	3.2	3.0
		1977 wet season			
8	F	3.0	3.5	3.3	3.3
	H	2.8	3.4	3.2	3.1
		1976 dry season			
5	F	3.3	3.9	5.1	4.1
	H	3.4	3.9	5.1	4.1
		1977 dry season			
5	F	3.8	4.3	5.9	4.7
	H	4.0	4.6	6.1	4.9

[a] Complete factorial experiment. Data are averages of the farmers' and the test varieties.

[b] F = farmers' level, H = high level.

rate of the farmer's package, the higher plant density practiced by farmers had a slight advantage over the crop planted at 20 x 20 cm spacing because higher plant density compensated for the low tillering ability of hills by having more original plants.

The intermediate level of management package increased the grain yield by 0.5 t/ha over the farmers' management levels, but the high cultural practices were no better than the farmers'. This was also true under the high level of management, where similar yields were obtained under farmers' and high cultural practices.

Farmers grew IR36 and a traditional variety, Masjava (Table 8). The test variety was IR42, which matured much later than IR36 and was damaged by typhoons. The test variety averaged slightly

lower yields than the farmers' variety at all management levels, suggesting that the short-duration variety is advantageous during the wet season if adverse weather is encountered.

During the 1977 dry season there was a definite yield advantage in using high cultural practices over the farmers' cultural practices under all management levels (Table 7).

Yields of farmers and test varieties were all compared at the three management levels on 5 farms. The test variety was IR36 on farms using other varieties and IR26 where farmers grew 36. Averaged Over all farms the test varieties gave slightly higher yields than the farmers' varieties at all levels of management (Table 8).

Management package experiment

During the 1976 wet season the management package experiment was conducted on one irrigated farm. The input levels used by the farmer M_1 and the tested management packages M_2 to M_5, are shown in Table 9. The farmer grew IR1529; the test variety was IR36.

The farmers' variety performed better than the test variety at all management levels except M_1 and M_4 (Table 10). The test variety yielded 0.6 t/ha higher at M_4. However, on the average, neither the test variety nor the higher management levels gave yield increases above the farmers' practice, partly because both farmers' varieties and test varieties were heavily damaged by rats.

During the 1977 wet season the same experiment was conducted on 2 pump-irrigated farms and one rainfed farm. The input levels used by the cooperating farmers and under various management levels are shown in Table 9. On the average, the farmers used higher fertilizer than the M_2 level. Farmers used only one hand or rotary weeding to control weeds and 2 or more foliar sprays of insecticides in the field to control insects. The irrigated farms used granular insecticides to supplement foliar application. The rainfed farm did not apply any granular insecticide.

All 3 cooperating farmers grew IR36 and the test variety was IR42 (Table 10). The farmers' variety under farmers' management levels yielded higher than the M_2 level, while the test variety produced higher yields than the farmers' yield at all higher management levels, averaging 0.5 t/ha higher across all management levels.

The rainfed farm suffered intermittent water shortage; yet the test variety performed better than the farmers' variety at all management levels. The irrigated farm had a severe whorl maggot problem, and

Table 8. Yields of farmers' varieties and of test varieties with high and farmers' levels of cultural practices at different input levels.[a] Camarines Sur, Philippines, 1976–77.

Trials (no.)	Variety	Grain yield (t/ha) Farmers'	Intermediate	High	Average
		1976 wet season			
6	Farmers'[b]	2.6	2.9	3.3	2.9
	Test (IR36)	2.8	3.3	3.3	3.1
		1977 wet season			
8	Farmers'[c]	3.0	3.6	3.2	3.3
	Test (IR42)	2.7	3.4	3.2	3.1
		1976 dry season			
5	Farmers'[d]	3.3	3.7	4.9	4.0
	Test (IR36)	3.4	4.1	5.3	4.3
		1977 dry season			
5	Farmers'[e]	3.5	4.5	6.0	4.7
	Test (IR26 and IR36)	4.0	4.2	6.1	4.9

[a] Data are averages of farmers' and high levels of cultural practices.

[b] Farmers used IR747, IR5, C4–63G, IR30 and IR26.

[c] Farmers used Masjava and IR36.

[d] Farmers used IR30, IR26, C4–63G.

[e] Farmers used IR1006, IR36 and IR747.

the farmers' levels of management yielded comparable to the M_4 level. Further, the test variety (IR42) on this farm lodged during a typhoon, therefore giving lower yields than the farmers' variety. On one irrigated farm higher yields were obtained using less than the farmers' level of nitrogen (82 kg N/ha), suggesting that the farmer did not use fertilizer efficiently.

During the 1977 dry season, the management package experiment was conducted on one canal–irrigatedfarm. The input levels used by the farmer and at the various management levels are shown in

Table 9. Average levels of farmers' inputs and levels of four management packages in management package experiments. Camarines Sur, Philippines, 1976 – 77.

Trials (no.)	Package level[a]	Fertilizer (kg/ha) N	P_2O_5	K_2O	Insect control[b] (no.) Seed bed F	G	Field R	F	G	Weed control (no.) M	C
					1976 wet season						
1	M_1	71	17	17	1	0	0	4	0	3	0
	M_2	40	10	0	0	0	0	2	0	1	0
	M_3	60	20	20	0	1	1	0	0	0	1
	M_4	80	30	30	2	0	1	0	1	1	1
	M_5	100	40	40	0	2	0	1	4	1	1
					1977 wet season						
3	M_1	47	12	12	0	0	0	2.6	0.7	1	0
	M_2	40	10	0	0	0	0	3.0	0	1	0
	M_3	60	20	20	0	1	1	0.5	0	0	1
	M_4	80	30	30	0	2	1	1.0	1	0	1
	M_5	100	40	40	0	2	0	2.5	4	1	1
					1976 dry season						
2	M_1	42	32	5	1.5	0	0	4	0	0.5	0.5
	M_2	40	10	0	0	0	0	2	0	1	0
	M_3	80	20	20	1	0	0	2	1	0	1
	M_4	120	30	30	2	0	0	2	2	0	1
	M_5	160	40	40	2	1	0	1	4	1	1
					1977 dry season						
1	M_1	64	0	0	0	0	0	4	0	1	1
	M_2	40	10	0	0	0	0	2	0	1	0
	M_3	80	20	20	0	1	1	0	0	0	1
	M_4	120	30	30	1	1	1	1	0	0	1
	M_5	160	40	40	0	2	0	1	4	1	1

[a] M_1 = farmers' level of application of the three inputs; M_2-M_5 = level of fertilizer, insect control and weed control as listed in the table.

[b] F = foliar, G = granular, R = root zone placement of liquid carbofuran

[c] M = mechanical weeding, either by hand or rotary weeder; C = application of chemical herbicide.

Table 10. Grain yields of farmers' and the test varieties compared at farmers' and four input management packages and grown under high levels of cultural practices. Camarines Sur, Philippines, 1976 – 77.

Trials (no.)	Variety[a]	Grain yield (t/ha)					
		M_1[b]	M_2	M_3	M_4	M_5	Av
		1976 wet season					
1	Farmers'	2.7	2.9	3.2	2.2	2.9	2.8
	Test (IR36)	2.7	2.7	1.9	2.8	2.4	2.5
		1977 wet season					
3	Farmers'	2.6	2.4	2.9	3.0	3.1	2.8
	Test (IR42)	2.8	2.7	3.6	3.4	3.8	3.3
		1976 dry season					
2	Farmers'	3.2	3.3	3.6	4.3	4.8	3.8
	Test (IR36)	3.6	4.2	4.5	5.2	6.3	4.8
		1977 dry season					
1	Farmers'	2.3	3.1	4.6	4.2	5.1	3.8
	Test (IR26)	4.4	5.0	5.1	3.7	5.1	4.7

[a] Farmer variety was IR1529 in 1976 wet, IR36 in 1977 wet, IR26 and IR30 in 1976 dry and IR36 in 1977 dry.

[b] M_1 = farmers' level of management.

Table 9. The nitrogen level used by the farmer was between the M_2 and the M_3 levels.

The test variety (IR26) outyielded the farmers' variety (IR36) under all management levels except at the M_4 level, where the crop lodged and was also damaged by rats (Table 10). The lowest grain yield was obtained using the farmers' management with his variety. Grain yields progressively increased from M_2 to M_5 as the levels of inputs were increased. On the average, the test variety yielded 0.9 t/ha higher than the farmers' variety over all management levels.

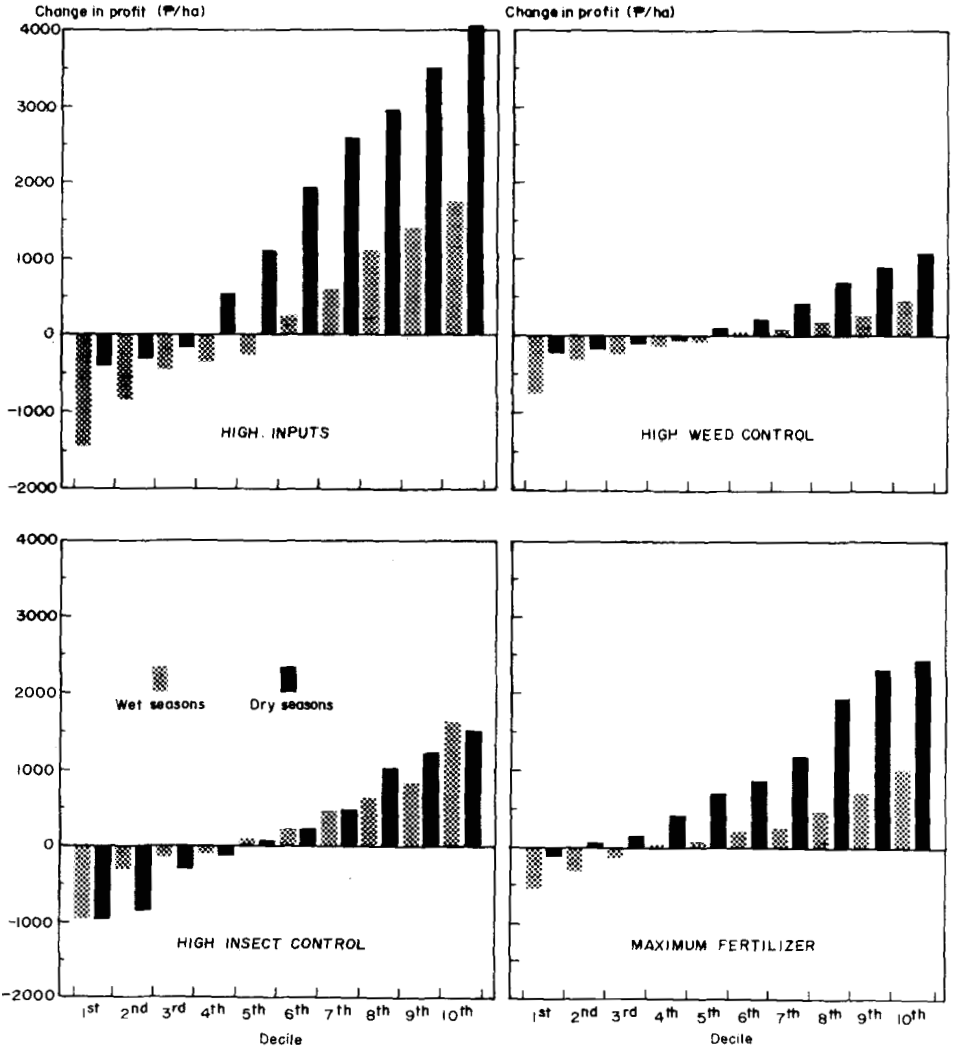
ECONOMIC ANALYSIS OF BIOLOGICAL CONSTRAINTS

The yields obtained by applying the high inputs were valued and input costs were subtracted to obtain net returns of test input costs. One-seventh of the value of yield was subtracted to allow for harvesting and threshing costs. All prices used were those reported to have been received or paid by farmers (Table 11). The net returns with high inputs were compared to net returns of input costs for the farmers' input levels (Table 12).

High inputs cost an average of about four times as much as farmers were spending in the dry season. In the three years, net returns in 20 dry season trials were about 13% higher with the high inputs than with the farmers' inputs. In 70% of the cases, the high inputs resulted in higher net returns, but in 30% they decreased (Figure 4). Most of the losses occurred in 1975, when the high input level was set very high and hence was very costly.

Table 11. Mode of prices of inputs as reported by farmers and used in constraints experiments. Camarines Sur, Philippines, 1975–77.

		Price (₱) per unit					
		Wet season			Dry season		
Input	Unit	1975	1976	1977	1975	1976	1977
Fertilizer							
Urea	50 kg	92.80	92.80	92.00	91.00	87.00	86.50
14–14–14	50 kg	70.00	70.00	71.00	72.00	72.00	11.20
16–20-0	50 kg	74.80	74.80	62.00	72.00	76.00	76.20
Insecticides							
Furadan 3G	16.7 kg	-	91.00	109.67	112.50	113.00	113.00
Hytox	0.5 kg	25.45	31.25	-	-	-	-
Lindane 6G	25.0 kg	72.00	-	90.00	112.00	112.50	112.50
Weed control							
Hand weeding	l ha	87.50	87.50	50.00	93.00	90.00	89.00
Rotary weeding	1 ha	30.00	30.00	-	-	-	-
2,4–D(G)	25 kg	68.00	65.00	60.00	66.00	67.60	67.60
Saturn D	15 kg	67.80	70.00	-	-	-	-
Agroxone	1 liter	-	27.00	-	-	-	-
Palay	1 kg	1.00	1.00	1.18	0.90	1.00	1.04



4. Changes in Profit (₱/ha) obtained from high inputs compared to farmers' inputs in 27 wet season and 20 dry season trials. Camarines Sur, Philippines, 1975–77. Average result grouped by decile.

Table 12. Comparison of anticipated maximum yield level of inputs with farmers' levels. Camarines Sur, Philippines, 1975 – 77.

Year	Trials (no.)	Input cost (₱/ha)		Yield (t/ha)		Net returns (₱/ha)	
		Farmers'	High	Farmers'	High	Farmers'	High
			Wet season				
1975	6	365	1221	3.5	4.6	2735	2779
1976	6	452	1285	2.7	3.4	1618	1325
1977	15	365	1487	3.6	3.8	2859	1945
All	27	384	1383	3.4	3.9	2556	1993
			Dry season				
1975	3	482	2492	3.9	5.6	2818	2308
1976	5	417	1689	3.3	4.8	2887	3149
1977	12	410	1920	3.5	5.9	2590	3180
All	20	423	1949	3.5	5.6	2698	3041

In 27 wet season trials the high input level averaged nearly 4 times the farmers' costs. Yields were increased by 0.5 t/ha, but net returns were decreased in 75% of the wet season cases.

Weed control. The high level of weed control added very little to yield but also added little to cost (Table 13). In the 1977 dry season and the 1975 wet season weed control increased farmers returns somewhat. However, there is little to suggest that weed control is a major constraint. Farmers' practices seem to be adequate.

Insect control. The high level of dry season insect control cost 8 times what farmers were spending on this input and increased the value of output by about half as much as it cost, clearly indicating that farmers' levels were preferable to the high levels (Table 14). Wet season results were similar. In nearly 80% of all trials, high insect control resulted in a larger reduction in net returns as compared with farmers' levels.

The intermediate level of insect control had a much lower cost than the high level -- it cost only twice what farmers were spending (Table 15). In the dry season, the intermediate level gave an average increase in net returns and resulted in losses only 20% of the time. In the wet season, however, the intermediate level was no more effective than the farmers' levels in protecting rice from pests. Average yield increase was nil.

Table 13. Economic comparisons of tested maximum yield level of weed control and of farmers' levels. Camarines Sur, Philippines, 1975 – 77.

Year	Trials (no.)	Input cost (₱/ha) Farmers'	Input cost (₱/ha) High	Increase resulting from high inputs: Yield[a] (t/ha)	Increase resulting from high inputs: Output value (₱/ha)	Increase resulting from high inputs: Net returns (₱/ha)	B – C ratio of increased inputs
				Wet season			
1975	6	89	117	0.16	160	132	5.7
1976	6	110	110	0.03	27	27	0.0
1977	15	65	157	– 0.09	-94	– 186	neg
All	27	80	138	0.0	-11	- 68	neg
				Dry season			
1975	3	71	210	0.03	30	– 109	0.22
1976	5	58	149	0.12	142	51	1.56
1977	12	109	158	0.23	230	181	4.69
All	20	91	164	0.17	178	105	2.43

[a]The share paid to the harvester has been deducted.

Table 14. Economic comparison of the tested maximum yield level and of farmers' levels of insect control. Camarines Sur, Philippines, 1975-77.

Year	Trials (no.)	Input cost (₱/ha) Farmers'	Input cost (₱/ha) High	Increase resulting from high inputs: Yield[a] (t/ha)	Increase resulting from high inputs: Output value (₱/ha)	Increase resulting from high inputs: Net returns (₱/ha)	B-C ratio of increased inputs
				Wet season			
1975	6	76	637	0.45	450	-111	0.80
1976	6	172	540	0.17	153	– 215	0.42
1977	15	76	710	0.18	187	– 447	0.29
All	27	97	656	0.24	238	– 321	0.43

continued on next page

Table 14 continued

			Dry season				
1975	3	167	1388	0.34	340	-881	0.28
1976	5	125	742	0.16	160	-457	0.26
1977	12	86	945	0.85	850	-9	1.00
All	20	108	961	0.60	601	-252	0.70

[a] The share paid to the harvester has been deducted.

Table 15. Economic comparison of the tested intermediate level of insect control and of levels used by farmers. Camarines Sur, Philippines, 1976–77.

Year	Trials (no.)	Input cost (₱/ha)		Increase from intermediate inputs			B-C ratio of increased inputs
		Farmers'	Intermediate	Yield[a] (t/ha)	Output value (₱/ha)	Net returns (₱/ha)	
			Wet season				
1976	6	172	243	-0.03	-27	-98	neg[b]
1977	8	66	221	0.07	73	-82	0.47
All	14	111	230	0.03	30	-88	0.25
			Dry season				
1976	5	125	191	0.05	59	-7	0.89
1971	6	88	243	0.34	340	185	2.19
All	11	105	219	0.21	212	98	1.86

[a] The share paid to the harvester has been deducted.
[b] neg = negligible.

Table 16. Economic comparison of the tested maximum yield level from fertilizer and of farmers' levels. Camarines Sur, Philippines, 1975 – 77.

Year	Trials (no.)	Input cost (₱/ha)		Increase resulting from high inputs			B – C ratio of increased inputs
		Farmers'	High	Yield[a] (t/ha)	Output value (₱/ha)	Net returns (₱/ha)	
				Wet season			
1975	6	200	467	0.36	360	93	1.35
1976	6	170	635	0.35	315	– 150	0.68
1977	15	224	620	– 0.31	– 322	– 718	neg[b]
All	27	207	589	– 0.01	– 29	– 411	neg
				Dry season			
1975	3	244	894	1.01	1010	360	1.54
1976	5	234	798	1.11	1310	746	2.32
1977	12	215	817	1.03	1030	428	1.71
All	20	224	824	1.05	1097	497	1.83

[a] The share paid to the harvester has been deducted.

[b] neg = negligible.

Fertilizer. In the wet season trials, the results showed an economic benefit from high fertilizer application in only one year (Table 16), In the 1976 and 1977 wet seasons the high fertilizer level cost more than it returned in value of rice, In 60% of the cases high fertilizer rates reduced net returns compared with farmers' fertilizer levels. The intermediate level of fertilization was also quite risky in the wet season, reducing net returns in 50% of the cases (Table 17).

In the dry season, the high level of fertilizer application cost 3 times what farmers were spending for fertilizer in the dry season (Table 16). The high fertilizer level increased net returns relative to farmers' levels and in a high percentage of cases, Thus, it appears that the 1.1 t/ha yield increase attributable to high fertilizer level would give a net return in the dry season.

Table 17. Economic comparisons of one tested intermediate level of fertilizer[a] and of farmers' levels. Camarines Sur, Philippines, 1976–77.

Year	Trials (no.)	Input cost (₱/ha)		Increase from intermediate inputs			B–C ratio of increased inputs
		Farmers'	Intermediate	Yield[b] (t/ha)	Output value (₱/ha)	Net returns (₱/ha)	
				Wet season			
1976	6	170	448	0.34	306	28	1.10
1977	8	184	441	0.26	270	13	1.05
All	14	178	444	0.29	285	19	1.07
				Dry season			
1976	5	234	559	0.69	814	489	2.5
1977	6	279	559	1.03	1030	750	3.7
All	11	259	559	0.88	932	632	3.1

[a]Two intermediate levels of fertilizer were tested. The higher level is analyzed here.

[b]The share paid to the harvester has been deducted.

Economically recoverable gap (ERG)

Analysis of the experiments shows that the treatments giving most frequently the highest increase in net returns in the wet season were the farmers' weed control, the intermediate level of insect control, and the second intermediate fertilizer level. In the dry season, the combination giving optimum economic performance was the farmers' weed control, the intermediate level of insect control, and the maximum fertilizer level. The yield difference between these input treatments and the farmers' inputs is defined as the economically recoverable gap (ERG). The ERG was equal to about 70% of the total gap in the 1975 and 1976 wet seasons. In the typhoon-ridden 1977 wet season, the highest level of inputs resulted in no yield increase and no gap, while the lower economic optimum combination gave a yield gap of 0.5 t/ha. In the dry season, the ERG averaged between 70% and 90% of the total gap.

The analyses in Tables 17 and 18 suggest that farmers should be able to recover part of the yield gap by using higher rates of

Table 18. Total gap and economically recoverable gap as determined from three years of experiments on farmers' fields. Camarines Sur, Philippines, 1975–77.

Year	Trials (no.)	Farmers' yield (t/ha)	High input yield (t/ha)	Total gap (t/ha)	Intermediate input yield[a] (t/ha)	Economically recoverable (t/ha)	ERG as % of total gap
				Wet season			
1975	6	3.6	4.6	1.0	4.3	0.7	70
1976	6	2.7	3.4	0.7	3.2	0.5	71
1977	8	3.3	3.3	0.0	3.6	0.3	0
All	20	3.2	3.7	0.5	3.7	0.5	100
				Dry season			
1975	3	3.9	5.6	1.7	5.5	1.6	94
1976	5	3.3	4.8	1.5	4.5	1.2	80
1977	6	3.5	5.9	2.4	5.2	1.7	71
All	14	3.5	5.4	1.9	5.0	1.5	79

[a]For 1976 and 1977, defined as farmers' weed control levels and in the wet season the higher intermediate fertilizer level; in the dry season, the maximum fertilizer level. In 1975, this refers to management package level M_3 in the wet season and M_4 in the dry season (IRRI Annual report 1975, p. 312).

fertilizer application in the dry season. To better understand why farmers were not using the higher fertilizer level the farmers with experiments and a random sample of farmers in the same barrios were asked why they did not use higher fertilizer rates. The primary reasons given were the lack of capital and the belief that they were already using enough fertilizer (Table 19). These were the same reasons expressed by farmers in other areas of the Philippines. The more detailed analysis in the Nueva Ecija chapter provides a basis for understanding these observations.

Table 19. Responses given by surveyed farmers[a] to the question of why they were unwilling to apply higher fertilizer rates. Camarines Sur, Philippines, 1975 – 77.

Reason	Wet season			Dry season	
	1975 (%)	1976 (%)	1977 (%)	1976 (%)	1977 (%)
Lacked capital	39	28	12	26	36
Used high enough rates	28	40	57	16	46
Plants may lodge	3	8	3	0	0
Plants infected by insects	0	0	2	0	0
No response	19	0	ll	45	0
Trying to economize	0	2	0	0	8
Lack of water	3	14	11	11	8
Others	8	8	4	2	2
Total	36	100	100	100	100

[a] Numbering 36 (1975) and 66 (1977) in the wet season, and 38 (1976) and 59 (1977) in the dry season.

Appendix Table 1. Grain yields under farmers' and test levels[a] of fertilizer, under farmers' and high levels of weed and insect control measures[b] in farmers' fields. Camarines Sur, Philippines, 1976 – 77 wet seasons.

Farmer	Variety	Weed and insect control level	Nitrogen applied Farmers' level Rate (kg/ha)	Timing[c] (DT)	Grain yield (t/ha) at N (kg/ha) of Farmers'	40	70	100
			1976 wet season					
Ranara	IR747	Farmers'	45	22, 36 & 41	3.7	3.9	4.0	3.7
		High			4.0	4.0	4.6	4.3
Viras	IR26	Farmers'	49	5 & 17	3.7	4.2	4.6	4.7
		High			3.7	4.2	4.7	4.8
Zamudio	IR747[d]	Farmers'	0	-	0.5	0.6	0.8	0.5
		High			0.4	0.4	0.6	0.7
Cezar	C4-63G	Farmers'	39	59	2.7	2.8	1.9	2.7
		High			2.7	3.1	3.1	3.0
Naldo	IR30	Farmers'	0	-	3.4	3.9	4.2	4.1
		High			3.8	4.5	5.0	5.0
Viñas	IR5	Farmers'	71	7 & 46	2.4	2.7	2.4	2.3
		High			2.7	2.5	2.6	2.5
Av		Farmers'	34		2.1	3.0	3.0	3.0
		High			2.9	3.1	3.4	3.4
			1977 wet season					
Orquita[d]	IR36	Farmers'	14	B	2.7	3.5	2.9	2.8
		High			2.8	3.1	3.1	2.7
Reyes[d]	IR36	Farmers'	41	33	3.7	3.4	3.9	2.9
		High			2.4	3.3	2.9	2.6
Lopez[d]	IR36	Farmers'	0	0	2.7	3.7	3.9	4.9
		High			3.1	4.6	4.6	4.1
Maderazo	IR36	Farmers'	46	42	4.2	3.5	3.6	4.0
		High			4.2	3.7	4.0	3.8
Mulin – tapang	IR36	Farmers'	82	6, 22 & 45	3.3	3.3	3.0	3.3
		High			2.9	3.4	2.9	3.5
Austria	IR36	Farmers'	55	43	3.8	3.7	4.3	3.9
		High			3.4	4.0	3.8	4.5
Baloro	Masjava	Farmers'	0	0	2.2	2.7	2.7	2.1
		High			2.7	2.9	2.8	2.1
Ballon	IR36	Farmers'	84	B, 39	4.0	4.0	3.2	3.9
		High			3.6	4.3	3.6	3.2
Av		Farmers'	40		3.3	3.5	3.4	3.5
		High			3.1	3.7	3.5	3.3

[a] Test rate of nitrogen. I – 1 = 40 kg N/ha, 1 – 2 = 70 kg N/ha, high level (H) = 100 kg N/ha. Time of N application: basal and 5 – 7 days before panicle initiation.

[b] For 1977 wet season data, complete factorial experiment.

[c] DT = days after transplanting, B = basal.

[d] Rainfed farms.

Appendix Table 2. Grain yields under farmers' and test levels[a] of fertilizer, under farmers' and high levels of weed and insect control.[b] Camarines Sur, Philippines, 1976–77 dry seasons.

Farmer	Variety	Weed and insect control level	Nitrogen applied Farmers' level Rate (kg/ha)	Nitrogen applied Farmers' level Timing[c] (DT)	Grain yield (t/ha) at N (kg/ha) of Farmers'	50	100	150
			1976 dry season					
Torrecampo	IR30	Farmers'	28	0 & 21	3.6	3.6	3.8	4.3
		High			4.2	3.7	4.7	5.0
Viñas	C4–63G	Farmers'	67	6, 21 & 49	3.4	3.3	4.4	5.0
		High			3.6	4.2	4.7	5.4
Vibares	IR30	Farmers'	38	20 & 40	4.5	5.0	5.1	5.5
		High			4.5	4.9	5.2	5.3
Requiero	IR26	Farmers'	62	0 & 28	1.9	2.2	3.1[d]	3.0
		High			2.5	2.2	2.9	2.9
Mallare	IR30	Farmers'	21	22 & 43	2.9	3.5	3.5	4.4
		High			3.2	4.1	4.0	5.4
Av		Farmers'	37		3.3	3.5	4.0	4.4
		High			3.6	3.8	4.3	4.9
			1977 dry season					
Ballon	IR36	Farmers'	77	35, 55	5.5	6.5	6.9	4.9
		High			6.1	7.5	7.2	5.7
Estadilla	IR36	Farmers'	42	26, 32	3.9	4.8	4.7	4.6
		High			4.4	4.4	6.3	5.8
Rombano	IR747	Farmers'	48	22, 41	2.7	2.7	4.1	4.9
		High			5.8	4.5	5.7	6.2
Maderazo	C4–63	Farmers'	90	B, 29 & 51	3.4	4.3	4.9	3.3
		High			5.1	5.3	5.7	5.0
Baloro	IR1006	Farmers'	18	21, 31	1.9	2.8	4.0	3.4
		High			3.3	3.9	5.7	6.6
Brazil	IR36	Farmers'	64	0	3.5	4.5	5.2	5.8
		High			4.8	4.6	5.8	6.2
AV		Farmers'	46		3.5	4.3	5.0	4.5
		High			4.9	5.0	6.0	5.9

[a] Test rate of nitrogen: I-1 = 50 kg N/ha, 1–2= 100 kg N/ha, high level (H) = 150 kg N/ha. Time of N application: basal, 30 DT and 5-7 days before panicle initiation.

[b] Complete factorial experiment.

[c] DT = days after transplanting. B = basal.

[d] One replication only.

REFERENCES CITED

International Rice Research Institute (IRRI). 1975. Annual report. Los Baños, Philippines.

International Rice Research Institute (IRRI). 1977. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Philippines.

National Census and Statistics Office. 1971. Census of Agriculture. Manila, Philippines.

Constraints to High Rice Yields, Iloilo, Philippines

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Iloilo has the fourth largest area planted to rice among the 7 most important rice-growing provinces in the Philippines. Because it is located in the Visayas, away from the Manila market, it represents somewhat different physical and socioeconomic conditions than the other Philippine study areas. Farmers use lower levels of inputs than in the other provinces in which constraints studies were conducted. A majority of the farmers practiced direct seeding in puddled soil using a high seed rate of 120 kg of palay per hectare. The high seeding rate was reported to better compete with weeds but because fertilizer application was low the higher plant density thereby achieved also contributed to higher yields.

Some unusual practices observed in the province were: (1) flooding the field 8 to 10 days after seeding to encourage the seedlings to grow faster and thus minimize weed competition; (2) in some transplanted fields, applying liquid or granular 2,4-D in the seedbed 3 days before pulling the seedlings in order, according to the farmers, to make the seedlings easier to pull; (3) direct seeding on paddies with 4-6 inches of standing water in the fields. Because the methodology of the yield constraints project was to have all non-test factors follow the farmers' practices, each of these unorthodox techniques may have affected the results of the experiments.

Yield gap and input levels

Insect control, weed control, and fertilizer application were used as test factors in 1976 and 1977. The high level of inputs was the same for the two wet seasons and farmers' levels were quite similar (Table 1). In the 1976 wet season all but one farmer applied less than 46 kg/ha of N. None applied fertilizer earlier than a month after transplanting or seeding. In the 1977 wet season farmers' fertilizer levels increased by about 10 kg N/ha but most applied their first fertilizer three weeks or more after transplanting. One hand or rotary weeding was common, with only

Table 1. High levels and farmers' levels of inputs. Iloilo, Philippines, 1976 – 77.

Input levels[a]	No. of trials[b]		Fertilizer (kg/ha)			Weed control[c] (no.)		Insect control[c] (no.)	
	I	R	N	P_2O_5	K_2O	M	C	F	G
				1976 wet season					
F	5	2	43	11	5	0.8	0.1	1.3	0.1
H			100	40	30	1.0	1.0	1.0	3.0
				1977 wet season					
F	19	4	55	12	5	0.9	0.3	2.3	0.0
H			100	40	30	0.9	1.2	2.0	3.5
				1976 dry season					
F	2	0	37	9	0	0.5	1.0	2.0	0.0
H			150	40	30	1.0	1.0	1.0	4.0
				1977 dry season					
F	17	0	66	11	3	1.3	0.7	1.8	0.2
H			150	40	30	0.8	1.0	2.3	3.6

[a] F = farmers' average input levels, H = high level.

[b] I = irrigated, R = rainfed trials.

[c] Data show average number of mechanical (M) weeding operations, either by hand or rotary weeding; C = chemical herbicide application.

[d] Data show average number of foliar (F) sprays -- Parapest, Mipcin, Azodrin, Brodan, etc., or granular (G) application of Basudin 10, Lindane, Furadan, etc. to paddy water.

one or two farmers using herbicides. Farmers averaged one insecticide spraying in the 1976 wet season and two in 1977 but used little or no granular insecticide.

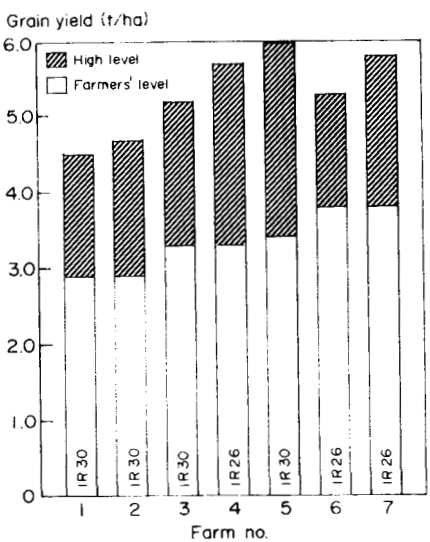
The wet season yield gap averaged 2.0 t/ha for 7 farms in 1976 (Table 2), with a substantial gap on every farm (Fig. 1). During the 1977 wet season, grain yields ranged from 2.3 t/ha to 4.9 t/ha

Table 2. Yields at farmers' levels and the high level of inputs. Iloilo, Philippines, 1976 – 1977.

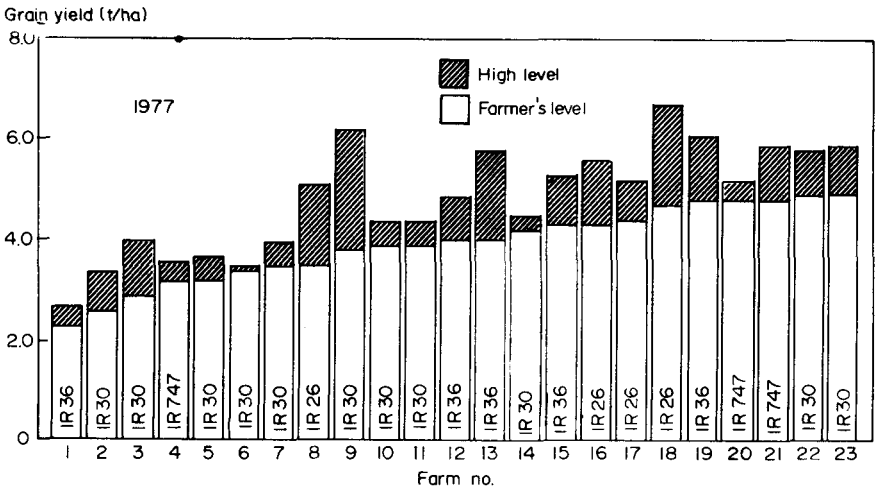
Year	No. of trials		Grain yield (t/ha)		
	Irrigated	Rainfed	Farmers' inputs	High inputs	Difference
			Wet season		
1976	5	2	3.3	5.3	2.0
1977	19	4	3.9	4.9	1.0
Both	24	6	3.8	5.0	1.2
			Dry season		
1976	2	0	3.1	5.6	2.5
1977	17	0	4.0	5.3	1.3
Both	19	0	3.9	5.3	1.4

at the farmers' levels of inputs (Fig. 2). The high input level produced yields ranging from 2.7 t/ha to 6.7 t/ha, averaging 4.9 t/ha. The average yield gap was 1.0 t/ha (Table 2).

The two farmer – cooperators in the 1976 dry season trials used a low fertilizer rate, but sprayed twice and applied a herbicide.



1. Variations in yield gap between farmers' fields and experimental fields. Iloilo, Philippines, 1976 wet season.



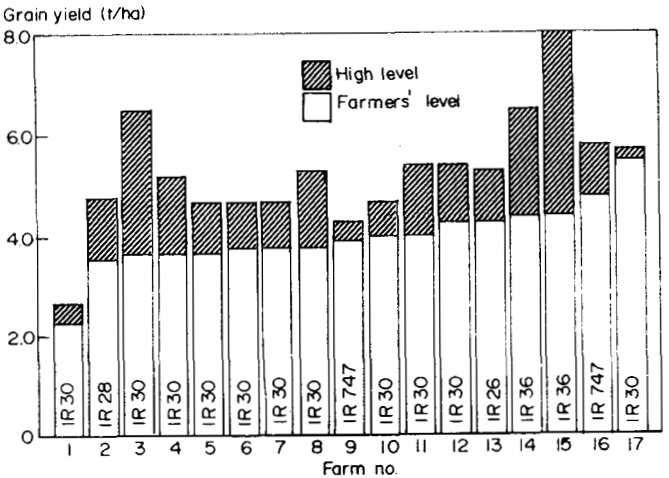
2. Variations in yield gap between farmers' fields and experimental fields. Iloilo, Philippines, 1977 wet season.

In 1977, the average level of fertilizer applied by the cooperating farmers was 66 kg N/ha, 11 kg P_2O_5/ha and 3 kg K_2O/ha (Table 1). One cooperating farmer applied none of the test inputs to his field. Except for that farm, all cooperating farmers used two or more foliar sprays of insecticides. One farmer used granular insecticides in addition to foliar sprays.

Thirteen out of 17 farmers used herbicides to control weeds. Ten used sprayable weedicide and three used granular. On one farm the farmer mixed granular 2,4-D and butachlor. Herbicides were applied at about 2 weeks after seeding. Hand weeding was done at 25 to 45 days after seeding in 12 farms.

The dry season yield gap averaged 2.5 t/ha on two farms in 1976 and 1.3 t/ha on 17 farms in 1977 (Table 2). In most dry season trials, the yield gap exceeded .25 t/ha, but in three 1977 trials it was less (Fig. 3). Grain yield at the farmers' levels of inputs ranged from 2.3 t/ha to 5.5 t/ha, averaging 4.0 t/ha. Insufficient water, poor management of inputs, and low levels of inputs on some farms contributed to the low yields.

At the high input level, grain yields varied from 2.7 t/ha to 8.0 t/ha, averaging 5.3 t/ha. The lowest yield (2.7 t/ha) was obtained on a farm where there was an acute water shortage. It was observed that crops receiving high fertilizer rate were affected more by drought than those receiving a low fertilizer rate. The highest yield was obtained with IR36 on a farm where



3. Variations in yield gap between farmers' fields. Iloilo, Philippines, 1977 dry season.

there was adequate water supply and good land preparation. Ten farms produced 5.0 tons or more per hectare, while the six other farms had grain yields of 4.2 t/ha to 4.8 t/ha.

Contributions of separate factors

In every season, fertilizer made the largest contribution to the yield gap, averaging 0.6 t/ha in the wet and 1.3 t/ha in the dry season (Table 3). Insect control made a modest contribution in the wet season while high weed control gave a smaller increase of 0.1 t/ha.

1976 wet season. The yield increase from high fertilizer levels was significant on 6 of 7 farms. Fertilizer accounted for 44% of the yield gap, because farmers applied low levels at the wrong time.

Insect control contributed 31% to the yield gap. Although the farmers had applied large amounts of foliar insecticides, crops on two farms were seriously damaged by leaf folders. The high level of insect control, however, did not control those either, and had a significant effect on grain yield on only one farm.

On four out of seven farms, weed control made a significant contribution to the yield gap, with an average of 0.4 t/ha or 25% for all seven farms. Late hand weeding -- 30 to 40 days

Table 3. Relative contribution of insect control, fertilizer, and weed control to the improvement of rice yields in farmers' fields. Iloilo, Philippines, 1976–1977.

Year	Trials (no.)	Grain yield (t/ha)			Contribution (t/ha) of [a]			
		Farmers' inputs	High inputs	Difference	Fertilizer	Weed control	Insect control	Residual
			Wet season					
1976	7	3.3	5.3	2.0	0.7	0.4	0.5	0.4
1977	16	3.6	4.6	1.0	0.6	0.3	0.4	-0.3
Both	23	3.5	4.8	1.3	0.6	0.3	0.4	0.0
			Dry season					
1976	2	3.1	5.6	2.5	1.6	0.4	0.2	0.3
1977	9	4.0	5.4	1.4	1.2	0.2	0.3	-0.3
Both	11	3.8	5.4	1.6	1.3	0.2	0.3	0.0

[a] Measured as yield decrease due to a reduction from the high to the farmers' levels of each input.

after transplanting -- by the farmers on two irrigated and one rainfed farm contributed to the gap. On one rainfed direct-seeded farm, no weeding was done by the farmer. On the three other irrigated farms, farmers hand-weeded between 22 and 25 days after transplanting.

1977 wet season. Twenty-three experiments were conducted in farmers' fields in the 1977 wet season -- 9 complete factorial, 7 minifactorial, and 7 supplemental trials. Four farms were rainfed. Two rainfed farms and six irrigated farms transplanted. The rest practiced direct seeding on puddled soil.

Averaging over the 16 farms with complete and minifactorial experiments, the yield gap between farmers' levels and the high level of inputs was 1.0 t/ha. Fertilizer contributed 46%, insect control 31%, and weed control 23% to the yield gap.

1977 dry season. During the 1977 dry season 4 complete factorial, 5 minifactorial, and 7 supplemental trials were conducted on the irrigated farms. Two cooperating farmers transplanted their crop, the rest direct-seeded on puddled soil.

The relative contribution of the test factors based on 4 complete factorial and 5 minifactorial experiments shows that fertilizer contributed 68%, insect control 19%, and weed control 13% to the yield gap.

Table 4. Farmers' levels and intermediate levels of fertilizer and insect control. Iloilo, Philippines, 1976 – 1977.

	Wet season		Dry season	
	1976	1977	1976	1977
Trials (no.)	7	9	2	4
	Fertilizer (kg/ha)			
Farmers'				
N	43	71	37	92
P_2O_5	11	22	9	6
K_2O	5	8	0	0
Intermediate I				
N	40	40	50	50
P_2O_5	20	20	20	20
K_2O	10	10	10	10
Intermediate II				
N	70	70	100	100
P_2O_5	30	30	30	30
K_2O	20	20	20	20
	Insec t control[a]			
Farmers'				
F	1.3	2.8	1.5	3.0
G	0.1	0.0	0.0	0.2
Intermediate				
F	0.0	2.4	0.0	1.8
G	2.0	2.7	0.0	2.0

[a] Average number of applications. F = foliar application, G = granular application.

Intermediate input levels and fertilizer efficiency

In addition to the farmers' levels and the high levels of inputs, two intermediate fertilizer levels and one intermediate insect control level were tested (Table 4). The yields with these yields with these intermediate levels, averaged over all levels of other inputs, are shown in Table 5.

intermediate levels, averaged over all levels of other inputs, are shown in Table 5.

Farmers' fertilizer rates and timing of application varied from farm to farm. Very few farmers applied fertilizer as a basal dose after the last harrowing. About half of the farmers used complete fertilizer and the rest used only nitrogen and phosphorus fertilizers. Most farmers applied their fertilizer in a single dose (Appendix Tables 1–4).

Table 5. Grain yield under different levels of inputs in farmers' fields.[a] Iloilo, Philippines, 1976–77.

Year	Trials (no.)	Grain yield[b] (t/ha)						
		Fertilizer				Insect control		
		F	I-1	I–2	H	F	I	H
				Wet season				
1976	7	3.8	4.2	4.5	4.5	4.0	4.3	4.6
1977	9	3.9	4.1	4.2	4.4	4.0	4.1	4.3
Both	16	3.9	4.1	4.3	4.4	4.0	4.2	4.4
				Dry season				
1976	2	3.7	4.6	5.3	5.4	4.7	4.8	4.8
1977	4	3.8	3.6	4.4	4.6	4.0	4.1	4.2
Both	6	3.8	3.9	4.7	4.9	4.2	4.3	4.4

[a] Complete factorial experiment only.

[b] F = farmers' level, I = intermediate level, H = high level. Data are averages over all levels of other test inputs.

In the 1976 wet season the application of high fertilizer gave similar grain yields to those obtained from the I-2 level of fertilizer, which was 0.7 t/ha above the farmers' levels. In the 1977 wet season the average nitrogen fertilizer level applied by the cooperating farmers was almost double that of the first intermediate fertilizer level (Table 4). Yield from the I-1 level however, was 0.2 t/ha higher than the farmers' levels (Table 5). The second intermediate fertilizer treatment (I–2) increased yield by 0.3 t/ha over the farmers' levels even though the same amount of fertilizer was applied.

In the 1977 dry season the average nitrogen fertilizer applied by the farmers was almost double that of the first intermediate fertilizer level (I – 1), but the yield difference was slight (Tables 4 and 5). The second intermediate fertilizer treatment (I – 2) gave a substantial increase over the farmers' yields, with almost the same quantity of fertilizer applied.

In the 1976 wet season the first intermediate fertilizer level increased yield by 0.7 t/ha over the farmers' levels under farmers' weed and insect management practices (Table 6). The nitrogen rate was lower than the farmers' levels; yet it produced higher yields, indicating that the farmers' use of fertilizer was not as efficient as the researchers' use. Under the high level of weed and insect control practices, the first intermediate level of fertilizer produced a modest yield gain of 0.2 t/ha over the farmers' levels.

Table 6. Average grain yield with farmers' levels and three test levels of fertilizer with farmers' levels and high levels of insect and weed control. Iloilo, Philippines.

Year	Trials (no.)	Weed and Insect control level[a]	Farmers' level		Yield (t/ha) with experiment nitrogen level[b]		
			Nitrogen (kg/ha)	Yield (t/ha)	I-1	I-2	H
			Wet season				
1976	7	F	43	3.3	4.0	4.2	4.2
		H	43	4.4	4.6	5.1	5.3
1977	9	F	71	3.7	3.8	3.9	4.1
		H	71	4.2	4.2	4.8	4.7
			Dry season				
1976	2	F	37	3.1	4.9	5.0	5.2
		H	37	4.5	5.0	5.5	5.6
1977	4	F	92	3.6	3.8	4.1	4.4
		H	92	3.9	3.6	4.5	5.0

[a] F = farmers' level, H = high level.

[b] Test rates of nitrogen: Wet season - I – 1 = 40 kg N/ha, 1 – 2 = 70 kg N/ha, H = 100 kg N/ha. Dry season - I – 1 = 50 kg N/ha, 1 – 2 = 100 kg N/ha, H = 150 kg N/ha. Time of N application: basal and 5 to 7 days before panicle initiation in the wet season and basal, 20 – 30 DT and 5 to 7 days before panicle initiation in the dry season.

In the 1977 dry season the I – 2 level, with 100 kg of N/ha, had a higher yield than the farmers' levels, with 92 kg/ha at either high or farmers' levels of weed and insect control (Table 6), indicating that the farmers did not apply fertilizer properly. Fertilizer rates of the farmers varied from farm to farm. Only two of the cooperating farmers applied phosphorus fertilizer without potassium, while the other two used nitrogen fertilizer alone.

These results are a good indication that the farmers' yields could be increased significantly if proper fertilizer management and improved insect and weed control practices were followed.

Common damaging insects were leaf folders, leaf rollers, stemborers, and caseworms. Armyworms were observed in the early reproductive stage of the crop on farm 18. High levels of insect control increased yield over the farmers' by 0.6 t/ha in the 1976 wet season and by 0.3 t/ha in 1977.

In the dry season, except for isolated cases, improved insect control practices gave no significant increase in grain yield. On four farms in the area leaf rollers and leaf folders were prevalent at the late reproductive stage of the crop. Whorl maggots were noted on only two farms. Brown planthoppers and green leafhoppers were present in all farms but caused little crop damage.

Cultural practices and varieties

The cultural practices associated with growing the crop were also tested. High cultural practices included the planting of 21 – day – old seedlings at the recommended spacing. A variety more recently released than the farmers' variety was also grown, at both the high and farmers' levels of cultural practices and at two input management packages above the farmers' levels.

1976 wet season. The effect of high cultural practices was modest under farmers' input management package practices (Table 7) when compared with the farmers' methods of planting and seedling age except on the rainfed farm, which was direct seeded. However, under intermediate and high input levels, grain yields with farmers' and high cultural practices were similar.

The test variety was moderately affected by bacterial leaf blight at four farms during the heading stage. There were no significant differences in grain yield between the test variety and farmers' varieties on six out of seven farms (Table 8).

Table 7. Yields with cultural practices at a high level compared to the farmers' levels.[a] Iloilo, Philippines, 1976–77.

No. of trials[b] I	R	Level of cultural practices[c]	Grain yield (t/ha) at input level: Farmers'	Intermediate	High	Average
			1976 wet season			
5	2	F	3.7	4.5	5.1	4.4
		H	3.9	4.6	5.1	4.5
			1977 wet season			
6	3	F	4.1	4.6	5.0	4.6
		H	3.9	4.3	5.0	4.4
			1976 dry season			
2	0	F	3.4	5.0	5.6	4.7
		H	4.0	5.4	5.9	5.1
			1977 dry season			
4	0	F	4.3	4.3	4.7	4.4
		H	4.1	4.4	5.9	4.8

[a] Complete factorial experiment only. Data are averages of the farmers' varieties and the test varieties.

[b] I = irrigated trials, R = rainfed trials.

[c] F = farmers' level, H = high level.

1977 wet season. The high level of cultural practices was no better than the farmers' at all management levels. The test variety IR42 outyielded farmers' varieties by 0.8 t/ha (Table 8). Yields of both farmers' and test varieties, however, increased with increasing management levels.

Because of a prolonged drought the test variety was not harvested on two farms. Lodging at the high management level was observed at all farms but was severe on one. At the high management level, the highest yield obtained from the test variety was 6.9 t/ha (farm 18), while the average of 6 farms was 5.3 t/ha. Averaged over seven farms, the test variety yielded 4.8 t/ha at the

Table 8. Yields of farmers varieties compared to test varieties for input packages grown with high and farmers' levels of cultural practices.[a] Iloilo, Philippines, 1976–77.

No. of trials[b]		Variety	Grain yield (t/ha)			
I	R		Farmers'	Intermediate	High	Average
			1976 wet season			
5	2	Farmers'[c]	3.6	4.5	5.2	4.4
		Test (IR36)	4.0	4.6	5.0	4.5
			1977 wet season			
6	3	Farmers'[d]	3.5	4.1	4.6	4.1
		Test (IR42)	4.5[e]	4.8[e]	5.3[f]	4.9
			1976 dry season			
2	0	Farmers'[c]	3.4	5.0	5.7	4.7
		Test (IR36)	4.1	5.4	5.8	5.1
			1977 dry season			
4	0	Farmers'[c]	3.7	3.8	5.0	4.2
		Test (IR36)	4.7	4.9	6.5	5.3

[a] Data are averages of farmers' and high cultural practices.

[b] I = irrigated trials, R = rainfed trials.

[c] IR26 and IR30.

[d] IR747, IR26, IR30, and IR36.

[e] Average of 7 farms.

[f] Average of 6 farms.

intermediate and 4.5 t/ha at the farmers' management levels (Table 8).

1977 dry season. At farmers' levels and the intermediate management level, high cultural practices were no better than the farmers' cultural practices on all farms. However, at the high-input management level high cultural practices increased grain yield by 1.2 t/ha over the farmers' cultural practices (Table 7).

Averaging over all management levels, the test variety IR36 gave an increased yield of 1.1 t/ha over the farmers' varieties (Table 8). Within a variety, however, yields with farmers' and intermediate input management levels were not different. One reason for this was a serious water stress condition which caused highly fertilized crops to dry up.

Under the high management level, the test variety gave the highest yield of 8.7 t/ha on farm 13, while the farmers' variety, IR26, yielded only 5.5 t/ha in the same farm. The high yield potential of IR36 with high inputs was further observed in a nearby minifactorial experiment.

In general, farmers in Iloilo used early-maturingvarieties or lines. Only one farm used the intermediate-maturingvariety IR26. Yield losses from various degrees of rat infestation were observed in some areas where there was continuous cropping throughout the year.

Economic analysis

Table 9 shows the economic comparison of the high levels of inputs with the farmers' levels. Farmers spent one-fourthas much as the high input level in the dry season but had net returns about equal to the high inputs despite the yield difference. In the wet season the picture was quite similar — high inputs raised yields but not profits.

Weed control. After deducting one-seventh for harvesting and threshing costs, net yields increased from 0.2 to 0.4 t/ha over the high level of weed control (Table 10). Because the costs associated with this yield increase were modest, there was an increase in net returns in both wet and dry seasons and a B:C ratio on the increased inputs that exceeded 3.0.

Insect control. The maximum level of insect control cost about 10 times the amount farmers were spending on insect control

Table 9. Comparison of anticipated maximum yield levels of inputs and farmers' levels. Iloilo, Philippines, 1976–77.

Year	Trials (no.)	Cost of inputs (₱/ha)		Yields (₱/ha)		Net returns (₱/ha)	
		F	H	F	H	F	H
				Wet season			
1976	7	313	1285	3.3	5.3	2162	2693
1977	16	401	1567	3.6	4.6	2272	1876
All	23	374	1478	3.5	4.8	2236	2122
				Dry season			
1976	2	301	1678	3.1	5.6	2021	2525
1977	9	451	1794	4.0	5.4	2519	2274
All	11	423	1772	3.8	5.4	2430	2322

[a] F = farmers' level, H = high level.

Table 10. Economic comparison of the tested maximum yield level of weed control and farmer's levels. Iloilo, Philippines, 1976–77.

Year	Trials (no.)	Input cost (₱/ha)[a]		Increase resulting from high inputs			B – C ratio of increased inputs
		F	H	Yield[b] (t/ha)	Output value (₱/ha)	Net return (₱/ha)	
				Wet season			
1976	7	21	110	0.38	342	253	3.84
1977	16	61	143	0.27	243	167	2.96
All	23	49	133	0.30	270	186	3.21
				Dry season			
1976	2	50	110	0.39	351	291	5.85
1977	9	78	143	0.18	162	97	2.49
All	11	73	137	0.22	198	134	3.09

[a] F = farmers' level, H = high level.

[b] The share paid to the harvester has been deducted.

Table 11. Economic comparison of the tested maximum yield level of insect control and farmer's levels. Iloilo, Philippines, 1976 – 77.

Year	Trials (no.)	Input cost (₱/ha)[a] F	Input cost (₱/ha)[a] H	Increase resulting from high inputs: Yield[b] (t/ha)	Output value (₱/ha)	Net return (₱/ha)	B – C ratio of increased inputs
				Wet season			
1976	7	76	540	0.51	459	– 5	0.99
1977	16	56	849	0.28	252	– 541	0.32
All	23	62	755	0.35	315	– 378	0.45
				Dry season			
1976	2	75	740	0.09	81	– 584	0.12
1977	9	67	897	0.28	252	– 578	0.30
All	11	68	868	0.25	221	– 579	0.28

[a] F = farmers' level, H = high level.

[b] The share paid to the harvester has been deducted.

(Table 11). The yield increases from the high level were modest, indicating relatively little insect infestation and, as a consequence, profits were reduced by applying the high level of insect control. The intermediate level of insect control gave similar results in all but one season (Table 12). There appears to be no incentive for farmers to use the higher insect control treatments although the average yield loss from insects was 0.5 t/ha in the wet season and 0.3 t/ha in the dry season.

Fertilizer. The maximum level of fertilizer cost about twice the amount farmers were spending but gave increased net returns in every season, on the average (Table 13). The B – C ratios approached 2:l in the dry season and 1.5:1 in the wet season. The intermediate fertilizer level gave slightly higher returns in the wet seasons but somewhat lower returns in the dry season (Table 14).

Table 12. Economic comparison of the tested intermediate level of insect control and farmers' levels. Iloilo, Philippines, 1976 – 77.

Year	Trials (no.)	Input cost (₱/ha)[a]		Increase from intermediate inputs			B-C ratio of increased inputs
		F	I	Yield[b] (t/ha)	Output value (₱/ha)	Net return (₱/ha)	
				Wet season			
1976	7	76	204	0.24	216	88	1.69
1977	9	64	583	0.12	125	– 394	0.24
All	16	69	417	0.17	165	– 183	0.47
				Dry season			
1976	2	75	203	0.09	81	-47	0.63
1977	4	90	299	0.04	42	-167	0.20
All	6	85	267	0.06	55	-127	0.30

[a]F = farmers' level, I = intermediate level

[b]The share paid to the harvester has been deducted.

Table 13. Economic comparison of the rested maximum yield level of fertilizer and farmers' levels. Iloilo, Philippines, 1976 – 77. 1976 - 77.

Year	Trials (no.)	Input cost (₱/ha)[a]		Increase resulting from high inputs			B-C ratio of increased inputs
		F	H	Yield[b] (t/ha)	Output value (₱/ha)	Net return (₱/ha)	
				Wet season			
1976	7	216	635	0.58	522	103	1.25
1977	16	284	570	0.47	423	137	1.48
All	23	263	590	0.50	450	123	1.38
				Dry season			
1976	2	176	828	1.42	1278	626	1.96
1977	9	306	754	0.96	864	416	1.93
All	11	282	767	1.04	936	451	1.93

[a]F = farmers' level, H = high level.

[b]The share paid to the harvester has been deducted.

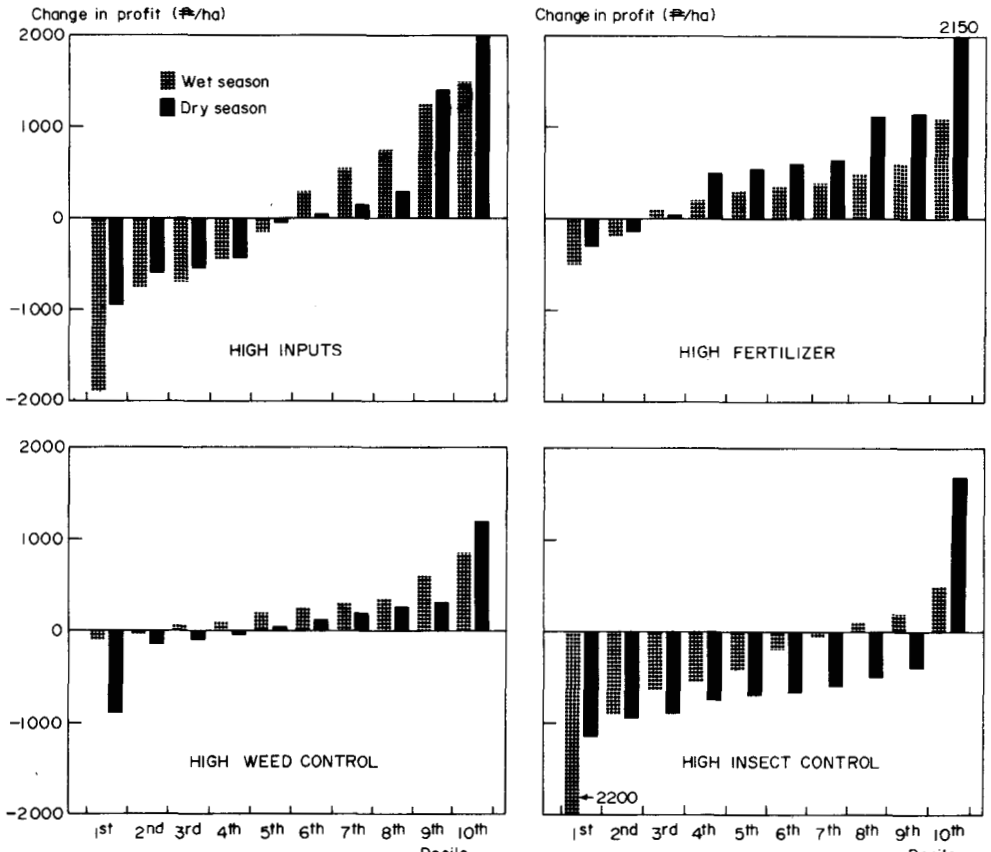
Table 14. Economic comparison of one of the tested intermediate levels of fertilizer and farmers' levels. Iloilo, Philippines, 1976 – 77.

Year	Trials (no.)	Input cost (₱/ha)[a] F	Input cost (₱/ha)[a] I	Increase from intermediate inputs: Yield[b] (t/ha)	Increase from intermediate inputs: Output value (₱/ha)	Increase from intermediate inputs: Net return (₱/ha)	B – C ratio of increased inputs
				Wet season			
1976	7	216	449	0.58	522	289	2.24
1977	9	352	404	0.20	208	156	4.00
All	16	293	424	0.37	345	214	2.63
				Dry season			
1976	2	176	566	0.56	504	114	1.29
1977	4	369	516	0.51	530	383	3.61
All	6	305	533	0.53	521	293	2.29

[a] F = farmers' level, I = intermediate level.

[b] The share paid to the harvester has been deducted.

Variability. Figure 4 shows the variability in returns from high inputs. The losses were large in the poorest 10% of trials reaching nearly ₱2000/ha. Except for the extremes of the distribution, the wet and dry seasons were quite similar. Maximum fertilizer application gave reduced profits in only 20% of the cases. High weed control level was less likely to be profitable in the dry season. Because the average profit was not increased by the use of high inputs, there was no incentive for farmers to use them.



4. Change in profit (₱/ha) obtained from high inputs compared to farmers' inputs in 23 wet season and 11 dry season trials. Iloilo, Philippines, 1976–77. Average grouped by deciles. (Experiments conducted by IRRI Agronomy Dept.)

Appendix Table 1. Grain yields under farmers' levels and test levels[a] of fertilizer under farmers' and high levels of weed and insect control measures. Iloilo, Philippines, 1976 wet season.

Farmer	Variety	Weed and insect control measures[c]	Nitrogen applied Farmers' level Rate (kg/ha)	Timing (DT)[b]	Grain yield (t/ha) Farmers'	I-1	I-2	H
Espino	IR30	F	44	38 & 55	3.4	4.2	4.8	4.5
		H			4.8	4.7	5.2	6.0
Cordon	IR26	F	46	50	3.8	3.8	4.4	4.6
		H			5.0	4.5	5.8	5.8
Gubatanga	IR30	F	38	30	3.3	4.1	4.4	4.6
		H			3.9	4.6	4.9	5.2
Barbera[d]	IR26	F	e		3.3	3.8	4.2	4.1
		H			5.2	5.1	5.5	5.7
Pinuela	IR30	F	24	28	2.9	3.9	3.2	3.4
		H			3.3	3.5	4.2	4.5
Arca	IR30	F	16	40	2.9	3.8	3.8	4.0
		H			4.1	4.4	4.1	4.7
Leonares[d]	IR26	F	70	4 & 60	3.8	4.6	4.6	4.3
		H			4.7	5.1	5.8	5.3
Average		F	43		3.3	4.0	4.2	4.2
		H			4.4	4.6	5.1	5.3

[a]Test rate of nitrogen: Intermediate levels I-1 = 40 kg N/ha; I-2 = 70 kg N/ha; High level (H) = 100 kg N/ha; Time of N application: basal and 5-7days before panicle initiation.

[b]DT = days after transplanting. [c]F = farmers' level, H = high level.

[d]Rainfed farm. [e]No data available.

Appendix Table 2. Grain yields under farmers' levels and test levels[a] of fertilizer under farmers' and high levels of weed and insect control measures[b]. Iloilo, Philippines, 1977 wet season.

Fanner	Variety	Weed and insect control measures[c]	Nitrogen applied Farmers' level Rate (kg/ha)	Timing (DS)[d]	Grain yield (t/ha) Farmers'	I-1	I-2	H
Valensuela	IR36	F	23	11 & 46[e]	4.8	5.3	4.9	5.5
		H			5.0	5.8	6.8	6.1
Magbanwa	IR30	F	39	36	2.9	3.0	3.1	3.4
		H			3.4	3.9	3.4	4.0
Cajelo	IR30	F	121	31 & 65	3.9	3.8	4.2	4.5
		H			4.3	4.2	4.6	4.4
Garcia	IR36	F	55	40	4.3	4.0	3.6	4.3
		H			5.5	4.7	5.5	5.3
Lanes	IR26	F	170	0, 27 & 67	4.6	4.7	5.1	4.6
		H			4.8	5.3	7.3	6.7
Dayon	IR747	F	53	48	3.2	2.6	3.6	3.1
		H			3.4	3.5	3.5	3.6
Hesmaña	IR26	F	90	20 & 51	3.5	4.6	4.2	5.0
		H			4.6	4.1	4.9	5.1
Vega	IR30	F	38	21 & 45	3.9	4.6	4.3	4.3
		H			4.1	4.1	4.1	4.3
Jamandre	IR36	F	50	0[e]	2.3	1.8	2.4	2.4
		H			2.6	2.1	2.9	2.7
Average		F	71		3.7	3.8	3.9	4.1
		H			4.2	4.2	4.8	4.7

[a] Test rate of nitrogen: Intermediate levels I-1 = 40 kg N/ha; I-2 = 70 kg N/ha; high level (H) = 100 kg N/ha. Time of N application: basal and 5-7 days before panicle initiation.

[b] Complete factorial experiment. [c] F = farmers' level, H = high level.

[d] DS = days after seeding. [e] DT = days after transplanting.

Appendix Table 3. Grain yield under farmers' level and test levels[a] of fertilizer under farmers' and high levels of weed and insect control measures in yield constraint experiments[b] in farmers' field. Iloilo, Philippines, 1976 dry season.

Farmer	Variety	Weed and insect control measures	Nitrogen applied Farmers' level Rate (kg/ha)	Timing (DT)[c]	Grain yield (t/ha) Farmers'	I-1	I-2	H
Cordon	IR26	F	24	35	2.5	4.6	4.9	5.3
		H			4.2	4.7	5.8	5.0
Pinuela	IR30	F	50	20 & 52	3.7	5.2	5.1	5.1
		H			4.8	5.3	5.3	5.4
Average		F	37		3.1	4.9	5.0	5.2
		H			4.5	5.0	5.6	5.2

[a] Test rate of nitrogen. Intermediate levels: I-1 = 50 kg N/ha; I-2 = 100 kg N/ha; high level (H) = 150 kg N/b. Time of N application: basal, 30 DT and 5-7 days before panicle initiation.

[b] Complete factorial experiment. [c] DT = days after transplanting.

Appendix Table 4. Grain yields under farmers' levels and test levels[a] of fertilizer under farmers' and high levels of weed and insect control measures. Iloilo, Philippines, 1977 dry season.

Farmer	Variety	Weed and insect control measures[c]	Nitrogen applied Farmers' level Rate (kg/ha)	Timing (DS)[d]	Grain yield (t/ha) Farmers'	I-1	I-2	H
Calucab	IR30	F	130	14, 44 & 74	2.3	2.3	2.9	2.7
		H			2.7	2.5	2.9	2.7
Magbanwa	IR30	F	27	33	3.7	4.5	4.4	5.2
		H			3.9	4.3	5.4	6.5
Cajelo	IR30	F	174	15 & 42	4.3	3.8	5.1	4.7
		H			5.2	3.2	4.9	5.4
Cordero	IR26	F	39	17 & 48	4.3	4.8	4.1	5.2
		H			4.0	4.4	4.8	5.3
Average		F	92		3.6	3.8	4.1	4.4
		H			3.9	3.6	4.5	5.0

[a]Test rate of nitrogen: Intermediate levels: I-1 = 50 kg N/ha; I-2 = 100 kg N/ha; high level (H) = 150 kg N/ha. Time of N application: basal, 30 DS and 5–7 days before panicle initiation.

[b]Complete factorial experiment. [c]F = farmers' level, H = high level.

[d]DS = days after seeding.

Constraints to High Rice Yields, Northwestern Central Plain, Thailand

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Rice is the most important commodity in the Thai economy. About 31% of Thailand's gross domestic product originates from the agricultural sector, and rice provides 32% of that. Rice farming occupies 65% of the total cultivated land. About 79% of the population is engaged in farming, 84% of which grow rice. Although rice is an important foreign exchange earner, almost all the rice produced is consumed in the country. Only 10% has been exported in recent years.

RICE PRODUCTION AND DEVELOPMENT IN THAILAND

Since 1967, Thailand has sought to increase rice production through irrigation improvement, new rice varieties, and extension of new rice technology to farmers. However, the level of new inputs by farmers is much less than recommended, and the use of traditional inputs continues. This paper reports on the results of research on the constraints to increased rice yields from 1974 through 1977.

Thailand's rice production increased by about 2.l%/year from 1960 to 1974. Most of this increase was from expansion of the cultivated area and an increase in the labor force. For 1960-64, average yields of rice were about 1.7 t/ha , 1.8 t/ha in 1970-74, and 1.9 t/ha in 1975-77. If rice yields cannot be further increased, Thailand will face a shortage of rice for export, and eventually, for domestic consumption.

Rice is grown in all regions of Thailand (Table 1). The most important region for commercial rice production is the Central Plain, which occupies about 30% of the total rice area of Thailand and produces about 33% of the total output. In the Central Plain, two crops of rice a year are grown wherever water is available.

- Wet season rice depends largely on rainfall. It is planted from May through August and is harvested from November through February. Most varieties grown in this season are local

Table 1. Area, production, and yield of rice by region. Thailand 1962-63 to 1976-77 (Division of Agricultural Economics, *Agriculture Statistical of Thailand 1976–77.* Ministry of Agriculture and Cooperatives).

Region	Crop Year					
	1962 – 72	1972 – 73	1973 – 74	1974 – 75	1975 – 76	1976 – 77
			Area (1000 ha)			
Northern	1,446	1,515	1,839	1,662	1,921	1,727
Northeastern	2,887	1,959	3,552	3,309	4,003	3,802
Central	2,149	2,298	2,479	2,397	2,409	2,424
Southern	538	617	493	614	564	623
Total	7,020	6,389	8,363	7,982	8,897	8,576
			Production (1000 ha)			
Northern	3,218	2,710	3,984	3,872	4,322	4,111
Northeastern	3,749	4,198	4,638	3,795	5,326	4,686
Central	3,926	4,483	5,451	4,829	4,647	5,103
Southern	864	1,022	825	890	1,005	1,168
Total	11,757	12,413	14,898	13,386	15,300	15,068
			Yield (t/ha)			
Northern	2.2	1.9	2.2	2.3	2.2	2.3
Northeastern	1.3	2.1	1.3	1.1	1.3	1.2
Central	1.8	1.9	2.2	2.0	1.9	2.1
Southern	1.6	1.7	1.7	1.5	1.8	1.9
Av	1.7	1.9	1.9	1.7	1.8	1.9

improved varieties that are well suited to the environment. In the 1972-73 wet season, about 5% of the nation's total rice area was planted to modern varieties. Today, in places such as the Chanasutr Project of Sing Buri, where land consolidation has been completed and the irrigation system is good, modern varieties are widely grown.

Dry season rice is planted from December through May and is harvested from April through August. The beginning and the end of the dry season crop vary depending on the harvesting of the wet season crop and the availability of irrigation water in each zone. In irrigated areas modern varieties are grown, mostly in the dry season.

The slight increases in Thai rice production have come from land expansion, adoption of modern varieties, and from the increased use of modern inputs such as fertilizer, insecticides, and herbicides. Use of fertilizer has increased by about 15%/year since 1962 (Table 2). During the early 1970s, about 60% of the total fertilizer use was for rice production (Division of Agricultural Economics 1975). On the average, farmers in the study area used about 30 kg N/ha for dry season rice, and about 25 kg N/ha for wet season rice.

Table 2. Fertilizer and irrigation in Thailand's agricultural sector, 1962–76 (Division of Agricultural Economics, Ministry of Agriculture and Cooperatives, unpublished data).

	Fertilizer nutrients (t)			Irrigated area[a] (1000 ha)			
	N	P	K	State projects	Tank projects	Pumps	Total
1962	13,126	6,795	1,955	1,477	52	70	1,599
1962–71	31,232	22,782	12,212	n.a.	n.a.	n.a.	n.a.
1972	57,242	41,653	38,657	2,197	83	216	2,496
1972–74	44,242	37,038	34,121	2,378	n.a.	220	2,598
1976	n.a.	n.a.	n.a.	2,448	n.a.	312	2,760

[a] n.a. = not available.

Farm machinery, especially farm tractors, has been rapidly adopted by Thai farmers. Farm tractors were introduced in 1951. By 1967 there were about 17,500 four-wheel tractors and about 2,000 two-wheel tractor-power-tillers in Thailand. About 52% of the large tractors were used in upland crop farming, and 48% were used for land preparation for broadcast rice. The large tractors were imported, expensive, and owned mostly by local merchants who rendered custom services to farmers. Because of the unsuitability of large tractors in the lowland rice area, especially for transplanted rice, the power tiller was developed locally and has been used since 1955 in areas growing transplanted rice. Of about 56,000 power tillers now used in rice farming, 80% were assembled in Thailand. Local privately-owned assembly plants produce 3- to 25-hp tillers at a much lower cost than imported tillers.

In addition to fertilizer, modern varieties, and machinery, irrigation is critical for rice production. The irrigated area in Thailand, however, is small compared to the total area

cultivated. From 1962 to 1972, irrigation expanded by nearly 60% (Table 2) to cover about 16% of the total cultivated area, mostly in the Central Plain. The policy of the Irrigation Department is to increase the irrigated area by 64,000 ha/year.

The Thai government has recognized the importance of rice as a source of employment and a foreign exchange earner for more than 100 years. The policies concerning rice in the Fourth Development Plan (1977–81) may be summarized as follows:

- increase rice yield on the land best suited to rice;
- urgently implement land reform and land consolidation;
- expand the sale of good quality seed through the Farmers' Market Organization;
- provide more supervised production credit through the Bank for Agriculture and Cooperatives;
- continue the rice price premium (rice export tax);
- maintain a price support on a limited scale to increase paddy prices at a somewhat faster rate than the general price level;
- encourage more farmers' associations;
- establish a rice buffer stock and a marketing board.

Potential rice technology

In Thailand, rice research efforts intensified after the release of the modern varieties RD1, RD2, and RD3 in 1969. Before that the maximum yields obtained from a simple demonstration program with available varieties in three regions were 3 to 5 t/ha, about 60% above farmers' yield levels (Lusanandana et a1 1967).

After the release of modern varieties, a program of field tests on rice yield improvement was conducted throughout Thailand. Yield trials of modern varieties and promising lines gave maximum yields of 4 to 5 t/ha in most regions except in Northeast Thailand, where soil fertility is extremely poor and rainfall distribution is uneven (Tongsang 1970). Interstation yield trials conducted by experiment stations throughout the country between 1971 and 1974 produced average maximum yields of 4.1 t/ha in the wet season and 4.6 t/ha in the dry season (Table 3). Suphan Buri Station ranked first with a maximum yield of 5.3 t/ha (Rice Division 1974). With the presently recommended

Table 3. Yields of experimental non-photoperiod sensitive rice lines in interstation yield trials. Thailand, 1971-1977 (Rice Division, Ministry of Agriculture and Cooperatives, unpublished data).

Regions	Stations (no.)	Yield (t/ha) [a]							
		1971	1972	1973	1974	1975	1976	1977	Av
					Wet season				
Central	8	4.5	3.9	3.9	3.5	4.4	3.6	4.0	4.0
North	3	4.1	2.9	2.8	3.9	3.7	4.4	4.3	3.7
Northeast	6	4.0	3.6	4.1	4.1	3.6	4.0	4.0	3.9
South	3	3.9	3.9	2.8	2.4	2.7	3.1	2.4	3.0
All	20	4.1	3.6	3.4	3.5	3.6	3.8	3.7	3.7
					Dry season				
Central	8	4.9	4.6	4.3	4.7	4.1	4.0	4.3	4.4
North	3	3.8	4.8	4.3	4.1	4.0	4.5	3.7	4.2
Northeast	6	5.0	4.3	5.0	5.1	3.4	2.7	3.6	4.2
South	3	3.8	3.6	4.7	2.8	2.2	n.e.	n.e.	n.e.
All	20	4.4	4.4	4.6	4.2	3.4	3.7	3.8	4.1

[a] n.e. = no experiment

varieties, nitrogen fertilization experiments gave maximum yields higher than 5 t/ha with RD7 at Suphan Buri in the wet season (Table 4).

Much progress has been made in developing new rice technology, and potential rice yields based on experiment station results are at least 5 t/ha. But actual yields obtained by farmers average less than 2 t/ha. This indicates a yield gap of about 3 t/ha, brought about by various physical, economic, and social factors, or combinations of the three. The specific constraints, if identified, should explain the yield gap, tell what is needed to help farmers raise yields, and ultimately lead to increased rice production.

Table 4. Effects of nitrogen rates on grain yields of recommended varieties and promising lines.[a] Suphan Buri Experiment Station, 1974 – 76 wet season (Rice Division, Ministry of Agriculture and Cooperatives, unpublished data)

Variety	Grain yield (t/ha)		
	1974	1975	1976
RD1	3.7	3.8	3.9
RD4	3.8	3.4	3.8
RD5	4.1	4.2	3.9
RD7	4.3	4.1	4.4
RD9	3.8	3.9	4.0
RDll	3.9	3.4	4.2
WP252 – 1	3.7	3.4	3.9
PMI6624 – 257 – 1	4.5	3.4	4.4
Av	4.0	3.7	4.1

[a] Data are averages over nitrogen levels of 0, 37.5, 75.0 and 112.5 kg/ha. In addition, 75 kg P_2O_5/ha and 37.5 kg K_20 were applied.

Objective and methodology of the study

To determine why the yield gap exists, a research project was carried out with four objectives:

1. to identify production techniques that give higher yields than what selected representative farmers can get on their farms;

2. to determine the relative contribution of several technical factors (inputs or cultural practices) to the gap between actual and potential yield;

3. to determine the extent to which use of technical factors can be profitably increased; and

4. to determine what social and economic factors prevent farmers from using technology that gives higher yields-

Both experimental and survey techniques were used. For objectives 1 and 2 agronomic experiments were conducted in farmers' fields. In the same villages, a larger sample of farms was surveyed to obtain data for objectives 3 and 4.

The study area

Beginning in the 1974 wet season, research was conducted in three different areas using different designs. In the first few seasons, only a few trials were conducted. In 1977, 20 trials were conducted each season (Table 5 and Figure 1).

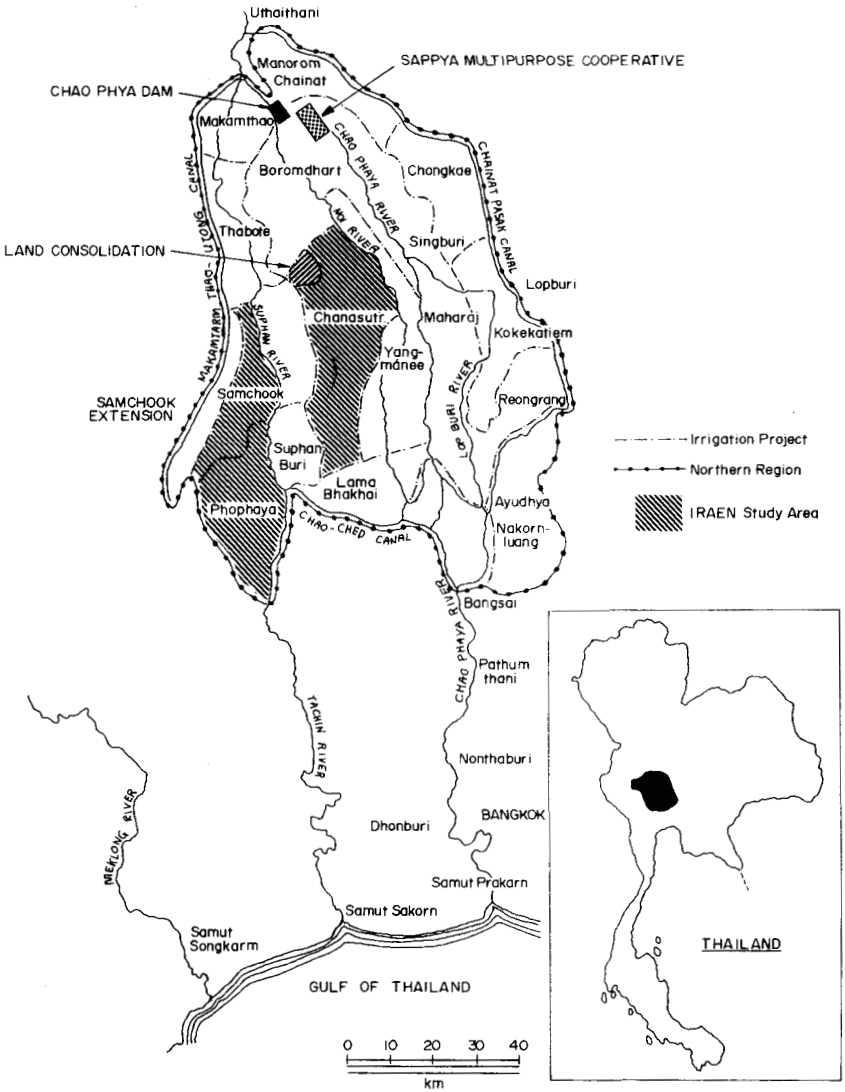
Table 5. Location and number of experimental trials in the constraints project. Northwestern Central Plain, Thailand 1974–77.

Year	Season	Location	Trials (no.)
1974	Wet	Wang Yang, Suphan Buri	3
1975	Dry	Wang Yang and Bang Ngarm, Suphan Buri	5
1975	Wet	Wang Yang and Bang Ngarm, Suphan Buri	7
1976	Dry	Sam Chook and Pho Phaya irrigation projects	6
1976	Wet	Sam Chook and Pho Phaya irrigation projects	6
1977	Dry	Chanasutr irrigation project	20
1977	Wet	Chanasutr irrigation project	20

The project was initiated in the 1974 wet season in irrigated double-cropping areas of *amphoe* Si Prachan, Suphan Buri, about 160 km northwest of Bangkok. Three sites were selected at *tambon* (hamlet) Wang Yang representing farmers who had low, medium, and high rice yields in the previous 2 years. The farms corresponded to areas with poor, moderate, and good water control. During the 1975 dry season, three more sites at Bang Ngarm in Suphan Buri were selected. They had two main soil types, clay and clay loam, and different degrees of water control. Experiments were repeated at the six sites for the dry and wet seasons of 1975.

In 1976, sites were selected from two zones in the Sam Chook Irrigation Project and one in the Pho Phaya Irrigation Project. A socioeconomic presurvey was first carried out. In each zone two sites were chosen where farmers reported average yields in the presurvey. They apparently faced problems of low soil fertility and inadequate control of weeds.

Later in 1977, the study area was shifted to Chanasutr Irrigation Project, which has its main headquarters at *amphoe* Bang Ra Chan, Sing Buri, a province near Suphan Buri. The areas are described as typical irrigated double-cropping rice areas under the largest irrigation project in the Central Plain. The project consists of 52 zones covering a water-supplied area of about 84,320 ha in five provinces: Sing Buri, Chainat, Suphan Buri, Ang Thong, and Ayudhaya. In each of the three subprojects, one zone with



1. The Greater Chao Phaya Project, showing IRAEN study areas.

more than 75% of the area in transplanted rice was selected on the basis of criteria like average yields, researchers' convenience in reaching the farms, and cooperation of farmers. One zone (zone 6) was especially selected because it was within a Land Consolidation Project. Compared with others, farmers under land consolidation are expected to have better water control, higher levels of inputs, and higher yields.

A preliminary survey obtained information on yields, the use of inputs, problems, and cooperativeness of farmers. One hundred farmers, representing subdivisions of the irrigation system (canals and ditches) and farms, were interviewed. The sample farms were divided equally into thirds by yield, the yield classes being low, medium, and high. One-thirdof the farmers were selected from each group to obtain the 20 experiment sites. Half of the sites were in zone 6, the land consolidation area.

Experimental design

In 1974 and 1975, two levels (farmers' M_1, and high M_5) of three factors -- fertilizer management, weed control, and insect control -- were incorporated in the experimental design. In addition, three other levels of management packages (M_2, M_3, M_4) were tested (Table 6). The treatments were replicated twice in each site in a factorial design.

During the 1976 dry and wet seasons, the experimental factors were reduced, and the number of levels increased. When the results of the first year showed that insect control did not increase yield significantly, four levels of fertilizer and three levels of weed control were tested to study their effects intensively. In addition, one treatment with high land preparation, high insect control, and optimal spacing was evaluated with high weed control and fertilizer (Table 6).

When the project was shifted to the Chanasutr Irrigation Project in 1977, the experiments were modified after the discussion at the fourth International Rice Agroeconomic Network workshop in Indonesia. Complete factorial, minifactorial, and supplemental trials were distributed on 20 farms in the proportion of 4:4:12. Variety, which had been the focus of some controversy in the methodology, was included as a factor in addition to fertilizer management and weed control.

The complete factorial experiment included eight factorial combinations of the three factors at farmers' level and high level, and three levels of management packages between farmers' level and high level. Two replications were made in a randomized complete block design with a plot size of 3 x 6 m. The mini-factorial had five treatments of three factors, one with all high, one all at farmers' level, and three with one factor at farmers' level and one at high (Gomez 1977). The treatments were in a randomized complete block design with two replications of a 3 x 6 m plot.

Supplemental trials to measure potential yield consisted of one plot with all three factors at the high level. Plots were 10 x 10 m.

Table 6. Levels of inputs used in constraints experiments in farmers' fields. Northwestern Central Plain, Thailand, 1974–77.

Treatment	Fertilizer (kg/ha) N	P_2O_5	K_2O	Weed control applications[a] (no.) HW	CW	Test variety[b] WS	DS	Insect control applications[c] (no.) F	G	
				1974 wet, 1975-dry, 1975 wet						
M_1	Farmers'			Farmers'		nt[d]		Farmers'		
M_2	18.8	12.5	0	1	0	nt		1	0	(1)
M_3	37.5	25.0	0	0	1	nt		1	1	(2)
M_4	56.3	31.3	0	1	1	nt		2	2	(3)
M_5	75.0	50.0	37.5	1	1	nt		2	2	(5)
				1976 dry and wet[e]						
M_1	Farmers'			Farmers'		nt			nt	
M_2	62.5	25.0	0	0	1	nt			nt	
M_3	93.8	25.0	0	1	1	nt			nt	
M_4	125.0	25.0	0	nt	nt	nt			nt	
				1977 dry and wet						
M_1	Farmers'			Farmers'		Farmers'			nt	
M_2	50.0	25.0	0	0	1	RD11	RD7		nt	
M_3	75.0	25.0	0	0	1	RDll	RD7		nt	
M_4	100.0	25.0	0	0	1	RDll	RD7		nt	
M_5	125.0	25.0	0	1	1	RD11	RD7		nt	

[a] HW = hand weeding, CW = chemical weeding of 2, 4-D (G), 0.8 kg/ha a.i. 4 days after transplanting (DT) for M_3, M_4 in 1974 and 1975; CW of benthiocarb (G)/2, 4-D (G), 1.0/0.5 kg/ha a.i., 4 DT for M_5 in 1974 and 1975; CW of benthiocarb (G), 2 kg/ha a.i., 4 DT for M_2 in 1976 and 1977.

[b] DS = dry season, WS = wet season .

[c] Numbers in parentheses show the number of applications in the 1974 wet season, those outside show the 1975 figures. F = foliar spray of Sevin 85 + malathion, G = granular, (BHC or Furadan).

[d] nt = factor was not tested in that season or at that level.

[e] In addition to the two major test factors (fertilizer and weed control), insect control, spacing, and land preparation were tested at the high level of fertilizer and weed control. The high levels were: insect control, 1.125 kg a.i. Furadan at 7 and 3 DT; spacing 25 x 25 cm; land preparation, additional harrowing, puddling, and leveling with small rotary puddler.

BIOLOGICAL CONSTRAINTS

The yield gap

Table 7 shows the average farmers' yields and high yields obtained in three locations during the 3 years of the study. Wet season farmers' yields were 4.0 t/ha. High inputs resulted in a yield of 5.0 t/ha averaged across all sites. In the dry season, farmers' yields averaged 4.2 t/ha and high input yields 6.0 t/ha. A substantial yield gap appears to exist, especially in the dry season.

The 1977 wet season gap, which averaged 1.4 t/ha, may be larger than that in the previous wet seasons because of the better water control in the Chanasutr area. In the 1977 wet season, the complete factorial experiment gave a higher measured gap than the minifactorial, which in turn gave a higher measured gap than the supplemental trials. In the dry season, however, all types of experiments gave roughly the same gap. The experiments were conducted on the same farms in consecutive seasons.

Farmers' level of input use

The wet season crop was planted in July through August and was harvested in November through December. Dry season cropping started in March-April and harvesting was in June-July. During the first season of the project, the cooperating farmers at Wang Yang applied inputs at a rate below M_2. In later seasons they tended to use higher levels after observing the treatments employed in the experiments (Table 8). Farmers applied between 8 and 40 kg N/ha and between 10 and 50 kg P_2O_5/ha from ammonium phosphate (16 – 20 – 0),7 to 15 days after transplanting. On some farms, weeds were controlled chemically and a few farmers used hand weeding, but many used no weed control in the wet season.

During the wet season, about 25% of the farmers grew high-yielding varieties like RD1, RD5, C4-63, and RD11; the rest grew local or traditional photoperiod-sensitive varieties. During the dry season, all farmers planted high-yielding, nonphotoperiod-sensitive varieties, including RD7, C4-63, RDll and some lines of IR661 x RD1.

During the 1976 dry and wet seasons, the input levels of farmers varied substantially. Fertilizer application ranged from 8 to 45 kg N/ha and from 10 to 50 kg P_2O_5/ha during the dry season, somewhat higher than during the wet season. Common sources of fertilizer were ammonium phosphate while a few farmers applied ammonium sulfate or urea as a top dressing. A few farmers

Table 7. Yield with farmers' inputs and high inputs, and yield gap in constraints experiments in farmers' fields. Northwestern Central Plain, Thailand 1974-77.

Year	Trials (no.)	Yield (t/ha) Farmers' inputs	High inputs	Gap	Type of trial[a]	Location
			Wet season			
1974	3	3.7	5.0	1.3	CF	Suphan Buri
1975	5	3.9	4.6	0.7	CF	Suphan Buri
1976	6	3.6	4.0	0.4	CF	Sam Chook, Pho Phaya
1977	4	3.4	5.9	2.5	CF	Chanasutr
1977	4	4.2	5.2	1.0	MF	Chanasutr
1977	12	4.4	5.2	0.8	S	Chanasutr
All	34	3.9	5.0	1.1	All	All
			Dry season			
1975	7	4.1	6.3	2.2	CF	Suphan Buri
1976	6	3.7	5.9	2.2	CF	Sam Chook, Pho Phaya
1977	4	4.0	5.8	1.8	CF	Chanasutr
1977	4	4.0	5.5	1.5	MF	Chanasutr
1977	12	4.7	6.2	1.5	S	Chanasutr
All	33	4.1	5.9	1.8	All	All

[a] CF = complete factorial, MF = minifactorial, S = supplemental.

controlled weeds by hand weeding; none used chemical control. Only one farmer controlled insects intensively with three sprays and two granular applications. Plant population ranged from 25 to 35 hills/m^2 compared to the 16 hills/m^2 rate used by researchers in the experiment.

At Chanasutr in 1977, farmers' input use in zone 6 was almost identical with that in zones 23 and 30 despite the hypothesis that adequate supply of irrigation water and well-leveled land in the land consolidation project would enhance the use of inputs (Table 9). During the wet season, both nonphotoperiod-sensitive and photoperiod-sensitive varieties were grown, but only nonphotoperiod-sensitive varieties were planted during the dry season. One split dose of fertilizer was as common as

Table 8. Average farmers' level of inputs used in constraints experiments in farmers' fields. Northwestern Central Plain, Thailand, 1974-77.

Year	Fertilizer (kg/ha)		Weed control applications[a] (av no.)		Insect control applications[b] (av no.)		Farmers using (no.)		
	N	P	H	C	F	G	Fertilizer	Insect control	Weed control
				Wet season					
1974	8.7	10.8	0.0	1.0	0.3	0.3	3	1	2
1975	22.0	27.5	0.3	0.0	0.3	0.2	6	3	2
1976	42.2	40.3	0.0	0.0	0.5	0.3	6	1	0
1977	27.2	27.2	0.4	0.4	0.4	0.3	20	6	12
				Dry season					
1975	22.1	27.7	0.0	0.0	0.7	0.2	6	3	3
1976	30.2	33.8	0.3	0.0	0.5	0.0	6	3	2
1977	30.9	29.7	0.5	0.7	0.7	0.2	20	11	19

[a] H = hand, C = chemical; [b] F = foliar, G = granular.

one or two split doses. Application of fertilizer ranged from 14 to 64 kg N/ha and 16 to 71 kg P_2O_5/ha in the dry season, and from 12 to 50 kg N/ha and 8 to 45 kg P_2O_5/ha in the wet season. Weed control was commonly practiced only in small fields where there was heavy infestation of weeds.

Factors contributing to the gap

In all seasons, insufficient fertilizer was the main factor that kept farmers' yields low (Figure 2). Except in the 1976 wet season, fertilizer contributed 0.5 t/ha or more to the yield gap (Table 10). Insect control, tested in 1974 and 1975, proved to be relatively unimportant and was subsequently dropped as a major test factor.

Apart from the three tested factors, inadequately controlled factors like water, low temperatures, and rodents were physical yield constraints in 1974-75. Socioeconomic constraints -- lack of technical knowledge, cash shortage, and unstable prices of inputs and output -- were all observed in relation to the use of tested inputs.

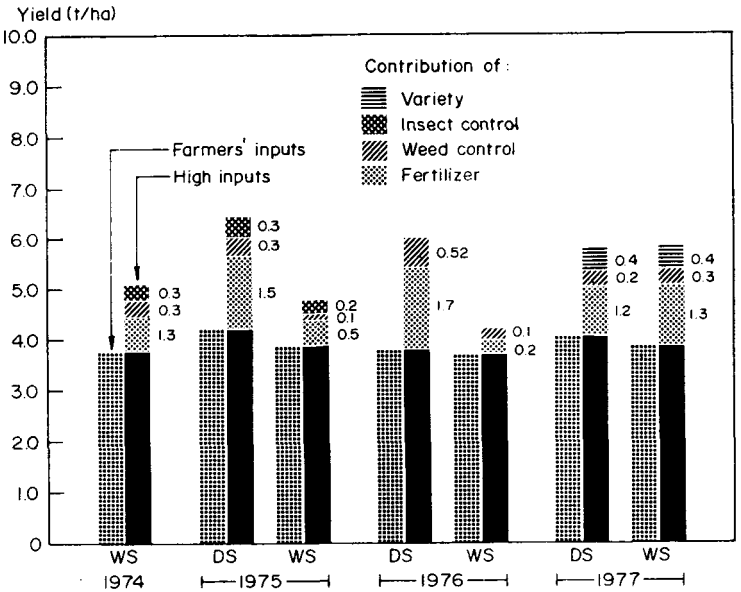
Table 9. Level of inputs used by farmers with constraints experiments within the land consolidation area of Chanasutr Irrigation Project compared with levels outside the project. Thailand, 1977.

Location		Fertilizer (kg/ha)		Weed control applications[a] (av no.)		Insect control applications[b] (av no.)		Farmers using (no.)		
		N	P	H	C	F	G	Fertilizer	Insect control	Weed control
					Wet season					
Within	$\bar{X}$	25.2	26.1	0.2	0.2	0.2	0.1	10	3	5
	S	9.1	17.9							
Outside	$\bar{X}$	29.3	28.3	0.5	0.5	0.5	0.4	10	3	7
	S	10.3	15.1							
					Dry season					
Within	$\bar{X}$	34.8	29.7	0.5	0.7	0.6	0.2	10	6	9
	S	15.2	18.8							
Outside	$\bar{X}$	27.1	29.6	0.5	0.6	0.6	0.1	10	5	10
	S	9.8	8.3							

[a] H = hand, C = chemical; [b] F = foliar, G = granular.

1976. In 1976, the yield gap from inadequate fertilizer use and inadequate weed control was greater in the dry season (2.2 t/ha) than in the wet season (0.4 t/ha). The gap represented increases of 57% in the dry season and 10% in the wet season over farmers' yields. In both seasons, fertilizer was the major factor contributing to the yield gap: 80% in the dry season and 60% in the wet season. The highest input level gave the highest yield in the dry season. But in the wet season, increasing the input level did not give any consistent yield increase (Table 12). Application of fertilizer to the probable adoption level (F_2 in Table 11) increased yield significantly over farmers' levels in 5 out of the 6 farms in the dry season and in 2 out of 6 in the wet season.

Chemical weed control by preemergence application of granular Benthiocarb (W_2) gave a significantly higher yield than farmers' practices on two farms during the dry season. The interaction



2. Yields with farmers' and high levels of inputs, and the contribution of inputs to the yield gap, 1974–77. WS = wet season, DS = dry season.

of fertilizer and weed control in either season gave no significant increase in grain yield (Table 12). In the same year, the cultural practices of spacing, insect control, and land preparation were tested at a high level of fertilizer and weed control. They did not significantly increase yield, except on one farm where a yield increase from additional insect control was observed (Table 13). Most farmers with trials used a spacing adequate to take advantage of the high levels of weed control and fertilizer.

1977. Results of the complete factorial and minifactorial experiments in Table 10 show an average yield gap of 1.0 to 2.5 t/ha in the wet season and about 1.6 t/ha in the dry season. The minifactorials showed large negative residuals: thus, more confidence was put in the complete factorial results. The contribution of fertilizer alone to the gap was about 1.2 t/ha or about 72%. Variety contributed 0.7 t/ha in the wet season but only 0.1 t/ha in the dry season when farmers used recently released modern varieties. The contribution of weed control was as high as 0.5 t/ha in the wet season.

In the complete factorial experiments the contribution of fertilizer was significant on all farms during both seasons. It was significant on only two farms in the minifactorial

Table 10. Yield gap and factors contributing to the gap in constraints experiments in farmers' fields. Northwestern Central Plain, Thailand, 1974–77.

Year	Trials (no.)	Yield gap (t/ha)	Contribution to the yield gap (t/ha) of: Fertilizer	Weed control	Variety	Insect control	Residual
			Wet season				
1974	3	1.3	0.7	0.3	nt[a]	0.3	0.0
1975	5	0.7	0.5	0.1	nt	0.2	-0.1
1976	6	0.4	0.2	0.1	nt	nt	0.1
1977	4[b]	2.5	1.3	0.5	0.7	nt	0.0
1977	4[c]	1.0	1.3	0.2	0.2	nt	-0.7
			Dry season				
1975	7	2.2	1.5	0.4	nt	0.3	0.0
1976	6	2.2	1.7	0.5	nt	nt	0.0
1977	4[b]	1.8	1.4	0.2	0.1	nt	0.1
1977	4[c]	1.5	1.0	0.2	0.7	nt	-0.4

[a] nt = factor was not tested in that season or at that level.
[b] Complete factorial. [c] Minifactorial.

experiments in the wet season. Variety contributed significantly to the yield gap on two farms during the wet season and on one farm during the dry season in the complete factorial experiments. It was not significant on any farm in the minifactorial trials. Similarly, weed control at the high level gave a significantly higher yield than that at farmers' levels on three farms during the wet season and on only one farm during the dry season in the complete factorial experiments.

The average yield gap in the supplemental trials was 1.2 t/ha for a 26% increase over the farmers' yield of 4.5 t/ha. The gap was comparatively larger during the dry season because of the consistent contribution of fertilizer. Farmers' varieties were mostly nonphotoperiod-sensitive modern types (Table 14), and so the yield contribution of variety (obtained by crop-cutting) was small. Some loss to rodents was observed throughout the study areas, and one minifactorial experiment was completely destroyed by them.

Table 11. Treatments, level, and rate of tested inputs. Suphan Buri, Thailand, 1976 dry and wet seasons.

Treatment[a]	Level	
Fertilizer (kg/ha)		
	Farmers' levels	
F_1	Probable adoption level	62.5 N, 25 P_2O_5
F_2	Maximum profit level	93.75 N, 25 P_2O_5
F_3	Maximum yield level	125.0 N, 25 P_2O_5
F_4		
Weed control		
	Farmers' levels	
W_1	Moderate level	Preemergence application of Benthiocarb (5% G), at 2 kg/ha (a.i.), 4 DT[b]
W_2		
W_3	High level	W_2 + 1 hand weeding, 30 DT

[a] Under high level of fertilizer and weed control (F_4W_3) three factors were tested:

L - land preparation - additional harrowing, puddling, and leveling with small rotary puddler.
I - Insect control - broadcasting of Furadan (3% G) at 1.125 kg/ha (a.i.) at 7 and 30 DT.
S - Spacing - 25 x 25 cm with plant population of 16 hills/m^2.

[b] Days after transplanting.

SOCIOECONOMIC CONSTRAINTS

The prices used in calculating costs of experimental and farmers' input packages are given in Table 15. The minimum rice price of ฿2,100/t guaranteed by the government was used in both the dry and wet seasons in 1976. In 1977, the price received by farmers was used (฿2,250 for the dry season paddy and $2,450 for the wet season).

The costs of input packages for the 1976 dry and wet seasons are shown in Table 16, and those for the 1977 dry and wet seasons in Table 17. The small differences between the 2 seasons were caused by changes in the quantities, kinds, and prices of inputs.

Table 12. Average grain yield (t/ha), with four levels of fertilizer and three levels of weed control in constraints experiments on six farmers' fields. Sam Chook and Pho Phaya Project area, Central Plain, Thailand, 1976.[a]

Weed control level	Grain Yield (t/ha)				Av
	F_1	F_2	F_3	F_4	
		Wet season			
W_1	3.7	3.4	3.8	3.9	3.7
W_2	3.8	3.8	3.9	4.0	3.9
W_3	3.8	3.7	3.6	4.0	3.8
Av	3.8	3.6	3.8	4.8	3.8
		Dry season			
W_1	3.7	4.3	4.6	5.5	4.5
W_2	4.1	4.8	5.2	5.7	5.0
W_3	4.2	4.8	5.4	5.9	5.1
Av	4.0	4.6	5.1	5.7	4.9

[a]Fertilizer and weed control levels are defined in Table 11.

Economics of separate inputs

The increased cost and increased value of yield with increasing input levels above farmers' levels are shown in Table 18. In the 1977 dry season in Sing Buri and Ang Thong, the increased use of fertilizer above farmers' levels rose substantially because good water control and the high level of solar radiation allowed a high response to additional fertilizer.

In 1974 and 1975, the increased cost of using high levels of insect control was greater than the increased value of rice because with low insect populations the high insect control had no chance to prevent insect damage. Insect control input was excluded in subsequent experiments. Increased weed control inputs cost more than was gained by the increased yield, except in Suphan Buri in 1976. However, the difference was still marginal.

In three years of wet seasons in Suphan Buri the increased use of fertilizer produced less additional return than the increased cost. In the 1977 wet season, however, the increase in fertilizer

Table 13. Additional yield (t/ha) with high levels of insect control, spacing, and land preparation when tested at high levels of fertilizer application and weed control in constraints experiments in farmers' fields. Sam Chook and Pho Phaya project areas, Central Plain, Thailand, 1976.

Farm no.	Yield (t/ha) with F_4W_3	Added yield from high level of[a] Insect control	Spacing	Land preparation	All three	Yield with F_4W_3 and all three others
			Wet season			
1	3.7	0.3	-0.2	0.1	0.0	3.7
3	4.4	0.8	0.3	0.7	0.0	4.4
4	5.1	0.2	-0.1	0.1	-0.8	4.3
5	4.2	-0.6	-0.8	-0.7	-0.3	3.9
6	2.8	-0.4	-0.1	0.2	0.0	2.8
Av	4.0	0.1	-0.2	0.1	0.2	3.8
			Dry season			
1	5.1	0.5	-0.4	-0.2	0.0	5.1
2	7.0	0.3	-0.1*	-1.1*	-0.4	6.6
3	4.3	1.0	0.8**	-0.1	1.9**	6.2
4	5.9	1.2	-1.1*	0.4	0.6	6.5
5	7.1	0.0	-0.9*	-0.3	-0.4	6.7
6	5.7	0.0	0.1	0.2	0.6	6.5
Av	5.8	0.5	-0.3	-0.2	0.4	6.3

[a] ** = significant at 1% level, * = significant at 5% level.

from farmers' levels to high level produced additional returns more than three times the additional cost. It is believed that perhaps the land consolidation in the 1977 study areas of Sing Buri and Ang Thong had resulted in better water control and hence higher fertilizer response during the wet season. The increased weed control inputs produced less additional returns than the additional cost when input levels higher than farmers' level were used in wet season 1977. The result was the same in the dry season. It appears that increased fertilizer use in the dry season will increase farmers' return; additional weed control inputs will not increase net return in either season; and additional fertilizer may be profitable in the wet season for those farmers who have good water control.

Table 14. Farmers' variety and fertilizer levels and the yield contribution of test variety and high fertilizer levels. Chanasutr Project Area, Thailand, 1977.

Farm no.	Farmers' Variety	Farmers' N + P (kg/ha)	Contribution (t/ha) of high[a] Variety	Contribution (t/ha) of high[a] Fertilizer
		Wet season		
1	RD7	79	-.12	1.30**
2	Kaoprakuat	38	1.16**	2.35**
3	RD7	68	1.45	1.64
4	IR66lxRD1	29	.39	1.01
5	IR66lxRDl	81	.49	.70
6	RD7	79	-.25[b]	1.57**
7	KhaoLuang	51		-
8	RD7	39	.27	1.72
		Dry season		
1	"Taiwan"	53	.05	1.15**
2	C4 – 63	46	.02	1.75**
3	C4-63	61	.09*	1.36**
4	C4-63	32	.19	1.29**
5	IR661xRD1	43	1.19	1.66
6	C4 – 63	55	.51	1.41
7	C4 – 63	71	.40	.03
8	C4 – 63	31	.50	.78

[a] ** = significant at the 1% level, * = significant at the 5% level.

[b] Trial was so damaged by rats that it was impossible to calculate the effects.

Analysis of management packages

Management packages were analyzed to determine the optimum level. In 1974 – 75, using inputs at the higher management packages brought about less additional return than the additional cost (Table 19). In the 1974 wet season, the optimum package was M_3. In the 1975 wet season, every management package higher than farmers' levels produced negative net returns. In the 1975 dry season, M_3 gave maximum net returns.

Table 15. Prices used in calculating the costs of experimental and farmers' input packages. Suphan Buri, Sing Buri, and Ang Thong, Thailand, 1976 – 1977.

Item	Unit	Prices (baht) [a]			
		Suphan Buri		Sing Buri & Ang Thong	
		1976 wet	1976 dry	1977 wet	1977 dry
Fertilizer					
16 – 20 – 0	kg	3.85	3.89	3.20	3.60
18 – 22 – 0	kg	3.67	3.90	4.10	3.85
20 – 20 – 0	kg	3.82	4.26	3.50	3.63
20 – 11 – 11	kg	-	4.75	-	-
Urea	kg	-	-	-	-
Ammonium sulfate	kg	1.68	1.45	2.30	1.90
Ammonium chloride	kg	2.08	2.49	3.00	-
Insecticide					
Furadan 3% G	kg	18	20	20	20
BHC	kg	10	11	10	-
Sevin 85	kg	78	86	100	100
Mipcin 50%	kg	90	90	-	-
Folidol E 605 W.P.	kg	40	-	40	-
Folidol E 605	500 cc	-	54	-	-
Endrin 20% E.C.	1000 cc	70	70	60	60
Azodrin 50% E.E.	1000 cc	-	-	230	290
Herbicide					
2, 4-D	kg	48	50	60	36
Saturn G	kg	19	20	20	20
Hand weeding	1 day	20	20	30	19
Price of paddy	1 t	2100	2100	2450	2250

[a] Exchange rate: US$l.00 = 20 baht.

In 1976, the experimental design included four levels of fertilizer application and three levels of weed control instead of the five packages. Analysis of the results is shown in Table 20. In the dry season, using increased quantities of fertilizer gave greater net returns at every level of weed control. Increased weed control had little economic benefit although F_4W_2 produced the highest net return, but because it

Table 16. Average cost of inputs used by farmers (F_1W_1) and in the test levels in the experimental farms.[a] Suphan Buri, Thailand, 1976.

Fertilizer	Average cost[b] (baht /ha)		
	W_1	W_2	W_3
	Wet season		
F_1	547	1047	1597
F_2	862	1362	1912
F_3	1041	1541	2091
F_4	1241	1741	2291
	Dry season		
F_1	875	1192	1742
F_2	963	1279	1829
F_3	1179	1495	2045
F_4	1395	1712	2262

[a] See Table 11 for description of fertilizer and weed control levels.

[b] US$l.00 = 20 baht.

was only 2% above F_4W_1, it is unlikely that farmers would undertake the extra cost for W_2. In the wet season of the same year, the use of higher levels of fertilizer and weed control did not increase net income, but instead decreased it at each higher input level. The F_1W_1 level was optimum in this wet season.

The experiment conducted in Chanasutr in 1977 investigated two factors: fertilizer and weed control. The results are shown in Table 21. The increases in net income at the M_3, M_4, and M_5 levels in the dry season were about the same. M_3 is the best management package for farmers with limited capital. The high input levels increased profits more in the wet season than in the dry season, simply because the farmers' yields were higher in the dry season, and the yield difference was smaller (1.8 t/ha) than in the wet season (2.5 t/ha) on the four farms with management packages.

Table 17. Average cost of inputs used by farmers (M_1) and in the tested input management package in the experimental farms. Sing Buri and Ang Thong, Thailand, 1977.

Input package level[a]	Average cost[b] (baht/ha)		
	Fertilizer	Weed control	Total
	Wet season		
M_1	472	61	533
M_1 (H)	472	811	1283
M_2	731	500	1231
M_3	1006	500	1506
M_4	1275	500	1775
M_5	1550	1250	2800
	Dry season		
M_1	523	62	585
M_1 (H)	523	557	1080
M_2	725	500	1225
M_3	950	500	1450
M_4	1175	500	1675
M_5	1400	975	2375

[a] See Table 6 for description of tested inputs (M_1 - M_5). M_1(H) = M_1 with extra hand weeding.

[b] US$l.90 = 20 baht.

Representative of experimental farms compared to other farms in the area

Three farm surveys were made in the research area: in the 1974 wet season, the 1975 dry season, and the 1977 dry season. Data on input use and production were analyzed and compared for the experimental farms and the random sample of other farms (Table 22). The amount of fertilizer used by the sample farms and the experimental farms did not differ greatly. The quantities of the other inputs used differed somewhat, but the difference was not statistically significant. However, it was observed that when experiments were conducted on a farm for several years, the experimental farm tended to use more and more fertilizer and, in two cases, very high amounts of hand weeding, while the use of insecticides and herbicides declined.

Table 18. Farmers' costs, increased costs and increased value of output with high levels of three inputs. Two areas in Thailand, 1974 – 77[a].

	Wet season					Dry season			
	Suphan Buri 1974	Suphan Buri 1975	Suphan Buri 1976	Sing & Thong	Ang Buri 1977	Suphan Buri 1975	Suphan Buri 1976	Sing & Thong	Ang Buri 1977
Farms (no.)	3	5	5	4		6	6		6
Fertilizer									
Farmers' cost (฿/ha)	298	600	547	472		832	692		523
Increase to high cost (฿/ha)	2264	1475	574	1078		1693	520		877
Value (฿/ha)	1725	1325	441	3168		3066	3570		3077
Weed control									
Farmers' cost (฿/ha>	75	147	19	61		38	183		62
Increase to high cost (฿/ha)	1210	1233	na	1189		1382	867		913
Value (฿/ha)	675	250	na	1128		924	1092		450
Insect control,									
Farmers' cost (฿/ha)	86	31	-	-		50	-		-
Increase to high cost (฿/ha)	2236	2988	-	-		3024	-		-
Value (฿/ha)	775	550	-	-		714	-		-

[a] US$l.00 = 20 baht.

Table 19. Economic comparisons of tested input management packages with farmers' levels of input. Suphan Buri, Thailand.

Input package level[a]	Increase (baht) from farmers' level (M_1)[b]		
	Gross return	Input cost	Net return
	1974 wet season, 3 trials		
M_2	1075	739	336
M_3	2275	1439	836
M_4	3525	4065	– 540
M_5	3425	5706	– 2281
	1975 wet season. 6 trials		
M_2	– 387	138	– 525
M_3	675	1801	– 1126
M_4	1113	4212	– 3099
M_5	1713	5669	– 3956
	1975 dry season, 6 trials		
M_2	504	140	364
M_3	2394	1908	486
M_4	3297	4465	– 1168
M_5	4641	6097	– 1456

[a] See Table 6 for definition of tested inputs (M_2 - M_5).

[b] US$l.90 = 20 baht.

Water depth

From the farm surveys, it was observed that higher fertilizer levels were applied in the dry season and that modern varieties were more frequently used in the dry season than in the wet season. To better understand this phenomenon records of the depth of standing water in the fields of a sample of farmers were maintained throughout the dry and wet seasons of 1976, spread over five zones of the Sam Chook and Pho Phaya irrigation projects in the Suphan Buri area. Farms were selected along the length of farm ditches to include both farms near the canal and farms far from the canal. On each farm, three observations were made: one in a shallow – waterarea; one in a moderately deep – waterarea; and one in a deep – waterarea. Observations were made daily.

Table 20. Economic comparison at each level of fertilizer and weed control.[a] Suphan Buri, Thailand, 1976.

	Cost and returns[b] (baht/ha)							
	Wet season				Dry season			
	F_1	F_2	F_3	F_4	F_1	F_2	F_3	F_4
W_1								
Gross return	7,833	7,224	8,043	8,127	7,812	8,967	9,744	11,529
Input cost	547	862	1,041	1,241	875	963	1,179	1,395
Net return	7,286	6,362	7,002	6,886	6,937	8,004	8,565	10,134
W_2								
Gross return	7,896	7,896	8,211	8,442	8,568	10,059	10,878	12,033
Input cost	1,047	1,362	1,541	1,741	1,192	1,279	1,495	1,712
Net return	6,849	6,534	6,670	6,701	7,376	8,780	9,383	10,321
W_3								
Gross return	7,980	7,686	7,062	8,448	8,715	10,059	11,298	12,306
Input cost	1,397	1,992	2,091	2,291	1,742	1,829	2,945	2,262
Net return	6,583	5,694	5,511	6,157	6,973	8,230	8,353	10,044

[a] See Table 11 for definition of tested inputs (F_1 - F_4 and W_1 - W_3).

[b] US$l.00 = 20 baht.

In the dry season, average water depth was about 10 cm, ranging from 0.24 cm to 39.40 cm (Table 23). There was about 5 cm difference between the shallow, moderate, and deep locations. Water was deepest in the middle of the growing season and shallowest between flowering and harvest. In the wet season, average water depth was about 12 cm, varying from 1.85 cm to 38.18 cm. Water was deepest between panicle initiation and flowering, and shallowest between flowering and harvest.

In the dry season, all farmers grew improved varieties, 96% used fertilizer, 32% used herbicide, and 51% used insecticide, while in the wet season, 62% grew improved varieties, 76% used fertilizer, 24% used herbicide, and 28% used insecticide (Table 24). There was no systematic relationship between water depth and input use in the dry season, apparently because none of the prevailing conditions were so bad as to discourage the

Table 21. Economic comparison of farmers' levels and management packages. Chanasutr irrigation Project. Thailand, 1977.

Level of managment package[a]	Input cost (฿/ha)	Gross return (฿/ha)	Net return (฿/ha)	Comparison with farmers' level (M_1) Added input cost (฿/ha)	Added gross return (฿/ha)	Added net return (฿/ha)	Marginal B C ratio
			Wet season				
M_1	533	8,208	7,675	-	-	-	-
M_1(H)	1,283	9,555	8,272	750	1,347	597	1.8
M_2	1,231	11,368	10,137	698	3,160	2,462	4.5
M_3	1,506	12,863	11,357	973	4,655	3,682	4.8
M_4	1,775	13,598	11,823	1,242	5,390	4,148	4.3
M_5	2,800	14,480	11,680	2,267	6,272	4,005	2.8
			Dry season				
M_1	585	8,978	9,393	-	-	-	-
M_1(H)	1,060	9,450	8,390	475	472	−3	-
M_2	1,225	11,273	10,048	640	2,055	1,655	3.6
M_3	1,450	12,083	10,633	865	3,105	2,240	3.6
M_4	1,675	12,308	10,633	1,090	3,330	2,240	3.1
M_5	2,375	13,028	10,653	1,790	4,050	2,260	2.3

[a] See Table 6 for definition of inputs tested (M_1- M_5). M_1(H) = M_1 with extra hand weeding.

investment of funds. There was some tendency for farmers to apply less fertilizer in the areas with deeper water in the wet season, but aside from that there was no systematic relationship between water depth and input use in the wet season.

Table 22 indicates that the yields of the survey farms were substantially lower than the yields of the experimental farms in all seasons. On the survey farms, farmers' yields were calculated by dividing production and area as reported by the

Table 22. Average input use and yields of a random sample of farmers and those with experiments. Northwestern Central Plain, Thailand, 1974–77.

Source	Year	Farmers (no.)	Fertilizer (kg/ha) N	Fertilizer (kg/ha) P	Expenditures (฿/ha) Insecticide	Expenditures (฿/ha) Herbicide	Expenditures (฿/ha) Weeding labor	Yield (t/ha)
				Wet season				
Survey	1974	165	9	11	27	5	2	2.7[a]
Experiment	1974	3	9	11	86	75	0	3.7[b]
Experiment	1975	5	22	28	31	0	147	3.9[b]
Experiment	1976	5	42	40	19	na	na	3.1[b]
Experiment	1977	4	24	30	8	6	55	3.4[b]
				Dry season				
Survey	1975	160	23	28	43	8	22	3.0[a]
Experiment	1975	6	22	28	50	38	0	4.1[b]
Experiment	1976	6	30	34	15	0	183	3.7[b]
Survey	1977	179	30	35	47	29	9	3.5[a]
Experiment	1977	20	30	30	44	17	6	3.9[b]

[a] Obtained from interviews.

[b] Obtained from crop-cuts.

farmers. In the experiments, yields were estimated by crop-cuts. It is not surprising that the estimates differ. Thus, a special study of the two methods was made.

Crop-cut estimates compared with interviewed estimates of yields

Both procedures of estimating yields by crop-cuts and through interviews have weak points. In crop-cutting, overestimation is generally anticipated, especially when a small cut is used. Interviews, on the other hand, tend to give underestimates. In 1974 and 1975, the constraints project was conducted at Suphan Buri where the new technology had been in use for a number of years and farmers were using modern practices. Interviews were used to estimate the average yield of a set of farms where 8 m^2 crop-cuts were also made. Estimates from the two methods showed

Table 23. Average depth of water (cm) in sample rice paddies on farms in five zones of the Sam Chook and Pho Phaya irrigation projects.[a] Suphan Buri, Thailand, 1976.

Location	Wet season, 29 farms			Dry season, 53 farms		
	T to PI	PI to F	F to H	T to PI	PI to F	F to H
Shallow	8.13	8.75	6.38	5.05	5.27	3.86
Moderate	12.44	13.28	10.34	9.59	9.83	7.65
Deep	16.10	17.83	13.76	15.14	16.39	12.83

[a]T = transplanting, PI = panicle initiation, F = flowering, H = harvest.

Table 24. Use of inputs by farms with different average depth of water standing in their rice paddies. Suphan Buri, Thailand, 1976.

Water depth (cm)	Fertilizer[a] (฿/rai)	HYV (%)	Herbicide (%)	Insecticide (%)	Yield (kg/rai)
		Wet season			
0-5	119	67	0	33	630
5-10	94	73	36	27	567
10-15	85	29	29	29	536
Over 15	73	15	12	25	500
		Dry season			
0-5	78	100	0	33	496
5-10	126	100	29	54	604
10-15	130	100	39	50	636
Over 15	108	100	50	75	651

[a]US$1.00 = 20 baht. One rai = 0.16 ha.

that the yield difference of crop-cuts from interviews was small if the interview was made soon after the farmers had sold their paddy (Table 25) as in the 1975 wet season.

When the study area was transferred to the nearby provinces of Sing Buri and Ang Thong in the Central Plain in 1977, crop-cutting and interviews were conducted again in the wet season.

Table 25. Caparison between grain yields estimated by crop-cutting and by interview. Suphan Buri, Thailand, 1974-75.

Tambon	Farms crop cut (no.)	Type of variety[a]	Yield (t/ha) Crop-cutting	Inter-view	Differ-ence[b]	Difference (%) of crop-cut from interview[c]
		1974 wet season,[d] Suphan Buri				
Wang Yang	5	MV	3.8	3.0	0.8*	20 ± 12
	6	LV	3.7	2.6	1.1**	28 ± 13
		1975 dry season,[e] Suphan Buri				
Wang Yang	14	MV	4.4	3.8	0.6**	13 ± 7
Bang Ngarm	13	MV	2.9	2.6	0.3**	7 ± 7
		1975 wet season,[f] Suphan Buri				
Wang Yang	7	MV	3.1	2.9	0.2[ns]	6 ± 20
	9	LV	3.2	2.6	0.6**	19 ± 15
Bang Ngarm	9	LV	2.3	2.2	O.l[ns]	4 ± 31
		1977 wet season, Sing Buri				
Bahn-ja	20	Mv	4.2	3.8	0.4[ns]	7 ± 24
	5	LV	3.9	2.7	1.2*	29 ± 23
		1977 wet season, Ang Thong				
Wang Nam Yen	16	Mv	4.2	3.6	0.6*	15 ± 24
	8	LV	3.2	2.8	0.4[ns]	11 ± 26
Rum-ma Sak	15	MV	4.4	4.5	-0.1[ns]	-13 ± 41
	4	LV	3.4	3.8	-0.4[ns]	-10 ± 29

[a]MV = modern varieties, LV = local varieties. [b]** = significant at the 1% level, * = significant at the 5% level, ns = not significant. [c]The average % difference ± the standard deviation. [d]The interview was held several months after the products were sold. [e]The interview was held one month after the products were sold. [f]The interview was held immediately after harvest.

Sample points were randomly selected from the intensive data parcel of survey farms and from 12 farms with supplemental trials. For areas smaller than 0.8 ha, two sample points were taken. Another sample cut was added for each additional 0.8 ha of planted area. Two cuts of 8 m^2 were made at each sample point. Interviews were made within a month after the sale of the farm products.

In 1977, the data showed significant differences between yields estimated by crop-cutting and by interview in two out of six cases. At Bahn-ja, Sing Buri, the difference between the two methods differed with variety. For the modern variety, the difference was 0.4 t/ha or 7%. For the local variety, the difference was 1.2 t/ha or 29%. Although the means differed, the variability of the difference was almost the same, with standard deviations of 23% for the modern variety and 24% for the local variety.

At Ang Thong the differences between the two methods were the same in both types of variety. At Wang Nam Yen the interview gave a lower estimated yield for both types of varieties, while in the other *tambon* it was the opposite. The difference for the modern variety (0.6 t/ha or 15%) was slightly larger than for the local variety (0.4 t/ha or 11%) while the degree of variability was similar (24% and 26%). The result obtained for *tambon* Rum-ma Sak showed a higher yield estimate by interview, and the variability of the estimated difference was higher for the modern varieties (41% vs 29%).

On the whole, the differences in the yield estimates by the two methods were in the same range as that in Suphan Buri. They ranged from 0.1 t/ha to 1.2 t/ha at the new site and from 0.1 to 1.1 t/ha in Suphan Buri.

At Suphan Buri, where farmers had been using new technology and had been interacting with the researchers for a longer time, the differences between crop-cutting and interview were smaller than those at Sing Buri and Ang Thong.

In some cases, interviews gave a higher estimation of yield than crop-cutting. This might be a reflection of the responsiveness of farmers to the introduction of new technology. The farmers' desire for high prestige might make them -- especially those who recently used new technology and had contact with researchers -- overestimate their production.

Farmers' reasons for not using higher inputs

The analysis showed that higher levels of fertilizer could be profitably applied to rice in the dry season and that higher levels of insect and weed control, up to the M_3 level, would also be of value. This issue was further explored.

The complementarity of modern varieties with high levels of fertilizer application is well-established; so one might argue that low fertilizer is related to the use of traditional varieties. However, the reasoning cannot hold in this case, because all farmers interviewed grew modern fertilizer-responsive varieties on their farms during the dry season. In the interviews farmers were asked why they did not use higher levels of inputs. The results are shown in Table 26.

A large proportion of the reasons given for not adopting modern practices are economic. Farmers either believe that the potential yield increase is not attractive enough to warrant the use of the higher levels of inputs, or felt that their use involved too high a risk. A large proportion of the nonusers reported unfamiliarity with insecticides and herbicides, and a number preferred their traditional practices in dealing with problems. The inputs were available, and farmers did not express any strong aversion to going into debt to use the inputs.

Fertilizer

In the 1975 dry season, 30% of the 141 sample farmers used a high level of fertilizer application, 62% used a low level, and 8% used no fertilizer at all. In the 1977 dry season, only 1% of 179 sample farmers used a high level of fertilizer application, while 94% used low levels. The most important reasons given by farmers who used no fertilizer or low levels were the high price of fertilizer and the fluctuating selling price of paddy.

Insecticide

Of 52 farmers who reported serious insect infestation in the 1975 dry season, 35% used no insecticide, mainly because they did not know how, were unfamiliar with it, or believed it was too costly. In the 1977 dry season, 24% of 123 farmers who had serious insect problems used no insecticide. The most important reasons given were the same as in the 1975 dry season.

Weeds

In the 1975 dry season, 69% of 104 farmers who had serious weed problems used no herbicides, mainly because they lacked knowledge of how to use them. In the 1977 dry season, 38% of 136 farmers who had serious weed problems used no herbicide. The most important reason given was the belief that the herbicides they had applied were not effective, and hand weeding was better. Some farmers also believed that herbicides

Table 26. Distribution of farmers giving various reasons for nonadoption of six modern practices. Suphan Buri, 1975, and Chanasutr, 1977 dry season.

Reason	Modern varieties		Fertilizer		High rate of fertilizer		Insecticide		Herbicide		Good land prepn	
	'75	'77	'75	'77	'75	'77	'75	'77	'75	'77	'75	'77
No. not using	0	0	11	9	87	168	18	30	72	52	84	102
	Farmers (%) citing the identified reason											
Costs or prices	0	0	55	50	57	46	22	13	8	19	41	45
Risk aversion	0	0	0	10	21	14	6	10	14	2	3	0
Debt aversion	0	0	0	0	0	9	0	4	0	4	0	0
Believed not effective	0	0	0	0	0	3	0	4	16	42	0	0
Unavailability	0	0	0	0	0	0	0	0	3	0	1	1
Physical problems	0	0	36	20	6	21	0	4	0	0	7	21
Lack of technical knowledge	0	0	0	10	7	6	28	45	46	19	13	7
Preference for traditional practice	0	0	9	10	8	0	11	7	10	12	6	0
Others	0	0	0	0	1	2	33	13	3	2	29	26

stop the growth of rice because, after herbicide application, their rice plants appeared red and weak. Some farmers did not know the proper rate and timing of application or the kind of herbicide that would control their weeds. Other important reasons given were the high price of herbicide and the fluctuating selling price of paddy.

Good land preparation

In both samples, nearly 60% of the farmers reported poor or rather poor land preparation practices, which might be related to unwillingness to use higher fertilizer levels. The most important reason cited was economic; some farmers had no money to buy a tractor and believed that hired tractors did not do the work properly. The other important reason given was uneven land.

Relationship of input use level to yields

To determine whether input use was related to yields, chi-square tests were run between the distribution of expenditures for fertilizer, herbicides, insecticides and yields. Farms were classified as zero, low, and high users of fertilizer, weed control, and insect control inputs. The average was the dividing point between the high and low levels. In the 1977 dry season the dividing point was 603 ฿/ha for fertilizer, 29 ฿/ha for herbicide, and 47 ฿/ha for insecticide. Farms were classified into two groups with respect to yield: those with yields of less than 3,538 kg/ha and those with yields of more than 3,538 kg/ha. The analysis of the 1975 dry season data rejected the hypothesis of independence between yields and fertilizer. In the same season, the chi-square test did not reject the hypothesis of independence between yields and insecticide or yields and herbicide cost. For 1977, the chi-square test rejected the hypothesis of independence between yields and insecticide costs but did not reject independence between yield and fertilizer or yield and weed control cost.

CONCLUSIONS AND IMPLICATIONS

The implications of the study are confined to areas of Thailand with good water control, because that condition existed in the study area. Such areas are not numerous, but they represent the irrigated rice-growing areas of the Central Plain.

Research began in the 1974 wet season and ended in the 1977 wet season. Field experiments were conducted each season and socioeconomic surveys in the 1974 wet, 1975 dry, and 1977 dry seasons.

The average yield gap was about 1 t/ha in the wet season and about 2 t/ha in the dry season (Fig. 2). The main contribution to the gap was from fertilizer: about 55% in the wet season and about 75% in the dry season. In the wet season, 27% of the gap was the result of inadequate weed control and 9% was the result of inadequate insect control. In the dry season, 15%

was the result of inadequate weed control and 5% was the result of inadequate insect control. The gap was nearly twice as large in the dry season as in the wet season, because better water control in the dry season allowed the profitable application of more fertilizer. In addition, there were more opportunities to control weeds and use other good cultural practices.

In 1977 research was conducted in an area that had undergone land consolidation. The immediate benefit of land consolidation is an even supply of irrigation water, although surface soil has been removed through grading and leveling and hence soil fertility is uneven. It takes a considerable time for soil fertility to recover but proper soil management can compensate for this problem. Most of the experiments were in recently completed land consolidation schemes and therefore the yields and the amount of inputs used by farmers within the land consolidation area were not significantly different from those outside. However, it is expected that with experience, farmers within the land consolidation area will increase their input use and yields.

We conclude that policies and extension efforts should be directed at increasing rice production in the dry season rather than in the wet season, because the same amount of inputs could give higher yields in the dry season. This might be achieved through recommendations for the most profitable fertilizer rate. the proper sources and timing, and recommendations tailored to suit different field conditions.

In the wet season, the present modest input levels used by farmers in the study area probably cannot be economically raised except where control conditions are exceptional. The Rice Division is now emphasizing the breeding of varieties suited to rainfed rice areas and for adverse wet season conditions.

This research effort has yielded information on rice production constraints in the well-irrigated rice-growing area of the Central Plain. The largest area planted to rice in Thailand -- about 90% of the total in 1977 -- is rainfed. Of that, about 50% is in the northeast. As a result of poorly distributed low rainfall in recent years, various trials on yield increases by the direct seeding method in the Northeast are now under way. Breeding efforts are also being aimed at the Northeast. Studies of yield constraints in the Northeast would help in the formulation of strategies for rice production there.

Research complementary to this study is recommended: analysis of the impact of land consolidation on water control; investigation of the lag in the adoption rate of new varieties; and study of the effects of the increased prices of paddy as the rice premiums are gradually reduced.

REFERENCES CITED

Bhasayavan, N. et al. 1978. Agro — economic experiments on rice yield constraints in farmers' fields under some transplanted areas of Chanasutr Irrigation Project. A paper presented at the IRAEN conference, April 24 – 26, 1978, IRRI.

Division of Agricultural Economics, Ministry of Agriculture and Cooperatives. Agricultural Statistics of Thailand, crop year 1962 – 63, 1972 – 73 and 1974 – 75. Bangkok, Thailand.

Gomez, K. A. 1977. On farm assessment of yield constraints: methodological problems, in International Rice Research Institute, Constraints to high yields on asian rice farms: an interim report. Los Baños, Philippines.

Lusanandana, B., S. Montrakul, and S. Dhammanuwong. 1967. Report on large scale demonstration on rice cultivation. Rice News Bulletin (Thai), 14 (124), October 1967. Bangkok, Thailand.

Rice Division, Ministry of Agriculture and Cooperatives. 1974. Effect of rates of nitrogen fertilizer of performance of promising non – photosensitive rice lines. Annual research report on rice cultivation experiment. Bangkok, Thailand.

Tongsang K. 1970. Field test on the yield of nonphotosensitive variety under farmers' condition in dry season 1967. Agronomy Management Branch research report no. A – 2 – 1. Bangkok, Thailand.

Constraints to High Rice Yields in Sri Lanka

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Rice occupies a predominant position in the economy of Sri Lanka. It accounts for about 45% of per capita calories and 40% of per capita protein in the average Sri Lankan diet. It is the single most important crop under cultivation, occupying a third of total cultivated area. It contributes 8–10% to the gross national product and provides employment for Over 42% of the agricultural work force.

In recent years Sri Lanka has experienced a relatively rapid diffusion of improved rice varieties. The first hybrid varieties were introduced in the mid–l950s, but their full impact was not felt until the late 1960s. The first of the new improved varieties was released to farmers in 1971–72, but they spread rapidly thereafter and today account for about 80% of the total rice area sown. National yield levels, however, do not reflect the substantial progress made in the diffusion of the new varieties. Yields have increased from an average of about 1.6 t/ha in 1955–57 to about 1.9 t/ha in 1965–67, and today stand at about 2.5 t/ha.

Domestic production is not sufficient to most rice requirements, and Sri Lanka has had to depend upon sizable imports. But rapid increases in domestic production over the last two decades have led to a decline in the relative importance of rice imports (Table 1). Rice production increased from 490,000 t in 1948–52 to Over 1.6 million t in 1977, registering an average annual compound rate of growth of about 6%. Apparent rice consumption, defined as the total of domestic rice production and imports, increased from about 1.0 million t to about 2.0 million t, an average annual growth rate of about 3%. Wheat flour, the other major cereal component of the diet (entirely imported), increased from 187,000 t to Over 400,000 t, reflecting an average annual increase of over 3.5% during this period. During the period the average annual rate of growth of population was around 2.5%. Per capita real incomes in the period 1961–71 are estimated to have increased at 2.3% per annum.

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Table 1. Production, area, yield, and imports of rice (paddy equivalents) and imports of wheat flour. Sri Lanka, 1948–77 (Department of Census and Statistics, Government of Sri Lanka).

Period	Production (1000 t)	Area planted (1000 ha)	Yield (t/ha)	Rice imports (Paddy equivalent (1000 t)	Wheat flour imports (1000 t)
1948-56	533	450	1.4	604	203
1957-59	725	522	1.7	709	216
1960-64	976	615	1.9	711	194
1965-70	1199	660	2.0	577	362
1971	1396	726	2.4	424	323
1972	1312	726	2.4	430	306
1973	1312	725	2.3	490	402
1974	1602	825	2.3	428	409
1975	1154	696	2.2	695	439
1976	1252	725	2.3	564	330
1977	1673	829	2.5	-	-

Rice production in Sri Lanka is strongly influenced by regional variations in topography and climate. Sri Lanka comes under the influence of the southwest monsoon from May to September and the northeast monsoon from November to January. The location of the central highlands in the path of the rain-bearing winds dictates the pattern of rainfall. The southwest quadrant of the island receives a mean annual rainfall of 100 to more than 200 in. Rainfall is well distributed, and because of the absence of any pronounced dry season, this area is customarily referred to as the wet zone. The remaining three quarters of the island receives a mean annual rainfall of less than 75 inches, mainly during the three months of the northeast monsoon. Because this area has a pronounced dry season from April to September, it is called the dry zone.

The area and production of rice in the major climatic regions are shown in Table 2. The dry zone accounts for about 60% of the area under rice. About 32% of the total area is served by major irrigation schemes, of which nearly 90% are in the dry zone. Minor irrigation schemes account for 28% and rainfed areas for 40% of the total area. The dry zone has nearly 70% of the area under minor schemes and 56% of the rainfed area. The dry zone contributes a little over 60% to production. Thirty two percent of the national production is purchased by the government, with most of that coming from the dry zone.

Table 2. National and regional rice statistics. Sri Lanka, 1969-71 average.

	Dry zone	Wet zone		Sri Lanka
		Low country	Hi11 country	
Area planted (1000 ha)	450.8	145.3	130.0	725.4
% of national total	62	20	18	100
% of area under Maha crop	44	11	11	65
Sources of water supply:				
Major schemes (1000 ha)	158.4	64	12.7	177.5
Minor schemes (1000 ha)	106.6	10.7	40.3	161.6
Rainfed (1000 ha)	128.5	73.9	27.2	229.6
Total production (1000 t)	931	197	330	1462
% of national production	63	14	23	100
Government rice purchases as a % of national production	26	1	5	32

Two seasons of rice production based on the pattern of rainfall distribution are recognized. The Maha or major season coincides with the northeast monsoon from October to February, and production is spread over the entire country. The Yala or minor season coincides with the southwest monsoon, and production is mainly confined to the wet zone and the major irrigation schemes in the dry zone. In the dry zone the main season Maha crop is similar to wet season crops in other Asian countries, while the Yala crop is more like dry season crops elsewhere. The Maha crop accounts for 65% of the total area sown and contributes about as much to total production. Rice production in the wet zone is almost entirely dependent upon rainfed cultivation, but because of better rainfall distribution in the wet zone, Yala cultivation is almost as important as Maha.

Increases in domestic production have cane about equally from increases in cultivated area and yields. The area under major irrigation schemes increased by 40,470 ha over the period 1960–74, compared with an increase of 31,970 ha under minor schemes and 40,065 ha under rainfed cultivation.

In addition to the expansion in cultivated area, there has also been an increase in the use of fertilizer, disbursement of credit, and area planted to new varieties. Table 3 presents information on fertilizer use, credit availability, and the area using the new varieties. Except for a brief period in 1975, when consumption fell drastically, fertilizer prices have been subsidized. Credit schemes have also been reorganized from time to time in order to

Table 3. Fertilizer use and credit disbursements for rice and area planted to new rice varieties, annual average. Sri Lanka, 1959–77 (Department of Agriculture, Government of Sri Lanka and Central Bank of Sri Lanka).

Period	Fertilizer use		Credit		Improved varieties	
	T	kg/ha	Total[a] (1000 Rs)	Rs/ha	Area (1000 ha)	% sown
1959-64	37,289	61	16,937	28	-	-
1965-69	62,127	93	43,276	64	na	na
1970	86,739	114	51,710	68	492	65
1971	91,432	126	29,280	40	478	66
1972	81,791	113	30,630	42	489	67
1973	98,384	136	28,260	39	500	69
1974	122,616	148	109,100	132	646	78
1975	43,800	63	77,250	111	519	75
1976	73,666	102	56,260	78	561	77
1977	82,665	100	38,365 [b]	71[b]	478	89 [b]

[a] Exchange rate used: US$1.00 = Rs12.

[b] Maha 1976–77 only.

ensure greater availability of credit to peasant farmers. In addition, the government has maintained a rice price for producers well above world market levels. During the 1960s the government purchase price averaged Rs0.60/kg, while imported rice cost Rs0.30/kg, and during the 1970s the government price increased to Rs0.96/kg, while imported rice increased to Rs0.88/kg. Perhaps most important of all is the success of government's efforts to develop and ensure the widespread diffusion of modern varieties. Since 1970, the modern varieties have covered more than 65% of the total rice area.

National yields, however, do not appear to reflect the widespread adoption of the new varieties. Average yield levels are far below the levels attained at experiment stations. The coordinated rice varietal trials conducted by the Department of Agriculture indicate that the potential of the new varieties is about double that of the traditional varieties. But average yield levels of the new varieties under farm conditions have been disappointingly low, hardly approaching 2.5 t/ha. Because adoption has been rapid, the reasons for the relatively low levels of yields must be sought elsewhere.

Since experiment station conditions cannot be duplicated on farmers' fields, it is hypothesized that yield differences exist between the levels obtained at experiment stations and the potential of

the same varieties on farmers' fields. This difference or *gap* is attributed to environmental differences between the experiment station and farmers' fields and to nontransferable technology. A further gap or difference is also observed between the potential farm yield, defined as the highest yield that can be obtained on farmers' fields using modern technology, and the actual yields obtained by farmers. It is this gap that is the focus of this study.

It is hypothesized that the gap is the result of both agronomic and socioeconomic constraints. The agronomic constraints refer to the nonadoption of certain aspects of improved technology that go with the new varieties, such as water control, fertilizer, insecticides, weed control measures, and cultural practices. The socioeconomic constraints, like cost–pricerelationships, limitations of institutions, input availabilities, and credit explain why farmers are not following the recommended management practices or using the recommended levels of inputs.

The basic objective of this study is to measure the actual and potential yields on farmers' fields and to identify the major agronomic and socioeconomic factors that explain the yield gap.

THE GENERAL METHODOLOGY

Experiments on farmers' fields and socioeconomic surveys were conducted. An area representative of rice farming was selected and from this area a few representative farmers were chosen. Experiments were placed on their fields to compare yields obtained from using their practices with those obtained with recommended inputs and practices for 3 or 4 selected test factors. The experiments were designed to enable a comparison of yields at farmers' levels and the recommended level of use of selected test factors and to apportion the yield gap among the factors. A second part of the experiment tested different management packages that were subsequently economically evaluated. A field of rice near the experiment was designated as the "comparable paddy". Input levels and practices on the test factors used by the farmers on the comparable paddy were continuously monitored and simulated on the farmers' level plots in the experiment.

A farm record–keepingproject and a socioeconomic survey were associated with the experiments. These were designed to determine the level of input use and management practices of the farmers, and to explain any constraint that might prevent farmers from following the recommendation.

In trying to measure potential and actual yields it is fully realized that yields vary from location to location and from season to season and that a large number of factors may help explain

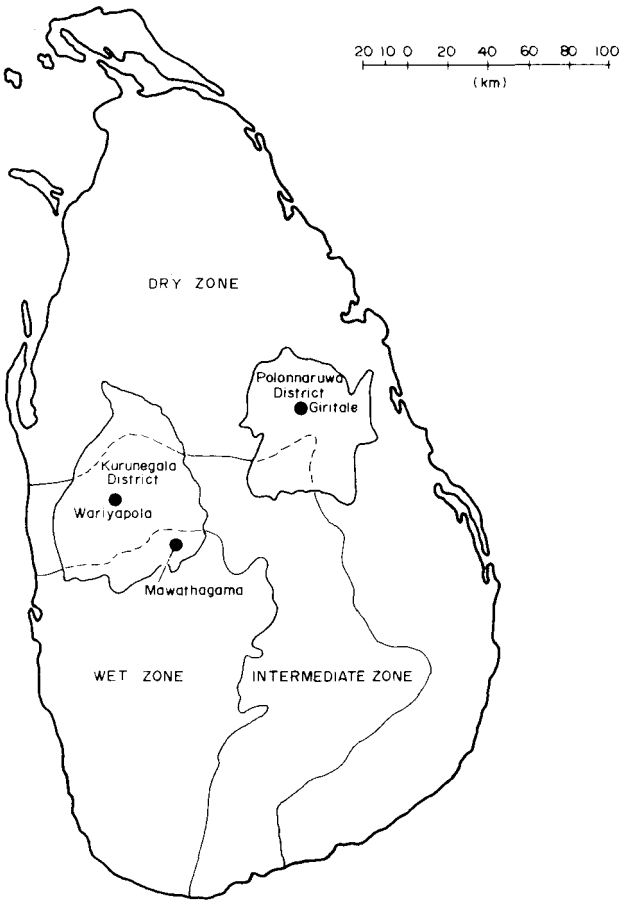
the yield gap. Because it is difficult to test a large number of experimental factors or locate experiments on a large number of farmers' fields, it is necessary to select a few factors considered to be the most important constraints in the area studied and to test them at the farmers' levels and the recommended level. The few farmers selected for study were representative of the area. To keep the study within manageable proportions, three or four factors were tested in about 12 farmers' fields in the first year of study. The greater the number of agronomic constraints identified and studied and the more complex the field experiments, the fewer the number of farms on which experiments could be located. But in order to generate information for planning and policy-making purposes, conclusions derived must be capable of generalization, at least over agroclimatic zones. It was thus necessary to devise an experimental technique suitable for covering a reasonable number of farm holding.

In the two years of the study, the major emphasis has been on developing a suitable methodology. In the first year of study, 12 experiments were located on farmers' fields, including 4 major and 8 minor factorials. These 12 farmers were part of a larger sample of 40 farmers selected on a random basis and representative of the area. They formed the sample that was subsequently interviewed for socioeconomic data, and they also kept farm record books. It was felt, however, that a sample of 12 farmers was far too small for valid generalizations, even given the extreme care with which they were selected.

In the second year the study was moved to the Kurunegala district in a different agroclimatic zone. The experimental procedure was simplified and 34 farmers were studied during the first season. The major factorial design was dispensed with and minifactorials were placed in 12 farmers' fields at Mawathagama falling within the wet zone and 8 fields at Wariyapola in the intermediate zone. Eight other farmers at Mawathagama and 6 at Wariyapola were selected for locating two management package experiments.

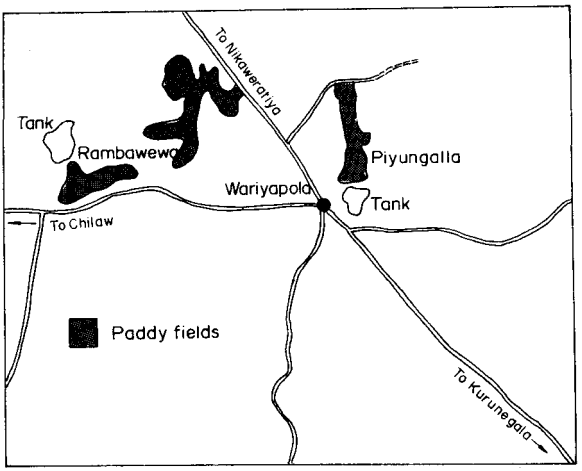
In the second season of the same year, because of water problems, the study was confined to Mawathagama and the experimental design was further modified. A major factorial design was tested on 5 farmers' fields, a management package on 15 farmers' fields, and a single-plot design consisting of the recommended management package was located on 29 farmers' fields, for a total of 49 farmers participating in the program. The field experiments were coordinated with socioeconomic surveys and farm record bookkeeping projects.

The study areas. This study was conducted in over two years in two different areas (Fig. 1). In the first year the experiments were located in the Polonnaruwa district, a major rice-producing

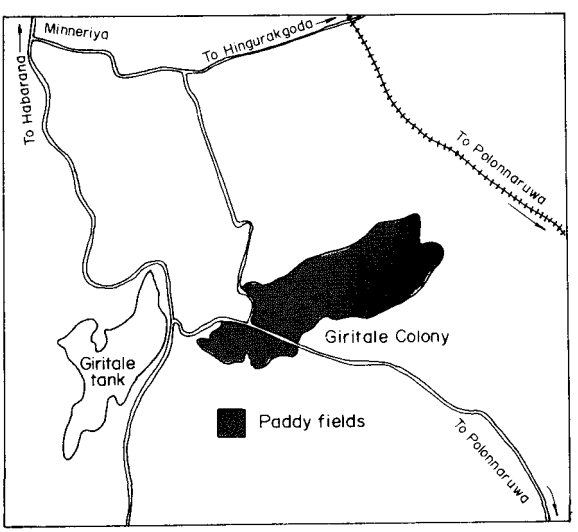


1. Location of study areas, Polonnaruwa and Kurunegala Districts, Sri Lanka.

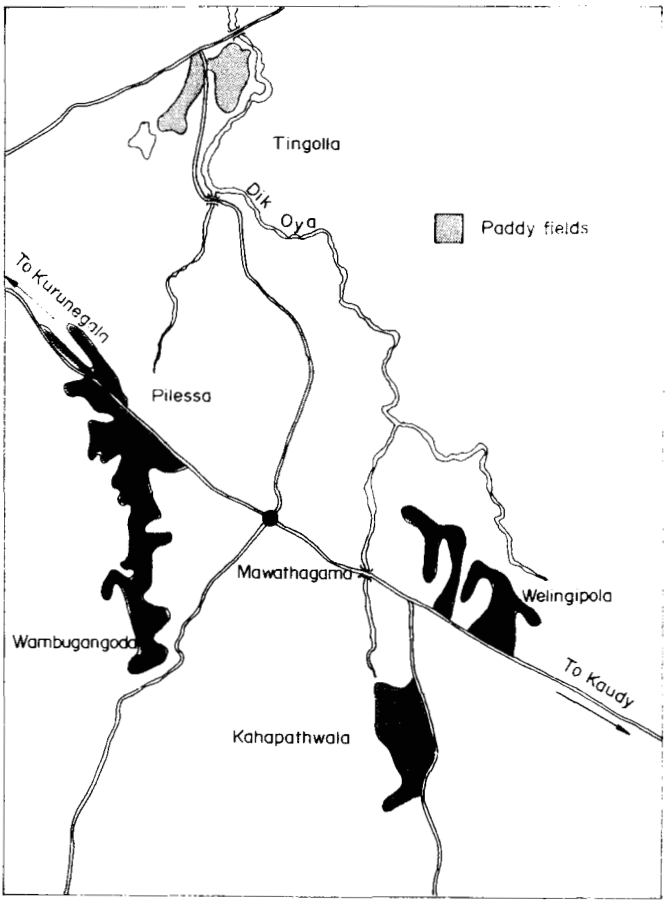
area in the dry zone of Sri Lanka. Giritale, a major irrigation scheme, was the site selected for the field experiments (Fig. 2). In the second year the study was shifted to the Kurunegala district, another important rice-producingarea. But it included within its boundaries portions of the dry zone, the intermediate zone, and the wet zone. Wariyapola and Matathagama were the sites selected (Figs. 3 and 4). They fall within the intermediate and wet zones respectively. Both sites were covered in the Maha or major season, but water problems confined the study to Mawathagama in the Yala or minor season.



2. Giritale, Sri Lanka.



3. Wariyapola, Sri Lanka.



4. Mawathagama, Sri Lanka.

The Polonnaruwa District. Polonnaruwa accounts for about 6% of the national area under rice cultivation and for about 10% of national rice production. Nearly 80% of all rice land in this district is serviced by major irrigation systems. Although much of the rainfall is confined to the four months from October to January, irrigation facilities permit extensive double cropping in normal years. Yield levels are relatively high, averaging over 3.5 t/ha compared with the national average of about 2.5 t/ha. Farms are relatively large, with holdings averaging over 1.6 ha and paddy holdings averaging over 1.2 ha. These are above the national averages of 1.0 ha and 0.7 ha. Rice is by far the most important crop, accounting for about 80% of average farm

incomes. The highlands are mainly under perennial tree crops and are underutilized.

The Kurunegala District. The Kurunegala district was selected for the second year of study. It has the largest rice area, accounting for about 11% of the national area, but yield levels are below the national average. Rice production depends upon rainfall. Thus while areas falling within the wet zone are double cropped, rice areas in the dry and intermediate zones are single cropped, except in the few cases where irrigation is available. Nearly 50% of the rice area in this district is rainfed and only 13% is served by major irrigation systems. Farm size averages 1.4 ha per holding with 0.6 ha of paddy. Highland cropping, especially coconuts, is important.

AGRONOMIC YIELD CONSTRAINTS

The experimental factors. Many factors are known to influence yields. Since it was beyond our resources to handle more than two or three factors, it was decided to concentrate on fertilizer use, weed control, and pest control. This decision was arrived at from previous surveys at Giritale and other dry zone irrigation schemes as well as from discussions with Department of Agriculture staff. At Giritale, depth of planting and spacing were also tested, at the request of Department of Agriculture officials. These factors were discontinued in the second year because of inconsistent results.

The experimental design. As initially conceived, the field experiments had two components, a two-level factorial and a four- to five-level management package. In the factorial experiment, the selected experimental factors were included at the level used by the farmer on whose field the trials were located and at the recommended level. The management package consisted of all factors at the farmers' levels, designated as M_1, and all factors at the recommended level designated as M_4. M_5 had all factors at a level higher than M_4, while M_2 and M_3 were at levels intermediate between M_1 and M_4. Table 4 shows the fertilizer levels in the managanent package treatments for the various levels. Table 5 shows the insect and weed control inputs for treatments M_2 through M_5. Weed control and insect control treatments for the M_1 level are indicated only by the average number of application farmers used because a wide range of chemicals were used at widely different dosages. About 15 chemicals were identified as being used. Even in the case of fertilizers, rates of application varied widely, the basal application ranging from 103 kg/ha to

Table 4. Fertilizer application rates (kg/ha) used in constraints management package experiments. Sri Lanka, 1975 – 77.

Package[a]	Fertilizer applied[b] (kg/ha) N		P_2O_5		K_2O		No. of applications[b]
			Giritale, Maha 1975 – 76 and Yala 1976				
M_1 (Maha)	167.8l		32.76		32.76		3.8
(Yala)	57.80		11.30		11.30		1.5
M_2	57.75		0		0		2
M_3	48.36		17.20		8.07		2
M_4	77.24		34.39		16.14		3
	(106.11)						(4)
M_5	91.67		51.59		24.21		3
	(120.54)						(4)
			Wariyapola, Maha 1976 – 77				
M_1	42.62		23.38		11.89		1.9
M_3	62.45	39.62	49.59	37.19[c]	28.69	21.52[c]	3
	(81.70)						(4)
M_4	79.24	52.2l[c]	73.38	55.78[c]	43.04	32.28[c]	3
	(108.12)						(4)
M_5	96.03	64.81[c]	99.17	74.38[c]	57.39	43.04[c]	3
	(134.53)						(4)
			Mawathagama, Maha 1976 – 77 and Yala 1977				
M_1 (Maha)	47.50		25.72		16.31		2.1
(Yala)	67.59		35.29		29.09		2.2
M_3	46.84		34.37		29.22		3
	(56.46)						(4)
M_4	63.04		51.55		43.83		3
	(77.48)						(4)
M_5	79.24		68.73		58.44		3
	(98.49)						(4)

[a] Data for M_1 level are averages.

[b] Data in parentheses refer to new improved varieties over a 4 – 6 month period.

[c] For old improved varieties only.

Table 5. Weed and insect control inputs used in constraints management package experiments. Sri Lanka, 1975-77.

Package[a]	Insect control		Weed control	
	Granular (no.)	Foliar (no.)	Hand weeding (no.)	Chemical (no.)
	Giritale, Maha 1975–76 and Yala 1976			
M_1 (Maha)	0.30	0.90	0.75	0.08
(Yala)	0.18	0	0	0.18
M_2	0	2	1	0
M_3	1	1	0	1
M_4	1	2	0	1
M_5	2	3	1	1
	Wariyapola and Mamthagama, Maha 1976-77[b]			
M_1	0.2	1.6	0.4	0.1
M_3	1	1	0	1
M_4	2	0	0	1
M_5	2	1	1	1
	Mawathagama, Yala 1977[b]			
M_1	0.4	0.9	0.7	0.1
M_3	1	1	1	0
M_4	2	1	2	1
M_5	3	0	3	1

[a]Data for M_1 level are averages.

[b]M_2 level not included.

250 kg/ha and the first topdressing ranging from 45 kg/ha to 250 kg/ha. Only 76% of the farmers on whose fields management packages were located applied the basal dressing, 85% the first topdressing, and 76% the third topdressing. None applied the second topdressing. The treatments tested at Kurunegala during the Maha season were about the same except that mixed fertilizers were not used at the M_3 and higher levels, and Furadan and Fenitrothion were also used. Because Wariyapola soils are deficient in phosphorus, much higher levels of P_2O_5 were used. M_2 was dispensed with in the second year's experiments, but a third component was added.

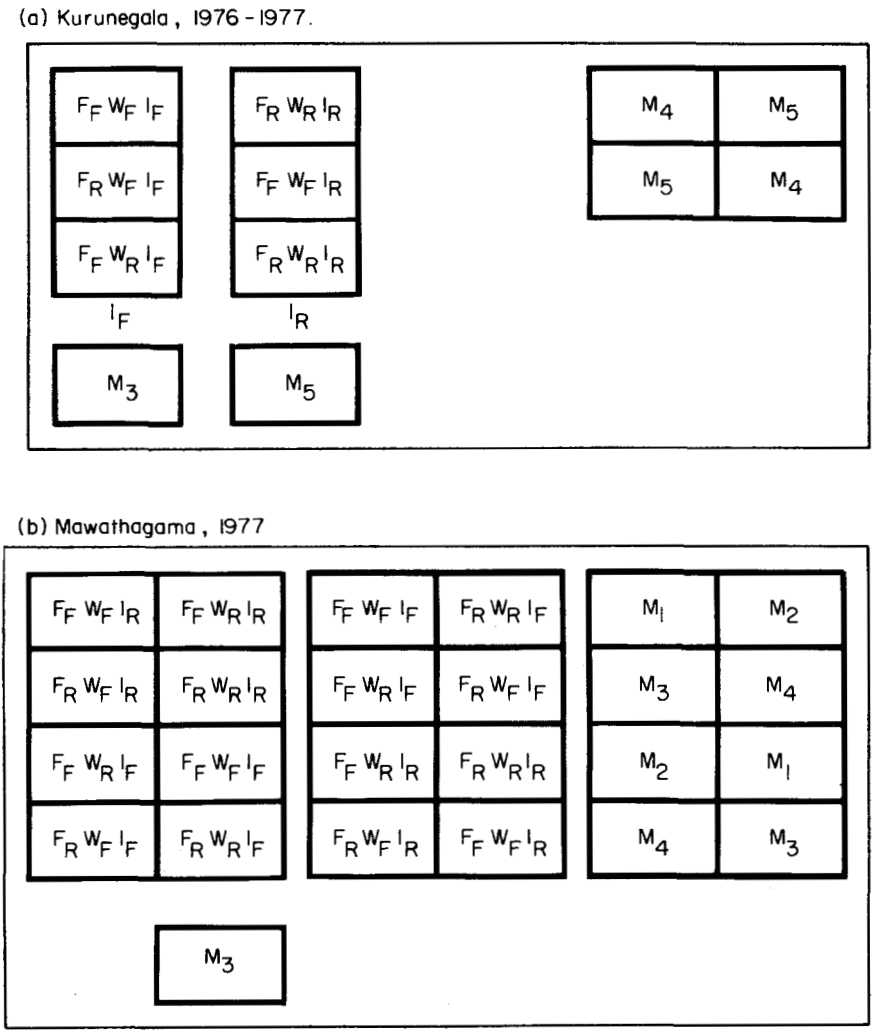
In addition to the two-level factorial and four-to five-level management package, a two-level management package at the recommended and higher level in the Maha season and a single management package at the recommended level in the Yala season were laid out in a number of additional farm sites. The idea was to have a reasonably large number of farms on which to lay out experiments to estimate the potential and actual farm yields and to make the estimation of the gap more representative.

Thus the experimental design, as finally developed at Mawathagama in the 1977 Yala season, took on a three-tiered pattern. This was in line with the decisions made at the Yogyakarta conference in 1976. Fifty farmers were initially selected to lay out the experiments. One site had to be subsequently discarded. The recommended management package was laid out in 49 sites. Fifteen sites were selected from these for a level management package, including the recommended management package. From these 15 sites, 5 were selected for the two-level factorial.

Layout of experiments. The layout of the experiments varied from location to location. At Giritale a large experiment or major factorial was laid out at 4 sites. It consisted of 14 treatments of the factorial and 6 treatments of the management package. A split-plot design with insect control as the main plot was used. Treatments were replicated twice. In 8 sites, a small experiment or minifactorial was laid out. It consisted of fertilizer, weed control, and pest control at farmers' levels and the recommended level. The treatments were random but unreplicated. Plot size in all cases was 15 m^2 (see *Interim report*).

When the experiments were shifted to Kurunegala, it was decided to dispense with the large experiment. Instead the minifactorial was laid out in 20 sites. The plots were randomized, but there were no replications (Fig. 5a). In addition, a two-level management package was also incorporated with input levels higher. and lower than the recommended level (M_4 and M_5). Fourteen additional sites were selected, and a two-level management package at the recommended and higher levels was laid out on 4 plots. Plot size was 20 m^2 in all cases.

The experimental design was further modified in the 1977 Yala season at Nawathagama, based on the discussions at the Yogyakarta conference of November 1976 (Fig. 5b). The major factorial design was introduced and laid out on 5 sites. It consisted of 8 treatments of the factorial. A split-plot design fully randomized and replicated was used. The management design was laid out on 15 other sites. In addition, a single-plot management package at the recommended level was laid out on 29 other sites. Plot size was 20 m^2 in all cases.



5. Layout of constraints field experiments, Sri Lanka, 1976–77.

The analysis. Yields were estimated by crop cuts, both on experimental plots and in farmers' fields, representing the comparable paddy. Table 6 presents a comparison of yields at farmers' levels and the recommended level of input. Yields at the level of input higher than the recommended level are also given for the seasons for which such estimation was possible. It can be seen that the potential farm yields were higher than

Table 6. A comparison of yields at farmers' (CF) levels, recanmended (M_4) and high (M_5) levels of inputs, for all locations and sites. Sri Lanka, 1975 – 1977.

Location	Season	Sites (no.)	Yield (t/ha)		
			CF	M_4	M_5
Polonnaruwa District					
Giritale	Maha 1975 – 76	4	2.9[a]	3.6	4.1
Giritale	Yala 1976	3	2.5	2.3	3.9
Kurunegala District					
Wariyapola	Maha 1976 – 77	10	0.9	1.9	2.0
Mawathagama	Maha 1976 – 77	18	2.8	3.4	3.8
Mawathagama	Yala 1977	43	2.6	2.9	-

[a] M_1 value.

the actual farm yields except at Giritale during Yala 1976. But, as mentioned earlier, water problems at Giritale in this particular season made the results inconsistent and inconclusive. In the other sites, the differences in yield ranged from 1.0 t/ha at Wariyapola to as low as 0.3 t/ha at Mawathagama. It also appears that levels of inputs higher than those recommended would increase yields still further, although here again there are wide variations between locations. There are also wide variations within locations. Thus, at Mawathagama in the Yala season, when the recanmended management package was laid out at 49 sites and yields reported from 43 sites, it was observed that yields on these sites varied from under 1.5 t/ha to over 5.0 t/ha. About 70% of the yields fell within the 2.6 t/ha to over 4.1 t/ha range.

The experiments from which these results are derived do not allow for a comparison of different management packages. These were laid out at fewer sites. Table 7 presents information comparing yields from the different management packages. The results show that yields increased consistently from M_1 (farmers' practices) to the higher levels of inputs. At Giritale, during the Yala season, however, the comparable paddy gave a higher yield than M_1, indicating that the M_1 package did not successfully simulate the farmers' practices. In Kurunegala, on the other hand, M_1

Table 7. Yields at different levels of management packages compared with farmers (CF and M_1) levels. Three locations, Sri Lanka, 1975 – 1977.

Location	Sites (no.)	Yield (t/ha)					
		CF	M_1	M_2	M_3	M_4	M_5
Polonnaruwa District							
Maha 1975 – 1976							
Giritale	4	-	2.9	3.4	3.4	3.6	4.1
Yala 1976							
Giritale	3	2.5	1.8	1.7	1.9	2.3	3.9
Kurunegala District							
Maha 1976 – 1977							
Wariyapola	3	1.1	1.2	-	1.9	2.1	2.3
Mawathagama	10	3.1	3.5	-	3.8	3.8	4.2
Yala 1977							
Mawathagama	14	3.0	3.1	-	3.1	3.3	3.5

yield levels were higher than CF levels in all 3 sites, but the differences do not appear to be great. A possible explanation may be the better management of farmers' practices on the M_1 plots.

The yield response from M_1 to M_5 was about 1.0 t/ha, except at Mawathagama, where it was only 0.4 t/ha. The yield response from M_1 to M_4 (the recommended package) was relatively small, except at Wariyapola, where all yield levels were relatively low. The rather wide disparity in yields between Wariyapola and Mawathagama in the same district and in the same season is to be noted. Physical conditions at Wariyapola are relatively poor but the response to higher levels of inputs was the highest.

Table 8 shows the yield gaps and contributions of the three inputs tested. The gaps between experimental yields with farmers' inputs and recommended inputs ranged from a high of 0.9 t/ha at Wariyapola to about 0.7 t/ha at Giritale to a low of about 0.2 t/ha at

Table 8. Yields with farmers' inputs and recommended inputs and contribution of each of the three inputs to the yield gap. Three locations, Sri Lanka, 1975–1977.

Sites (no.)	Yield (t/ha)			Contribution (t/ha) of			
	Farmers'	Recon-mended inputs	Gap	Ferti-lizer	Weed control	Insect control	Resi-dual
			Giritale, Maha 1975–1976				
12	3.2	4.0	0.8	0.1	0.2	0.7	–0.1
			Giritale, Yala 1976				
12[a]	2.9	3.5	0.6	0.2	–0.2	0.1	0.5
			Wariyapola, Maha 1976–1977				
8[b]	1.2	2.1	0.9	0.3	0.1	–0.1	0.5
			Mawathagama, Maha 1976–1977				
12[c]	3.6	3.8	0.2	0.2	0.1	–0.2	0.2
			Mawathagama, Yala 1977				
5	2.3	2.5	0.2	-	0.2	0.1	0.1

[a] One site abandoned.

[b] Five sites abandoned.

[c] Two sites abandoned.

Mawathagama. Insect control accounts for the yield gap at Giritale in the Maha season, and fertilizer appears to explain about half the gap at Wariyapola. In the other locations, the three factors tested (fertilizer, weed control, and insect control) gave relatively small yield increases.

SOCIOECONOMIC CONSTRAINTS

The results of the experiments located on farmers' fields show that a small gap does exist between farmers' levels of input use and the recommended level. Yields also show a consistent increase with increasingly higher levels of input use. Farmers, however,

are more interested in maximum profits than maximum yields. In the following section, the results of the experiments are subjected to economic analysis. Data from the follow-upsurvey are also presented to describe the socioeconomic environment in which farmers operated.

Analysis of costs and returns. A comparison of the additional costs and additional returns from using higher levels of inputs is shown in Table 9. In this analysis only the costs of the inputs tested were used in the calculation. Labor costs were included only for hand weeding, and it was assumed that only

Table 9. Economic comparisons of tested input management packages with farmers' levels of inputs (M_1) in constraints experiments. Sri Lanka, 1975–1977.

Compared to farmers' levels, increased	Location, year	Difference from M_1 (Rs/ha)			
		M_2	M_3	M_4	M_5
	Maha (wet) season				
Gross return	Giribale,	727	808	1132	1827
Input cost	1975–76	-801	-591	303	972
Net return		1528	1399	928	855
Gross return	Wariyapola,	-	1116	1417	1738
Input cost	1976–77	-	429	1150	1428
Net return		-	689	267	310
Gross return	Mawathagama,	-	415	476	1010
Input cost	1976–77	-	86	884	1242
Net return		-	329	-408	-232
	Yala (dry) season				
Gross return	Giritale,	-539	–836	210	916
Input cost	1976	-17	193	951	1755
Net return		-522	-643	-741	-839
Gross return	Mawathagama,	-	17	264	598
Input cost	1977	-	370	1040	1630
Net return		-	-353	-776	-1032

family labor was used for other operations. The prices used in the calculation are shown in Table 10 and the average costs of input packages in Table 11.

The results in Table 9 show that at Giritale management package M_2 gave the highest increased net return over M_1. In the Maha it entailed considerably lower costs than M_1. The M_3 package gave the highest return, both at Wariyapola and Mawathagama, in the Maha season of 1976 – 77. The Yala season results were disappointing. At both Giritale and Mawathagama none of the tested packages gave an increased return over M_1.

The experimental data showed increased yields at input package levels higher than the farmers' levels in the Maha season. The most profitable level was M_3, which gave an average increased yield of 0.5 t/ha compared with the 1.0 t/ha increase achieved with M_5, with a much lower increased profit than M_3. In the Yala season all of the package levels higher than the farmers' levels gave lower profits, despite an average yield increase of 1.25 t/ha.

Table 10. Prices used in calculating costs of input packages. Kurunegala, Sri Lanka, 1976 – 1977.

Input	Unit	Prices (Rs)	
		Maha	Yala
Fertilizer			
Urea	50 kg	60.00	56.00
Basal	50 kg	60.00 to 66.00	63.00
TDM	50 kg	58.00	54.00
Insecticides			
Furadan	2.3 kg	35.00	35.00
Fenitrothion	16 oz bot.	45.00	not applied
Weedicides			
MCPA	16 oz bot.	17.50	19.50
Saturn	2.3 kg	41.00	not applied
Hand weeding			
Rice (paddy)	Rs/kg	346	1.50

Table 11. Average cost (Rs/ha) of inputs at farmers' level (M_1) and in the tested input managenent packages in experiments on farmers' fields. Giritale, Wariyapola and Mawathagama, Sri Lanka, 1975 – 1977.

Input package level	Av cost (Rs/ha)			
	Fertilizer	Insect control	Weed control	Total
	Giritale, Maha and Yala 1975 – 1976			
M_1	1278	138	46	1462[a]
M_1	442	0	96	538[b]
M_2	342	136	1l3	596
M_3	418	297	81	796
M_4	721	365	449	1535
M_5	938	662	449	2049
	Wariyapola, Maha 1976 – 1977			
M_1	222	79		301
M_3	518	131	79	728
M_4	592	410	449	1451
M_5	650	479	600	1729
	Mawathagama, Maha 1976 – 1977			
M_1	289	121	-	410
M_2	-	-	-	-
M_3	286	131	79	496
M_4	435	410	449	1294
M_5	573	479	600	1652
	Mawathagama, Yala 1977			
M_1	328	89	79	496
M_3	318	400	151	869
M_4	410	738	390	1538
M_5	509	1079	538	2126

[a] Maha , including costs of application.

[b] Yala.

Survey methodology and results. A follow-up survey was conducted to identify the social and economic constraints that prevented farmers from adopting the recommended practices and inputs. The survey was conducted at Giritale after the Maha season; at Mawathagama it was conducted after the Yala season. The objectives of the survey were to find out whether farmers were aware of the improved technology and its advantages; if so, whether they adopted them; if not, the reasons for nonadoption. Farm record books for study farmers were maintained by field assistants who visited the farmers at least twice a week.

Giritale. To identify the reasons why farmers did not adopt recommended practices, 40 farmers at Giritale were selected from a representative area to participate in the record-keeping project. From these, 12 were selected for locating the experiments. The follow-up survey covered 80 farmers in the same area, including the 40 record-keeping farmers. The record books sought information on input use, labor use, water management, and yields.

The results showed that nearly all farmers used improved varieties. Farmers were generally aware of the recommended cultural practices, but not all used them. For example, while all farmers were aware of the advantages of row transplanting, only 10% reported practicing it. The major reason adduced for not following recommendations was that the methods followed cost less and required less work.

Nearly all farmers reported using chemical fertilizers, but there were wide variations in the timing of applications. Farmers did not appear to understand the need for split applications. Nearly 40% reported using more fertilizer than the recommended rate, the reason given being that they were either unaware of the recommended rate or thought that the recommended rate was too low.

Farmers were questioned closely on the practice of insect control and weed control measures. Nearly 80% did not appear to be familiar with the measures recommended. About 40% indicated that there was no insect damage, while among those who used control measures, nearly 90% did not follow recommendations. Farmers appeared to prefer hand weeding because, in their opinion, it was a better way of controlling weeds.

Survey farmers reported yields averaging over 4.0 t/ha, but only 23% of the farmers indicated that they were satisfied with those yields. More than 70% indicated that yields were less than expected, primarily because of water problems. Other reasons given (in order of importance) were insect damage, fertilizer shortage, delayed planting, and rat and bird damage.

Mawathagama. The survey in the Kurunegala district was confined to the Mawathagama area. It was carried out following the Yala 1977 harvest. Five villages were purposively selected, and 12 farmers were chosen at random from each village for maintaining record books. Ten from each village were chosen for field experiments. For the survey, 40 record-keeping farmers were selected, including 35 experimental farmers, Another 40 farmers were chosen at random from these same villages, thus constituting a sample of 80 farmers for the survey. The major findings are briefly summarized here.

Table 12 presents information on yields and levels of fertilizer use, data on family size, and size of holdings derived from the record books and the survey. The data compare well except for yields. Yields reported by the survey farmers were well below those derived from crop cuts on 38 farms from the record-keeping farmers. It is well known that crop cuts tend to overestimate yields and farmers tend to underestimate yields.

The survey sought information on the level of technology, the farmers' awareness of the improved technology, and their reasons for not adopting a particular set of practices (Table 13). Farmers in general believed that the improved varieties were to be preferred, but only 70% used them. They cited reasons such as water shortage, resistance to pests and diseases, and low fertilizer requirements as reasons for not using the new varieties. About 90% of the farmers used their own seed. They were aware of the advantages of using certified seed issued by the Department of Agriculture but experienced serious difficulties in getting it.

Nearly 95% of the farmers reported applying chemical fertilizers, but levels of application varied. The average rate of basal

Table 12. A comparison of selected data from record books and survey. Mawathagama, Sri Lanka, Yala season 1977.

Characteristics	Record books	survey
Size of family	6.8	6.6
Size of holding (ha)	1.1	1.0
Size of paddy holding (ha)	0.5	0.5
Fertilizer use (kg/ha)	250	277
Insecticide (Rs/ha)	12.7	11.8
Weed control (Rs/ha)	1.2	1.2
Yield (t/ha)	3.1	1.6

Table 13. Percentage of survey farmers adopting major improved practices and major reasons given for nonadoption by those not adopting the practices. Mawathagama, Sri Lanka, Yala season 1977.

Practices	Percent using	Reasons for nonuse
New varieties	70	Water shortage, high fertilizer requirements, not resistant to pests and diseases
Certified seed	8	Not available
Fertilizer: Basal	75	)
1st T.D.[a]	78	) Not available in time, not
2d T.D.	8	) available, difficulty in getting
3d T.D.	54	) fertilizer
		)
Insect control	72	Difficulty in getting insecticide
Weed control	76	Not a problem
Credit	42	No need

[a] T.D. = topdressing.

application was lower than the recommended rate, but the first top dressing was about 3 times higher than the recommended rate. While rates of fertilizer application in general compared well with overall recommendations, the proper timing and dosages were not followed (Table 14). About 50% of the farmers complained of not being able to get the fertilizer on time: 38% reported that fertilizer was not available. Only 6% appeared to be unaware of recommendations. Twenty percent also complained of the lack of credit facilities.

The same problems were evident with the use of insecticides. Nearly 60% of the farmers reported some loss from insect damage. However, difficulties in getting insecticides and their non-availability on time were reported by about 50% of these. A lack of knowledge was reported by only 7% of the farmers. Heavy rains and ineffectiveness of applications were also reasons cited.

Hand weeding was the preferred method of weed control with about 62% reporting weeding their fields by hand. However, about 25% used no weed control. Among those who hand weeded, only 3% weeded twice. Nearly 90% of them used family labor.

Queries about institutional arrangements revealed that 72% of the farmers were satisfied with the credit granted, but abut 60% indicated that they had no need for credit. Seventy-fivepercent

Table 14. Survey of farmers' knowledge of correct timing and dosage of fertilizer applications. Mawathagama, Sri Lanka, Yala season 1977.

Fertilizer application [a]	Percent reporting correct application
Timing	
Basal	61
1st T.D.	23
2nd T.D.	6
3rd T.D.	14
Dosage	
Basal	30
T.D.	38
No. of T.D.	23

[a] T.D. = topdressing.

Table 15. Survey farmers' reasons for lower than expected yields. Mawathagama, Sri Lanka, Yala season 1977.

Reported constraint	Percent of farmers reporting	Ranking of reasons				
		1	2	3	4	5
Fertilizer	56	26	21	7	1	-
Water shortage	40	18	16	6	-	-
Weeds	17	1	4	10	-	2
Insects	69	40	18	6	5	-
Excess water	14	6	8	-	-	-
Rat damage	20	2	8	8	1	1

patronized cooperatives and other official sources for their fertilizer requirements but purchased their insecticides and weedicides from private sources.

Farmers indicated that yields could be increased and gave insect control, water problems, and fertilizer as the major limitations (Table 15).

CONCLUSIONS

In conclusion, a few general observations on the implications of the constraints studies as set out above may be made.

1. It appears that the importance of the factors tested and the size of the gap varies from location to location. If the results of such research are to be useful to policy-makers and planners, the experiments should cover a larger number of sites in each of the major agroclimatic zones.

2. Fertilizer, weed control, and insect control were the factors generally tested. Water control and other factors may also be important. It is necessary to identify and incorporate them in the experiments.

3. The results of the experiments imply a relatively wide gap between experiment station yields and potential farm yields. Researchers must pay more attention to developing varieties that will suit microenvironments.

4. Farmers know about the new technology, but extension workers should now pay more attention to the details of using inputs. It should be possible to develop recommendations suited to each microenvironment.

REFERENCE CITED

International Rice Research Institute (IRRI). 1977. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Philippines.

Agroeconomic Study of Rice Production in Taiwan

Carson Wu, Yi-Chung Kuo, and Cheng-Chang Li

Rice is the single most important crop in Taiwan's economy, earning much of the foreign exchange needed for economic development in the past three decades. The value of rice in the total agricultural output varied between 40% in 1956 and 23% in 1972, before returning to 26% in 1976. Rice has been and will continue to be the staple food in the Chinese diet. Rice has assured the economy of self-sufficiency in a basic food. Hence, increase in rice yield by full utilization of the limited arable land in Taiwan has been a national agricultural and economic policy.

Measures for increasing rice production have changed from production subsidies to price incentives (parity prices) (Wu and Mao 1976). This policy gives the farmers more choices in combining inputs. Yields per hectare increased from 2.7 t/ha in 1960 to 3.4 t/ha in 1976 (Table 1). Production is concentrated mainly in the southern and central parts of Taiwan because these areas are best suited to growing rice. In 1976 the total area of paddy field was about 520,000 ha, or 57% of the cultivated area. Of the paddy fields, 70% were double-cropped and the rest were single-cropped. Although the planted area of the second-season crop (fall rice) was about 19% more than that of the first-season crop (spring rice), its average yield was about 30% less in all regions (Table 2). The difference in yield between the two seasons is more significant in the southern region (Kaohsiung area). Under the policy of increasing rice production in Taiwan, increasing the yield of the second crop is an immediate target.

Rice production in Taiwan is generally served by a well-controlled irrigation system and has high-quality inputs (e.g., the high-yielding variety Tainan No. 5). Much of the high yield on farms has resulted from the application of large amounts of fertilizer. The average amount of fertilizer applied on rice in terms of plant nutrients was 156 kg/ha in 1960 and 240 kg/ha in 1976 (Table 3). However, the high percentage of cash costs and the desire for maximum profit in commercial rice farming have set the ceiling for the amount of fertilizers to be used. Noncash inputs embodied in cultural practices offer another dimension in raising rice yield.

Table 1. Production, area, yield, and export of paddy. Taiwan 1960 – 76 (Taiwan Statistical Data Book 1977, and Taiwan Agricultural Yearbook 1977).

Period	Total production (1000 t)	Planted area (1000 ha)			Yield (t/ha)	Export (t)
		First crop	Second crop	Total		
1960 – 64	2,079	332	439	771	2.7	77,823
1965 – 69	2,396	338	447	785	3.1	118,618
1970 – 74	2,385	335	420	754	3.2	49,591
1975	2,494	358	432	790	3.2	5,679
1976	2,713	361	425	786	3.4	1,389

Table 2. Area planted to rice and yield by region. Taiwan, 1976 (Department of Agriculture and Forestry, Provincial Government of Taiwan).

Region	Area				Yield(t/ha)		Total production (1000 t)
	First crop		Second crop		First crop	Second crop	
	1000 ha	%	1000 ha	%			
Taipei	41	11	37	9	3.3	2.6	228
Sinchu	76	21	72	17	3.2	2.7	435
Taichung	99	28	101	24	4.0	3.2	725
Tainan	64	18	126	29	4.3	3.4	709
Kaohsiung	58	16	67	16	4.9	2.8	476
Taitung	22	6	22	5	3.4	3.0	141
Total	361	100	425	100	3.9	3.0	2714

RESEARCH OBJECTIVES AND METHODOLOGY

Drawing upon the earlier experiments of Kuo et al (1977), the constraints project was designed to determine the potential for farmers to increase rice yields profitably in central and southern Taiwan. The specific objectives of the research were to:

1. identify production techniques that give yields higher than the farmers were realizing in given physical environments;

Table 3. Use of chemical fertilizer for rice. Taiwan, 1960–76 (Taiwan Provincial Food Bureau).

Year	Total fertilizer applied (t)	Average applied (kg/ha)	Nutrients (kg/ha)			
			N	P_2O_5	K_2O	Total
1960 – 64	586,245	761	114	37	32	183
1965 – 69	682,153	869	151	33	35	219
1970 – 74	496,683	659	109	26	29	164
1975	664,512	841	143	40	45	228
1976	710,011	903	146	42	52	240

2. determine how much each technical factor (e.g., cash input or cultural practice) contributes to the gap between actual and potential yield in different localities;

3. determine the extent to which the use of each technical factor can profitably increase the yields in different localities;

4. determine the social and institutional factors that prevent farmers from using technology that gives profitable high yields in different localities.

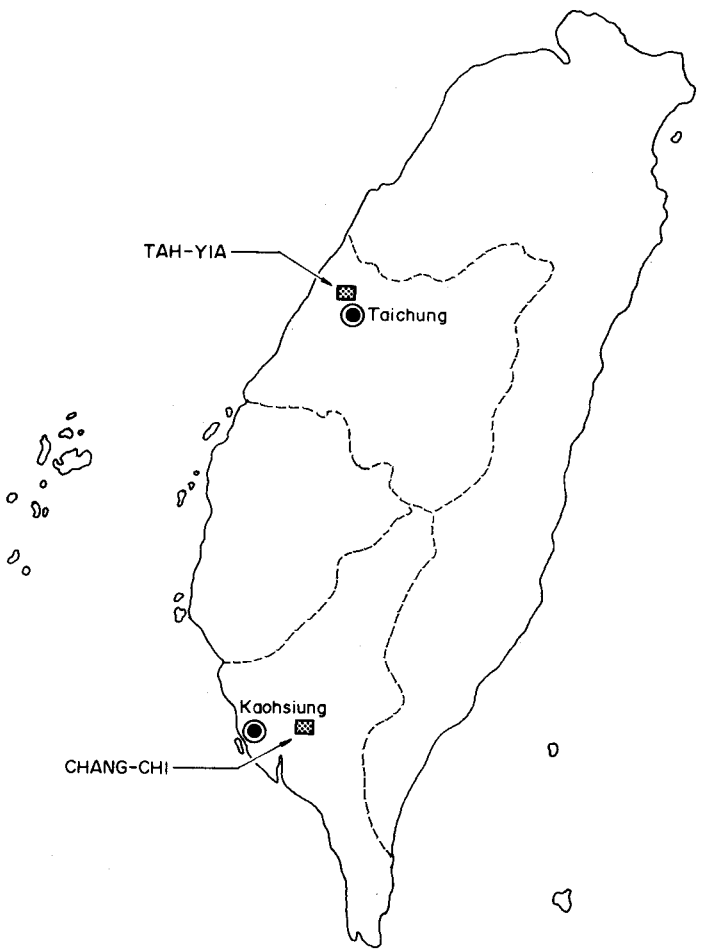
We followed the methodology developed by the International Rice Research Institute (IRRI) and used in the International Rice Agroeconomic Network (IRAEN) for measuring constraints to higher rice yields by experiments in farmers' fields and by socioeconomic research among the same farmers and other farmers in the same region.

The agronomic experiment measured the yield gap in farmers' fields, and quantified the inputs and practices that constrain yield. Three types of experiments were carried out in the farmers' fields: a two-levelmultifactor input package including the farmers' levels of inputs (complete factorial design), a minifactorial or incomplete factorial design, and a supplementary experiment. The results were analyzed with a simple budgeting method to determine the profitability of each package.

At the same time, data on socioeconomic factors were collected by interviewing farmers in the same region. Multiple regression analysis was used to understand their behavior. Sixty farmers (including farmers in experiments) chosen by random sample in each locality were interviewed in July 1977 and January 1978.

The study area

The study area consisted of two sites. Tah-yia village in the Taichung area, one of the most important rice-producing regions, represented the central region of Taiwan, and Chang-chi village in Kaohsiung area, which has the highest potential for rice production, represented the southern part of Taiwan (Fig. 1). The average yield of the southern area is higher than that of the other regions. However, the low yield of the second crop creates a marked yield difference between the first and the second rice crops (Table 2). It was thus hypothesized that the yield gap of the second rice crop in this area would be large.



1. Location of villages in agroeconomic study of rice production. Taiwan, 1977.

Table 4. Average farmers' levels of inputs (M_1) and four other input packages in complete factorial management package experiments. Taiwan, 1977.

Input package	Site[a]	Fertilizer (kg/ha) N	P	K	Plant density (hills/m^2)	Compost or manure (kg/h)
			First crop season			
M_1	TC	129	44	88	20.24	0
	KS	88	48	109	16.40	0
M_2	TC	90	40	50	17.36	5,000
	KS	100	40	40	16.00	5,000
M_3	TC	118	50	60	18.67	7,500
	KS	120	50	60	19.75	7,500
M_4	TC	145	60	70	19.75	10,000
	KS	150	60	65	27.43	10,000
M_5	TC	172	70	80	23.15	12,500
	KS	180	70	80	32.00	12,500
			Second crop season			
M_1	TC	106	47	76	20.04	0
	KS	78	48	120	20.05	0
M_2	TC	90	40	50	17.36	5,000
	KS	100	40	40	16.00	5,000
M_3	TC	110	50	60	18.67	7,500
	KS	120	50	60	19.75	7,500
M_4	TC	132	60	70	23.15	10,000
	Ks	150	60	70	23.15	10,000
M_5	TC	150	70	80	19.75	12,500
	KS	182	70	80	27.43	12,500

[a] TC = Taichung, KS = Kaohsiung. There were 3 farms at each site.

Each of the farms in the study was at least 1 ha in size, because that size of farm will be Taiwan's major concern in the future. Ten farms in Taichung and 12 in Kaohsiung (Table 4) were chosen. The area around Tah-Yiais mainly clay loam soil; that of Chang-Chi is silty clay loam soil. The characteristics of the soil of the cooperating farms in the study are shown in Appendices A and B.

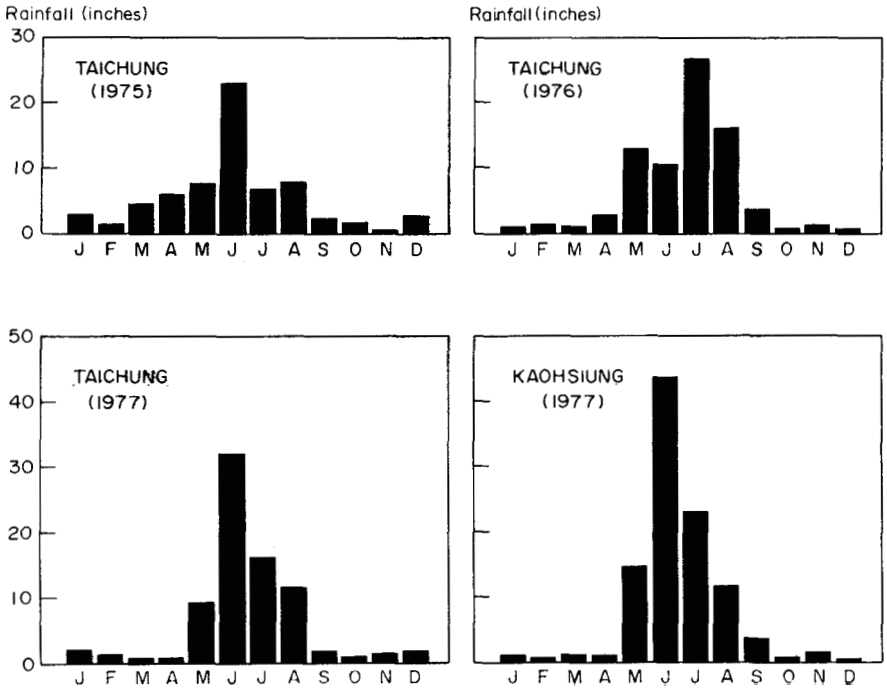
Growing conditions

For the first crop in Taiwan, temperature and solar radiation are low during the early growth stages but high during the ripening stage. For the second crop, temperature is constantly high

throughout the crop season in the Kaohsiung area (about 28°C) but changes from high to low (28°C to 20°C) in the Taichung area. Solar radiation is slightly lower during the ripening stage than during the early growth stage, particularly in the Kaohsiung area.

Rainfall distribution was uneven; and most rainfall was recorded from May to August 1977. Heavy rainfall in May and June 1977 (Fig. 2) caused lodging in the ripening stage and some grain germination in some farmers' paddy fields. In addition, typhoons hit the area several times in July, and September during the second Crop's growth period. Even though the rainfall was much higher than during the first year of constraints research in 1975, rice damage was not high, compared with past years.

To control diseases and insects, most farmers used many kinds of chemicals and resistant varieties. The plants showed no particular deficiency in any nutritional element.



2. Distribution of total monthly rainfall. Taichung and Kaohsiung, Taiwan, 1975 and 1977.

The experimental designs

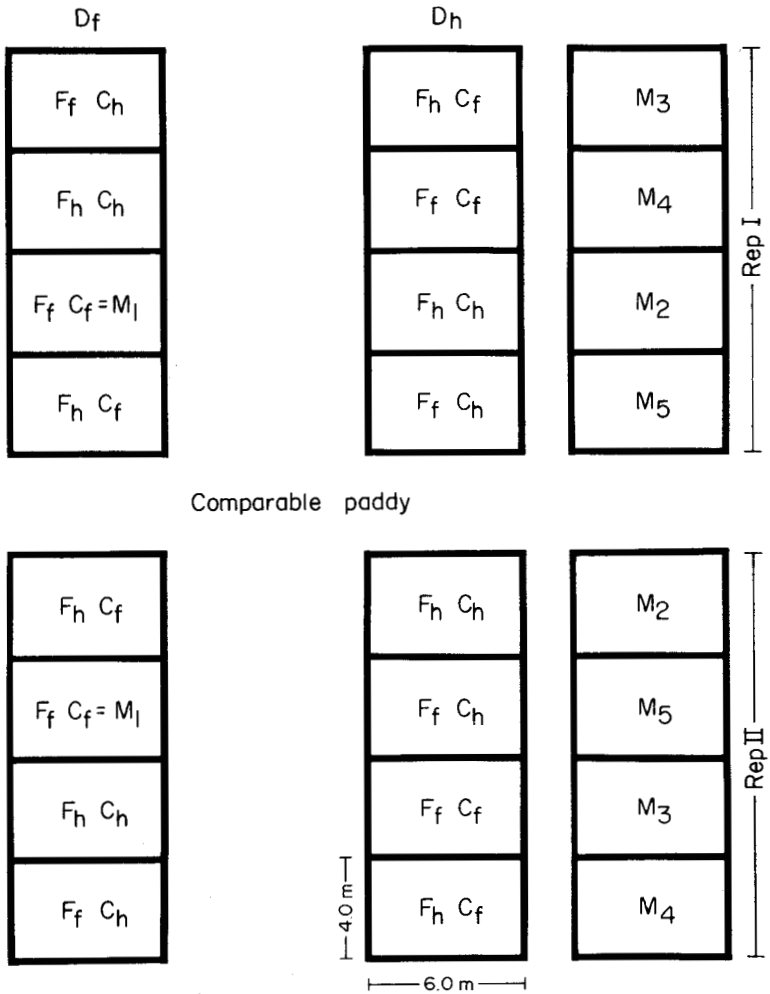
Complete factorial design combined with management package components. To investigate the gap between high potential yield and the farmers' yields, a combined factorial and 5-level management package experiment was used on 3 farms in each village. Thirteen treatments with varying levels of fertilizer (F), plant density (D), and manure (C) were tested. The factors were determined through discussions with local farmers and consultations with the District Agricultural Improvement Station staff. Experience from the 1975-76 study when fertilizer, insecticide, and weed control were used also convinced us that fertilizer, density, and manure were major constraints. The 13 treatments consisted of the 8 complete factorial treatments of the three factors at two levels and 5 management packages (Table 4) replicated twice.

Fertilizer. The fertilizer factor was chosen because the farmers in Taichung and Kaohsiung appeared to use incorrect rates and poor timing of fertilizer applications. The split application of nitrogen (25% before transplanting, 20% at 15/10 days, 30% at 30/20 days, 15% at panicle initiation, 10% at full heading) was the standard for high inputs and M_2 to M_5 levels. The fraction 15/10 and 30/20 days indicate the number of days after transplanting in the first and second crops.

Plant density. Density of plants in a field (or plant spacing) is an important factor in obtaining high yields. Rice is transplanted in two ways: mechanically with a transplanter and by hand. Most farmers used a planting density of 17-20 hills/m^2, which is low. The spacing in farmers' fields may be attributed mostly to the characteristics of the particular variety and fertilizer application.

Manure. Stable manure or compost used as a basal dressing is applied at the time of the initial plowing. Most farmers with high yields appeared to use high amounts of stable manure. Recently most of them began using a low level of manure.

The management packages consisted of M_1 with all factors at the farmers' levels. This M_1 level may or may not be higher than M_2. M_2 was based on the input level of fertilizer supplied by the Taiwan Provincial Food Bureau. M_5 with all factors, was a maximum-yield level, and M_3 and M_4 were intermediate levels (Table 4). Figure 3 shows a typical plot design used at both Taichung and Kaohsiung. Three farms at each site were selected for field experiments. The plots totaled 24, each measuring 4 m x 6 m.



3. Typical plot layouts used in experiments studying yield constraints in farmers' fields. Taiwan, 1977.

Minifactorial design. The minifactorial design, an incomplete factorial, was also used for investigating the yield gap. It differed from the complete factorial in the hypothesis of no factor interaction. Three factors and two practices were the same in the complete factorial design, with five plots on each farm, replicated twice (Table 5).

Table 5. A minifactorial yield constraints trial in farmers' fields with test factors, planting density, fertilizer, and compost (or manure). Taiwan, 1977.

Treatment no.	Input level[a]		
	Fertilizer	Planting density	Compost or manure
1	F	F	F
2	H	H	F
3	F	H	H
4	H	F	H
5	H	H	H

[a]H = high level; F = farmers' level.

Table 6. Average farmers' and high levels of inputs.[a] Taiwan, 1977.

Input level	Site[b]	Farms (no.)	Fertilizer (kg/ha) N	P	K	Plant density (hills/m^2)	Compost or manure (kg/ha)
			First crop season				
F	TC	10	132	41	73	19	2,460
H	TC	10	172	70	80	23	12,500
F	KS	12	97	49	139	19	0
H	KS	12	150	60	65	27	10,000
			Second crop season				
F	TC	10	111	59	75	19	2,327
H	TC	10	132	60	70	23	10,000
F	KS	12	99	48	120	20	569
H	KS	12	150	60	70	23	10,000

[a]F = farmers, H = high.

[b]TC = Taichung, KS = Kaohsiung.

Supplementary experiment. On each selected farm a single plot measuring 8 m x 12 m using the recommended practice was cultivated, but only an area of 4 m x 6 m was harvested.

Analysis

The average farmers' input levels for all 3 types of trials and the have level used are shown in Table 6. The individual farm levels are given in Appendices C and D. The yield gap was measured as the difference between the plots with all inputs at the high level and the plots with all inputs at the farmers' levels. The 22 yield gaps were obtained from 6 farms with complete factorials, 6 farms with minifactorials, and 10 farms with supplemental trials. The contribution of each individual input to the increase in yield was determined by comparing the average yield of all treatments with the factor at the farmers' levels and at the high level. For the analysis 12 observations for yield contribution of each input factor were obtained: 6 from the farms with complete factorials and 6 from the farms with minifactorial trials. The factorial component was statistically analyzed to determine whether significant effects of each individual input and interactions were present. The magnitude of interaction was determined by comparing the yield gap with the particular factors at increased levels.

BIOLOGICAL CONSTRAINTS

Components of the yield gap

Earlier findings (Kuo et al 1977) gave the yield gap between farmers' levels and the high level of inputs as about 0.8 t/ha. Fertilizer accounted for the major portion of the yield gap in both seasons.

Fanners' fields at the two sites were divided into three categories: complete factorial and management package (farmers 1, 2, and 3), minifactorial (farmers 4, 5 and 6), and supplemental trials (farmers 7 to 10 in Taichung, farmers 7 to 12 in Kaohsiung). Tables 7 and 8 indicate that grain yields in both seasons tended to increase as the levels of inputs increased in the complete factorial and minifactorial experiments. The analysis of variance of the experiments is given in Table 9. Planting density was significant in five cases, fertilizer in seven cases, and compost (or manure) in two cases. Interaction between test factors also appeared in a few cases.

Taichung site. On the 6 farms with complete factorial and minifactorial experiments in Taichung, the farmers applied an average of 132 kg N/ha, 41 kg P_2O_5/ha, and 73 kg K_2O/ha in the first crop season (Appendix C). The average number of split applications of nitrogen was 3.6. The average planting density was 19.36 hills/m^2, which two farmers maintained with a transplanter. The average amount of compost (or stable manure) applied was low (2,460 kg/ha). Three out of six farmers used manure.

Table 7. Yield of complete factorial experiments in farmers' fields. Taiwan, 1977.

Treatment[a]	Yield (t/ha)						
	Taichung			Kaohsiung			
	1	2	3	1	2	3	Av[b]
First crop season							
FfDfCf	6.0	6.3	6.4	6.1	7.0	6.7	6.5
FfDmCf	6.2	7.2	6.5	6.1	7.6	7.1	6.9
FmDfCf	6.5	6.5	6.8	7.2	7.1	7.4	6.9
FmDmCf	6.8	7.4	6.8	6.1	8.3	7.8	7.4
FfDfCm	6.2	6.4	6.5	5.6	7.8	7.2	6.8
FfDmCm	6.4	7.3	6.8	4.5	7.3	7.4	7.0
FmDfCm	6.9	6.8	6.4	5.1	8.1	7.1	7.1
FmDmCm	6.7	7.4	6.6	4.4	8.2	7.9	7.4
Second crop season							
FfDfCf	6.0	5.2	5.6	3.0	4.1	2.1	4.3
FfDmCf	6.0	5.6	5.8	3.1	4.9	2.3	4.6
FmDfCf	6.2	4.9	6.2	3.5	4.6	2.4	4.6
FmDmCf	6.4	5.8	6.1	3.4	4.8	2.5	4.8
FfDfCm	5.9	5.5	6.0	3.4	4.1	2.1	4.5
FfDmCm	6.5	5.7	6.0	2.6	4.6	2.3	4.6
FmDfCm	6.3	5.9	6.5	3.2	4.4	2.5	4.8
FmDmCm	6.5	6.0	6.5	3.8	4.7	2.4	5.0

[a]F = fertilizer, D = density, C = compost, f = farmers' level, m = maximum level.

[b]Because of lodging and brown planthopper damage, the data from farm 1 during the first crop season in Kaohsiung were excluded in calculating the average.

With these inputs, farmers' yields varied from 6.0 to 6.5 t/ha, averaging 6.2 t/ha. The high level (M_5) of the three factorial inputs produced yields ranging from 6.6 t/ha to 7.4 t/ha, averaging 6.9 t/ha (Table 10). The yield gap averaged 0.7 t/ha, ranging from 0.2 to 1.1 t/ha. The variability of the yield gap among the farms was low (cv = 20%), except on one farm, where the gap increased slightly. The low yield gap on farm 3 was due to lodging caused by heavy rainfall in June and late fertilizer application.

The contribution of each factor to the yield gap was calculated as the difference between the average yield of all plots with the low level of factors and all plots with the high level. The data indicate that fertilizer contributed 0.31 t/ha (40%), planting

Table 8. Yield of minifactorial experiments in farmers' fields. Taiwan, 1977.

Site[b]	Farms (no.)	Variety	Yield (t/ha) at input treatments[a]				
			FfDfCf	FmDCf	FfDmCm	FmDfCm	FmDmCm
			1977 first crop season				
TC	4	Taichung 181	6.2 b	6.6 ab	6.5 ab	6.6 ab	6.9 a
TC	5	Tainan 5	6.5 c	7.1 ab	6.8 bc	6.8 bc	7.3 a
TC	6	Tainan 5	6.0 ab	6.2 ab	5.9 ab	5.7 b	6.7 a
KS	4	TS 3	7.1 a	7.3 a	7.0 a	7.1 a	7.1 a
KS	5	KS 139	6.7 a	7.5 a	7.5 a	7.5 a	7.3 a
KS	6	Tainan 6	6.9 c	7.4 abc	7.2 bc	7.8 a	7.6 ab
Av			6.6	7.0	6.8	6.9	7.2
			1977 second crop season				
TC	4	Tainan 5	6.4 c	7.1 ab	6.8 b	6.9 b	7.3 a
TC	5	Tainan 5	5.9 b	6.2 ab	6.1 ab	6.1 ab	6.5 a
TC	6	Tainan 5	5.7 b	6.4 ab	6.2 ab	6.6 a	6.6 a
KS	4	KS 1	5.3 c	5.4 bc	5.5 abc	5.6 ab	5.7 a
KS	5	SC 61	5.3 a	5.2 a	5.3 a	5.3 a	5.4 a
KS	6	Tainan 6	4.4 c	4.4 c	5.0 b	4.8 b	5.2 a
Av			5.5	5.8	5.8	5.9	6.1

[a] Any two means having a common letter are not significantly different from each other at the 5% level.

[b] TC = Taichung, KS = Kaohsiung.

density 0.36 t/ha (46%), and compost (or stable manure) 0.11 t/ha (14%) to the yield gap (Table 10). The effect of interaction of the factors is not important to the yield gap. Among the six farms, planting density was significant to the yield gap on one farm; fertilizer, on two farms; and planting density and fertilizer on one farm (Tables 8–10).

In the second crop season, the same six farms and experimental designs were used. On the average, the farmers applied 111 kg N/ha, 59 kg P_2O_5/ha and 75 kg K_2O/ha (Appendix D). Most farmers applied less N in the second crop. The P_2O_5 and K_2O, however, were slightly higher than in the first crop (Table 4). The average number of split applications of nitrogen was 3.2. The average planting density and stable manure were similar to those of the first crop.

Table 9. Significance test of inputs in the analysis of variance in yield constraints experiments. Taiwan, 1977.

Inputs	Significance[a]											
	First-crop season						Second-crop season					
	Taichung			Kaohsiung			Taichung			Kaohsiung		
	1	2	3	1	2	3	1	2	3	1	2	3
Density (D)	-	*	-		-	**	*	*	-	-	*	-
Fertilizer (F)	**	-	-		#	**	*	-	**	*	-	*
D x F	-	-	-		-	#	-	-	-	#	-	-
Compost or manure (C)	-	-	-		-	-	-	*	**	-	-	-
D x C	-	-	-		#	-	-	*	-	-	-	-
F x C	-	-	-		-	*	-	-	-	-	-	-
D x C x F	-	-	-		-	*	-	-		-	*	-	-

[a] - = probability > .l0; # = probability .10-.05; * = probability .05-.01; ** = probability <.01.

[b] Because of lodging and brown planthopper damage, the data were not considered.

The yields with farmers' inputs ranged from 5.2 to 6.4 t/ha and averaged 5.8 t/ha. Compared with the first crop, the second crop had a 6.5% decline. The yields with the high input level (M_4) ranged from 6.0 to 7.3 t/ha and averaged 6.6 t/ha. The yield gap was small, ranging from 0.5 to 0.9 t/ha with an average of 0.8 t/ha (13%). The variability of the yield gap among farms was 23%, indicating that the yield gap among the six farms was more consistent for the second crop. The major portion of the yield gap, 40% (0.37 t/ha), was due to improved fertilizer use. Close spacing and improved manure rate each contributed 30% or 0.27 t/ha (Table 11).

Kaohsiung site. Because farmer 1 practiced poor husbandry in his field, the yield data from his plots were not averaged with the others in the first-crop season. Five farmers who applied fertilizers averaged 95 kg N/ha, 37 kg P_2O_5/ha, and 124 kg K_2O/ha. The average number of split applications of nitrogen was 3.4, and the average planting density was 18.97 hills/m^2 (Appendix C). These farmers did not apply compost (or stable manure). The yield with farmers' inputs ranged from 6.1 to 7.1 t/ha and averaged 6.9 t/ha (Table 11), which was higher than that of the first crop at the Taichung site (Table 10). The high level of inputs (M_4) produced yields ranging from 4.4 to 8.2 t/ha and averaging 7.6 t/ha. The yield gap averaged 0.7 t/ha and ranged from 0 to 1.2 t/ha.

Table 10. Yield gap and yield effect of factors in constraints experiments. Taichung, Taiwan, 1977.

Farm. no.	Yield (t/ha) Farmers' inputs	High inputs	Gap	Yield effect (t/ha) Fertilizer	Density	Manure	Residual
			First crop				
1	6.0	6.7	0.7	0.52	0.11	0.19	-0.12
2	6.3	7.4	1.1	0.20	0.84	0.13	-0.07
3	6.4	6.6	0.2	0.10	0.14	-0.10	0.06
4	6.2	6.9	0.7	0.37	0.28	0.29	-0.14
5	6.5	7.3	0.8	0.43	0.39	0.18	-0.20
6	6.0	6.7	0.7	0.23	0.42	-0.02	0.07
Av	6.2	6.9	0.7	0.31	0.36	0.11	-0.09
			Second crop				
1	6.0	6.5	0.5	0.25	0.25	0.15	-0.15
2	5.2	6.0	0.8	0.17	0.41	0.39	-0.15
3	5.6	6.5	0.9	0.46	0.06	0.30	0.07
4	6.4	7.3	0.9	0.51	0.43	0.26	-0.27
5	5.9	6.5	0.6	0.27	0.26	0.14	-0.09
6	5.7	6.6	0.9	0.58	0.25	0.40	-0.35
Av	5.8	6.6	0.8	0.37	0.28	0.27	-0.16

The variability of the yield gap among the five farms was large (cv = 66.17%). No yield gap occurred at farm 4 because the farmer applied adequate fertilizer on time and used close spacing (22.45 hills/m^2). In the second crop the same farmer also had a low yield gap (0.3 t/ha or 6%). On the average, fertilizer contributed 0.41. t/ha (44%), planting density 0.28 t/ha (30%), and manure 0.24 t/ha (26%) to the yield gap.

In the second-crop season the average farmer applied fertilizers at 95 N kg/ha, 55 P_2O_5 kg/ha, and 108 K_2O kg/ha (Appendix D). The average number of applications of nitrogen was 3.2, which was similar to the first crop. The average application of manure was low (1,137 kg/ha); four out of six farmers did not use manure at all. The average planting density was 20.45 hills/m^2, a closer spacing than for the first crop. The yield with farmers' inputs ranged from 2.1 t/ha to 5.3 t/ha and averaged 4.0 t/ha (Table 11).

In Kaohsiung the yield with farmers' inputs was 42% lower in the second season, while the difference was only 6% in Taichung. This agrees with the observation that the yield difference between

Table 11. Yield gap and yield effect of factors in constraints experiments. Kaohsiung, Taiwan, 1977.

Farm no.	Yield (t/ha)			Yield effect (t/ha)			
	Farmers' inputs	High inputs	Gap	Fertilizer	Density	Manure	Residual
			First crop				
1[a]	6.1	4.4	-1.7	-0.75	-0.75	−1.46	-1.26
2	7.0	8.2	1.2	0.52	0.32	0.34	0.02
3	6.8	7.9	1.1	0.42	0.45	0.15	0.08
4	7.1	7.1	0	0.09	0.07	−0.12	0.04
5	6.7	7.3	0.6	0.18	0.18	0.14	0.10
6	6.9	7.6	0.7	0.84	0.38	0.68	−1.20
Av	6.9	7.6	0.7	0.41	0.28	0.24	-0.23
			Second crop				
1	3.0	3.8	0.8	0.46	-0.04	0.01	0.40
2	4.1	4.7	0.6	0.20	0.47	-0.15	-0.18
3	2.1	2.4	0.3	0.25	0.15	−0.13	−0.11
4	5.3	5.7	0.4	0.16	0.04	0.22	−0.08
5	5.3	5.4	0.1	0.03	0.04	0.10	-0.01
6	4.4	5.2	0.8	0.11	0.23	0.56	-0.15
Av	4.0	4.5	0.5	0.20	0.15	0.12	-0.02

[a] Because of lodging and brown planthopper damage, the yield and yield effect were not calculated as the average.

the first and the second crops is much larger in the southern area than in the rest of Taiwan. The variability of the yield gap was larger (cv = 58.15%). The average yield gap was 0.5 t/ha (13%), indicating that fluctuations in the yield of the first crop is much less than that in the yield of the second crop. However, the contribution of the factors to the yield gap was quite similar to that of the previous season. Fertilizer application contributed 43%, planting density 31%, and manure 26% to the 1977 yield gap (Table 11).

Effect of interactions. Several interactions caused a difference in the size of the yield increase. In the first crop season of farmer no. 2 at the Kaohsiung site, neither the close spacing nor the increased manure alone contributed significantly to the yield gap. But together they produced an interaction effect of 1.11 t/ha (Table 12). A similar finding was observed in the second

Table 12. Effects on farm yields (t/ha) of interaction between planting density and manure levels. Kaohsiung and Taichung, Taiwan, 1977.

Planting density	Yield (t/ha) Farmers' manure level	Improved manure level	Difference
First crop season (Kaohsiung, Farm 2)			
Farmers'	7.08	7.97	0.89
High	7.95	7.73	-0.22
Difference	0.87	-0.24	-1.11
Second crop season (Taichung, Farm 2)			
Farmers'	5.05	5.73	0.68
High	5.75	5.86	0.11
Difference	0.70	0.13	– 0.57

Table 13. Effects on farm yields (t/ha) of interaction between fertilizer and planting density levels. Kaohsiung and Taichung, Taiwan, 1977.

Fertilizer level	Yield (t/ha) Farmers' planting densify	Improved planting density	Difference
First crop season (Kaohsiung, Farm 3)			
Farmers'	6.99	7.26	0.27
High	7.23	7.87	0.64
Difference	0.24	0.61	0.37
Second crop season (Kaohsiung, Farm 1)			
Farmers'	3.18	2.87	-0.31
High	3.37	3.61	0.24
Difference	0.19	0.74	O.55

crop of farmer no. 2 at the Taichung site: interaction effect on yield was 0.57 t/ha. This indicates that the yield increase from improved spacing was greater with farmers', and that with high manure level was greater with farmers' levels of manure. Compared with the single high-inputslevel the combined two high-inputs levels would decrease the yield by about 0.22 t/ha in the former case, and increase it by 0.11 t/ha in the latter. This might be due to the use of animal dung too rich in organic matter. Interaction between fertilizer and planting density was present in two cases (Table 13). The interaction effect of planting density and fertilizer was 0.37 t/ha in the first crop season and 0.55 t/ha in the other, indicating that the yield increase from high fertilizer application was greater with high fertilizer rate. It can be concluded that close spacing and high levels of fertilizer will maximize yields.

The interaction effect of fertilizer and manure was 0.5 t/ha in one experiment (Table 14). The yield increase from high fertilizer application was greater with farmers' rates of manure, and that from the high manure rate was greater with farmers' fertilizer rates (av 0.54 t/ha). Combined, both factors showed no increase in yield when compared with a single high-input level.

The general conclusion that close spacing and high levels of fertilizer will maximize yields in the second crop season, while high fertilizer levels and wide spacing are optimum during the first crop season must be examined for variety and location interactions. The seasonal variation in yields generally shows increases of 40% in the first crop season, when abundant light and high temperature at the reproductive stage are available for photosynthesis. These improved yields depend on the availability of irrigation and can be enhanced by applying higher rates of nitrogen fertilizer. Improved varieties for planting in the second crop season and availability of water and its control and managanent in the first crop season are primary limiting factors in rice production.

Figure 4 shows that the effect of the interaction between any two high inputs in the second crop season was larger than the effect of the single high-inputfactors used in the farmers' fields. Yields on 12 farms with experimental plots in farmers' fields (6.5 t/ha first crop and 4.9 t/ha second crop) seemed to be generally similar to those for the 22 farms by crop-cutestimates in farmers' fields (6.4 t/ha first crop and 4.9 t/ha second crop).

Variability of yield gap among farmers

There were 10 experimental farms at the Taichung site, and 11 at the Kaohsiung site in the first season and 12 in the second season giving 21 (22) observations on the yield gap. These were obtained

as follows: 6 from the treatment corresponding to the supplemental treatment on farms with complete factorials, 6 from the treatment corresponding to the supplemental treatment on farms with minifactorials, and 9 (10) from farms with supplemental trials only. Figure 5 shows the yields at farmers' inputs and high inputs on each farm. Points above the 45° line show farms where the yield gap was positive. Points below the line represent farms where yields with farmers' inputs were higher than those with the high level of inputs. At the Taichung site the yield gap was positive for most farmers, except for two with the first crop and one with the second crop. The average yield with farmers' inputs was 5.98 t/ha for the first crop and 5.80 t/ha for the second. The average yield with high inputs in both seasons was 6.45 t/ha. The yield gap among 10 farmers was highly variable with a cv of 147% in the first crop and 190% in the second crop. The small or negative yield gap in the first crop for farmers 3, 8, and 9 was caused primarily by heavy rainfall in June, which stimulated about 6% spikelet germination in the paddy fields. The small yield gaps were due to generally good cultural practices, such as good water control, good husbandry, including timely transplanting, close spacing, reasonably heavy fertilizer application, and intensive weed and pest control. This indicates that the Taichung area does not seem to have serious yield limiting factors and that farmers' yields are relatively close to the potential.

At the Kaohsiung site, the yields with high inputs were higher than that with farmers' inputs, except in two cases in the first crop and another two in the second crop (Fig. 5). The yields with farmers' inputs were higher than those of the first crop at the Taichung site, averaging 6.97 t/ha. The average yield gap among 11 farms was 0.2 t/ha. During the second-crop season, there was considerable yield variability with farmers' inputs as well as with high inputs. Adverse weather and soil conditions caused the yields with farmers' inputs to decrease by 2.92 t/ha compared to the first crop. The yield gap among the 12 farms was also quite variable during both seasons with a cv of 143% in the first crop and 127% in the second crop. The small or negative yield gap during the first crop for farmers 4, 9, and 12 may have been due to heavy rainfall that caused lodging and spikelet germination in the paddy fields. Small or negative yield gaps in the second crop of farmers 5, 9, and 10 may have been caused by poor husbandry and rat damage (4%) in the plots with high inputs. Farmer no. 7 showed no yield gap in either season. This may have been due to the silty clay soil that had poor drainage.

The yield gap obtained with each variety used by the 21 farmers in the constraint experiments is shown in Table 15. This shows that the yield gap was large with two varieties (Tainan 5 and 6) used in farmers' fields. A yield gap of 0.4 t/ha was observed with the varieties Taichung 181 (first crop) and Kaohsiung no. 1 (second

Table 14. Effect on farm yields (t/ha) of interaction between fertilizer and manure levels, first crop season (Kaohsiung, farm 3) 1977.

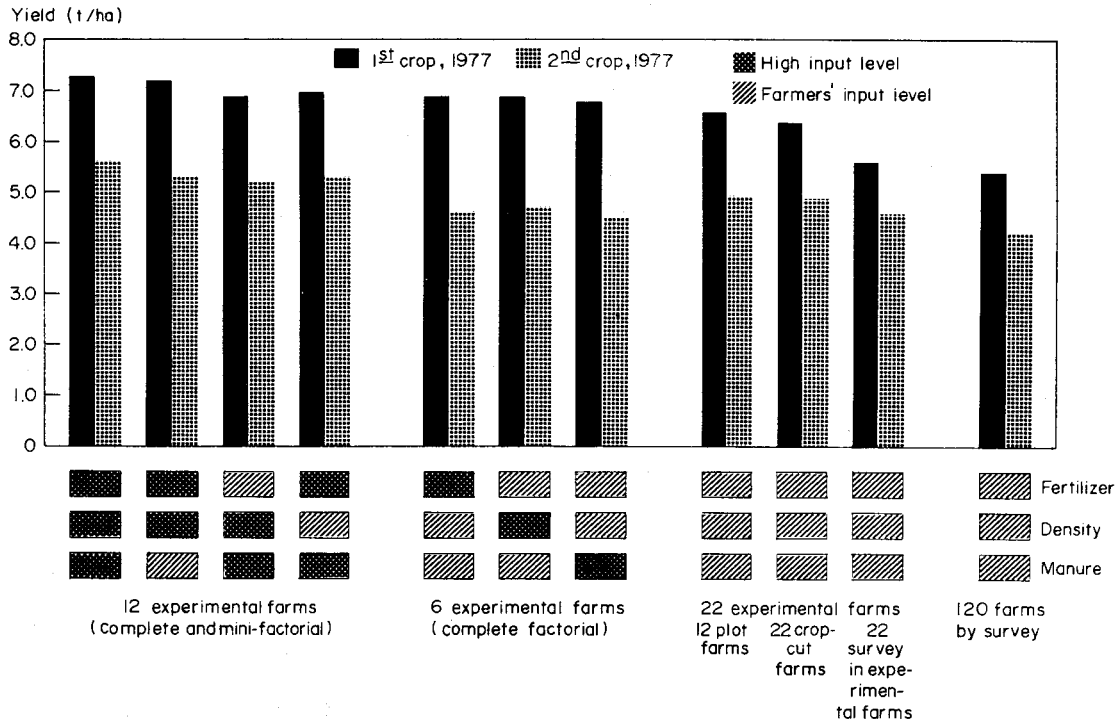
Fertilizer	Farmers' manure level	Improved manure level	Difference
Farmers'	6.93	7.33	0.40
High	7.60	7.50	–0.10
Difference	0.67	0.17	–0.50

crop). The other four varieties (Kaohsiung 139, Kaohsiung 53, Taichung Sen 3, and Hsinchu 61) showed no yield gap in either season. This type of fluctuation indicates that most of the farmers in Taiwan have enough knowledge to choose rice varieties adaptable to prevailing cultural conditions. There was considerable variability from farm to farm and from one season to the next in the effects of variety and cultural practices.

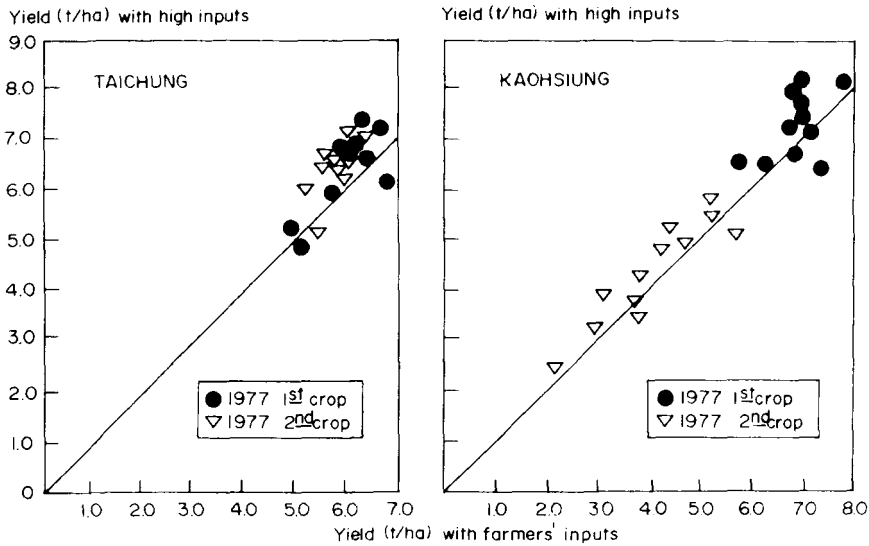
Input packages

The average yield showed a gradual increase as the level of all inputs increased from M_1 to M_5 in both seasons (Table 16). A statistical analysis on yield indicates that there was a significant difference between management treatments on farm no. 1 at Taichung site and farm no. 2 and 3 at Kaohsiung site in the first crop season. In the second crop season there was a significant difference between the same treatments only for farmer no. 3 at Taichung.

First crop season. Average yield rose steadily from 6.5 t/ha at M_2 to 7.4 t/ha at M_5. At the Taichung site farmers were using nitrogen in the range of M_3 to M_4 levels. At Kaohsiung, two out of three farmers were using high levels of potassium and were getting no benefit from their extra expediture because those three farmers at M_1 did not apply stable manure in the first crop and the farmers at the M_1 level applied nitrogen three times in split applications before panicle initiation. The rate of application of nitrogen fertilizer was very high, and this fertilizer was partly lost when applied in three splits because of leaching and denitrification. In the M_2 to M_5 treatments nitrogen applied was in five split applications. Table 16 shows that in the first crop season, maximum yield was obtained with M_5 inputs



4. Yields of rice grown on farmers' fields with three levels of inputs. Taiwan, 1977.



5. Yields with farmers' and high inputs in experiments on farmers' fields. Taichung and Kaohsiung, Taiwan, 1977.

at Taichung, but with M_4 inputs at Kaohsiung. The yield gap between farmers' practice M_1 and the M_5 treatment at Taichung was 10% (0.6 t/ha) while the gap between M_1 and M_4 at Kaohsiung was 23% (1.6 t/ha). This was attributable to the high variability within treatments, especially within treatments M_3, M_4, and M_5, with a cv of 17%. This high variability may be the result of (1) the use of only two replications in this experiment, (2) nonuniformity in the distribution of soil fertility on the surface, (3) a small amount of rat damage during the drainage period, and (4) heavy rainfall in June (Fig. 2), causing slight spikelet germination in the paddy fields.

Second crop season. Average yields at the two sites rose from 4.3 t/ha at M_1 to 4.8 t/ha at M_4 but tapered off from M_4 to M_5. The yields at the Kaohsiung site were considerably lower than those in Taichung at all input levels. This was attributable to such factors as adverse soil in the Kaohsiung area, poor drainage and high temperature interacting with the soils, and the absence of a fallow period before transplanting. This may have caused the reduction of total dry matter and grain-to-straw ratio. The average yield increase from M_1 to M_4 was 0.5 t/ha. The yield gap between farmers' practices (M_1) and the high yield potential treatment (M_4) was 12%.

Table 15. Yield gap for each variety used by farmers in constraints experiments. Taiwan, 1977.

Variety	First-crop season (t/ha)				Second-crop season (t/ha)			
	Number using	Farmers' inputs	High inputs	Gap	Number using	Farmers' inputs	High inputs	Gap
Taichung 181	6	6.0	6.4	0.4	2	5.7	5.7	0.0
Tainan 5	5	6.1	6.8	0.7	14	4.9	5.6	0.7
Tainan 6	2	6.7	7.5	0.8	1	4.5	5.2	0.7
Kaohsiung 139	6	7.2	7.1	-0.1	4	4.5	4.6	0.1
Kaohsiung 53	1	6.6	6.5	-0.2	-	-	-	-
Kaohsiung 1	-	-	-	-	1	5.3	5.7	0.4
Taichung Sen 31		7.1	7.1	0.0	1	5.3	3.8	-1.5
Hsinchu 61	-	-	-	-	1	5.3	5.4	0.1

ECONOMIC ANALYSIS OF EXPERIMENTAL TREATMENTS

The cost of inputs and experimental treatment

The costs of various inputs used by the farmers in 1977 are listed in Table 17. Compared with 1976 costs, there were no significant changes. Only chemical fertilizer, density, and manure were designated as experimental factors in the 1977 experiments. Insecticides and herbicides were not included. The costs of these two items were then treated in the same manner in the various management packages: they were calculated based on the experimental farmers' average expenses for these items. Costs of labor were also calculated from the experimental farmers' averages. The average wage rates in Taichung were higher than the rates in Kaohsiung perhaps because of differences in job opportunities in the two regions.

Prices of chemical fertilizers are uniform over the entire island because they are regulated by the government. The price of compost manure is based mainly on estimates because manure is processed by individual farmers. Since farm labor in rural areas is in short supply, the amount of manure used in the field depends mainly on the availability of family labor and the number of livestock raised. To establish a market price for manure for calculating the costs, two sources were used: the survey data and data published by the Provincial Department of Agriculture and Forestry (PDAF) in the *Survey of Production Costs of Crops in Taiwan.* The survey data based manure costs on the labor input estimates made by the farmers.

Table 16. Yield with farmers' inputs and with four input packages in experiments on farmers' fields. Taiwan, 1977.

Site[a] farm	Variety	Yield (t/ha) at package level[b] M_1	M_2	M_3	M_4	M_5
		First-crop season				
TC, 1	Taichung 181	6.0 c	5.9 c	6.0 c	6.3 b	6.5 a
TC, 2	Taichung 181	6.3 a	6.2 a	6.4 a	6.9 a	6.9 a
TC, 3	Taichung 181	6.4 a	6.6 a	6.6 a	6.8 a	7.0 a
KS, 1[c]	Tainan 5	6.1	5.6	5.8	5.2	4.6
KS, 2	KS 139	7.0 b	6.6 b	7.7 a	8.6 a	8.5 a
KS, 3	Tainan 5	6.7 b	7.2 b	7.6 ab	8.3 a	7.8 ab
Av		6.5	6.5	6.9	7.4	7.4
		Second-crop season				
TC, 1	Tainan 5	6.0 a	5.8 a	6.0 a	6.2 a	6.3 a
TC, 2	Tainan 5	5.2 b	5.2 b	5.5 ab	6.0 a	6.0 a
TC, 3	Tainan 5	5.6 c	5.8 bc	5.8 b	6.4 a	6.3 a
KS, 1	Tainan 5	3.0 a	3.0 a	3.2 a	3.9 a	3.6 a
KS, 2	KS 139	4.1 3	3.8 b	3.7 b	3.9 ab	3.8 ab
KS, 3	Tainan 5	2.1 b	2.2 b	2.2 b	2.6 a	2.5 ab
Av		4.3	4.3	4.4	4.8	4.7

[a] TC = Taichung, KS = Kaohsiung.

[b] Any two means having a common letter are not significantly different at the 5% level.

[c] Because of lodging and brown planthopper damage, the data were not included in the averages.

They are the sum of the values of the materials and the labor used in camposting manure. The unit value ranged widely from farmer to farmer, from NT$0.l/kg to NT$2.4/kg. The average value varied across the seasons and the regions (Table 17). We found that manure prices were significantly and consistently lower in the PDAF than in our survey in both regions and seasons. We decided to use both prices in the economic analysis. We will refer hereafter to the survey data and PDAF data as *high* and *low* manure costs, respectively. The manure costs constitute a significant portion of various experimental management packages. Because manure is one of the test factors in the examination of the yield gap, and it cannot be

Table 17. Prices of agricultural inputs. Taiwan, 1977.

Input	Unit	Price (NT $)[a]
Fertilizer		
Urea	1 kg	6.08
Ammonium sulphate	1 kg	3.79
Calcium superphosphate	1 kg	2.72
Potassium chloride	1 kg	4.48
Insecticide		
Sumithion	1,000 cc	300.00
Furadan	3 kg	160.00
Benlate	1 kg	1,200.00
Hinosan	500 cc	220.00
Mon	500 cc	85.00
Hopcide	250 g	60.00
Herbicide		
Machete	3 kg	85.00
Saturn M	2.5 kg	100.00
Manure[b]		
1st crop		
Taichung	kg	0.16 - 0.70
Kaohsiung	kg	0.26 - 0.77
2d crop		
Taichung	kg	0.45 - 1.08
Kaohsiung	kg	0.48 - 1.28
Wage rates		
Male, Taichung	workday	250 - 320
Male, Kaohsiung	workday	200 - 300
Female, Taichung	workday	150 - 250
Female, Kaohsiung	workday	100 - 200

[a]US$l = NT$38.

[b]Estimated value of manure based on the amount of labor and material used in the production and application of manure. The lower cost is based on estimates by the Provincial Department of Agriculture and Forestry. The higher cost is based on data obtained from our study.

Table 18. Average costs of 5 input packages in constraints experiments in farmers' fields. Taiwan, 1977.

Input package level	Fertilizer (NT$/ha)	Herbicide (NT$/ha)	Insecticide (NTS/ha)	Manure[a] (NT$/ha) I	Manure[a] (NT$/ha) II	Labor (NT$/ha)
			First crop, Taichung, 3 farms			
M_1	3,653	839	4,047	0		21,438
M_2	2,602	839	4,047	3,500	800	21,698
M_3	3,334	839	4,047	5.250	1,200	21,828
M_4	4,045	839	4,047	7,000	1,600	21,958
M_5	4,758	839	4,047	8.750	2,000	22,088
			Kaohsiung, 2 farms			
M_1	3,398	1,057	3,452	0		22,723
M_2	2,708	1,057	3,452	3,850	1,300	22,931
M_3	3,371	1,057	3,452	5,775	1,950	23,035
M_4	4,099	1,057	3,452	7,700	2,600	23,139
M_5	4,901	1,057	3,452	11,550	3,900	23,317
			Second crop, Taichung, 3 farms			
M_1	3,183	761	2,448	0		19,569
M_2	2,602	761	2,448	5,400	2,250	19,829
M_3	3,190	761	2,448	8,100	3,375	19,959
M_4	3,814	761	2,448	10,800	4,500	20,089
M_5	4,360	761	2,448	13,500	5,625	20,219
			Kaohsiung, 3 farms			
M_1	3,035	1,043	4,156	0		18,376
M_2	2,708	1,043	4,156	6,400	2,400	18,584
M_3	3,371	1,043	4,156	9,600	3,600	18,688
M_4	4,136	1,043	4,156	12,800	4,600	18,792
M_5	4,944	1,043	4,156	19,200	7,200	19,000

[a]I = high-priced manure, II = low-priced manure.

purchased in the market, we hope to suggest some implications in the comparison of economic effects of different manure costs.

The average costs of input packages calculated for Taichung and Kaohsiung for each season are shown in Table 18. Since the levels of inputs other than those identified as test factors are the same for the different packages, the variation in total costs is

obviously due to different levels of test factors, especially fertilizer and manure. In general, labor constitutes the largest portion among the components of costs. At the farmers' levels wages account for more than 70% of the total costs. Except for the application of manure, the high levels of management packages do not incur more labor inputs; hence wages make up a decreasing proportion of wages in the higher level packages.

Table 19. Economic comparisons of different management packages in constraints experiments with guaranteed price for rice.[a] Taiwan, 1977.

Input package level	Average increase (NT$) over farmers' level[b]					NT$ return per NT$ invested	
	Gross return	Input cost		Net above input cost			
		I	II	I	II	I	II
				First crop, Taichung			
M_2	-241	2,709	9	-2,950	-250	n.a.	n.a.
M_3	621	5,321	1,271	-4,700	-650	0.12	0.49
M_4	4,991	7,912	2,512	-2,921	2,479	0.63	1.99
M_5	6,532	10,505	3,755	-3,973	2,777	0.62	1.74
				Kaohsiung			
M_2	149	3,368	818	-3,219	-669	0.04	0.18
M_3	9,119	6,060	2,235	3,059	6,884	1.50	4.08
M_4	17,779	8,817	3,717	8,962	14,062	2.02	4.78
M_5	14,674	13,677	6,027	997	8,647	1.07	2.43
				Second crop, Taichung			
M_2	230	5,079	1,929	-4,849	-1,699	0.05	0.12
M_3	2,323	8,497	3,772	-6,174	-1,449	0.27	0.62
M_4	7,107	11,951	5,651	-4,844	1,456	0.59	1.26
M_5	6,750	15,327	7,452	-8,577	-702	0.44	0.91
				Kaohsiung			
M_2	-920	6,281	2,281	-7,201	-3,201	n.a.	n.a
M_3	-770	10,248	4,248	-11,018	-5,018	n.a.	n.a.
M_4	4,589	14,317	6,317	-9,728	-1,728	0.32	0.73
M_5	2,887	21,733	9,733	-18,846	-6,846	0.13	0.30

[a] Rice price at NT$11.50/kg. [b] I = high-priced manure, II = low-priced manure.

Comparison of management packages

The profitability of the four input packages was compared with that at the farmers' levels of inputs (Table 19). In case I (high-priced manure), all packages, except in the first season at Kaohsiung, were significantly less profitable than the farmers' levels, although the yields of some packages were higher. However, the yields of the first crop with M_2 at the Taichung site and of the second crop at the Kaohsiung site with M_2 and M_3, were lower than that at the farmers' levels. High inputs seemed much less profitable on the second crop than on the first at both sites. At Kaohsiung M_3, M_4, and M_5 in the first crop were more profitable than the farmers' levels, especially M_4, which gave the highest net return. In case II (low-priced manure), the profitability of the management packages was somewhat higher, being positive in several additional cases. In addition to the three packages in the Kaohsiung site mentioned earlier, M_4 and M_5 at Taichung had positive net returns over the farmers' levels. In the second crop all packages, except M_4 at Taichung, remained less profitable than M_1.

The price of rice used in the analysis was the guarantee price of NT$11.50/kg. In 1977 the market prices of rice were 10 to 20% lower than the guarantee price because there was a large surplus. Nevertheless, the profitability picture does not change when the price of rice is lowered.

In summary, most of the designed input packages were not economically feasible for the farmers. This may be attributable to the infeasibility of the application of manure at high levels and under the estimated costs. However, some high level packages were profitable at the Kaohsiung site for the first rice crop in spite of the high costs of manure.

Separate input effects

Because of the undeterminable values of manure, the above results become meaningful only when the relative economic contributions of separate inputs are analyzed. The relative costs and returns of the test factors were analyzed in a complete factorial experiment.

Table 20 shows the expenditure level of farmers and the increase in costs and value of output for the high level compared to the farmers'. Among the test factors, transplanting density is a "noncash technology improvement" rather than an "input." Therefore, no cost is incurred for it in any management package. Although most of the high levels of management packages reduced profits, the high level of fertilizer and planting density, considered separately, gave gains in net economic returns. This implies that the high level of chemical fertilizer and denser transplanting

Table 20. Farmers' cost, increased cost and increased value of output from high level[a] of 3 inputs compared with average farmers' levels in yield constraints experiments in farmers' fields. Taiwan, 1977.

Site, farms	Fertilizer (NT$/ha)			Density (NT$/ha)		Manure (NT$/ha)		
	Farmers' cost	Increase to high		Increase to high		Farmers' cost	Increase to high	
		cost	Value	Cost	Value		Cost[b]	Value
First crop, 1977								
Taichung, 3	3,653	1,105	2.400	0	3,421	0	8,750 (2,000)	654
Kaohsiung, 3	3,398	701	4,542	0	3,700	0	7,700 (2,600)	2,358
Second crop, 1977								
Taichung, 3	3,183	631	3,115	0	2,530	0	10,800 (4,500)	3,014
Kaohsiung, 3	3,035	1,101	2,375	0	1,638	0	12,800 (4,800)	–489

[a] M_5 is the high level for site 1 in the first crop and M_4 for the others

[b] The figures represent high-priced manure (case 1) and low-priced manure (case 11) (in parentheses).

would give farmers additional net returns. When the separate contributions for different sites and seasons were compared, the high level of fertilizer in the first crop at Kaohsiung was most profitable. The average value increased tremendously over that of additional costs. For the second crop, the Taichung site gave more profit than the Kaohsiung site. The results for site 1 agree with the findings in the 1975–76 experiment of Kuo et al (1977).

High level density was more profitable in the first crop than in the second at both sites, and the net gains were equivalent to or even more than those of chemical fertilizer.

The results show that the increased costs of high levels of manure significantly exceeded the increased value of output, even with low-priced manure. Since it is hypothesized that there is a time gap between manure application and its effect on output, the effect of manure may not be fully revealed in the experiment within one year. Furthermore, the economic conditions may change the value of manure. Thus, before final conclusions are made regarding the economic contribution of manure, further investigation of its physical and economic relationships is needed.

The preceding analysis is based on the data of farms with complete factorial experiments. Because the minifactorial design was used in the 1977 experiments, more data for analyzing separate input contributions are needed. The additional observations do not change the results of the preceding analysis (Table 21).

SURVEY OF REPRESENTATIVE AND EXPERIMENTAL, FARMS

To determine the representativeness of the experimental farms, other farmers in the same villages were randomly selected for interview. Sixty farmers, including those with experiments, were interviewed twice at each site. The general features of both the experimental and the other farms are compared in Table 22. Their grain yields and inputs are compared in Table 23.

Generally speaking, the two sets of averages are fairly similar. The proportion of income from rice in Kaohsiung was higher than that in Taichung, and the proportion of income from nonfarm sources in Kaohsiung was lower than that in Taichung (Table 22) but Kaohsiung farmers had a higher proportion of non-rice farm income. The average yield of the three experimental farms was slightly higher than the average of the farms in the survey (Table 23).

Table 21. Farmers' costs, increased costs, and increased value of output (av of complete and minifactorial designs).

Site, farms	Fertilizer (NT$/ha)			Density (NT$/ha)		Manure (NT$/ha)		
	Farmers' cost	Increase to high		Increase to high		Farmers' cost	Increase to high	
		Cost	Value	Cost	Value		Cost	Value
First crop 1977								
Taichung, 6	3,591	1,167	3,555	0	4.179	2.613 (5971	6,137 (1,403)	1,261
Kaohsiung, 5	3,202	897	3,868	0	2,122	0	7,700 (2,600)	1,725
Second crop, 1977								
Taichung, 6	3,508	306	4,268	0	3,184	2,580 (1,075)	8,220 (3,425)	3,147
Kaohsiung, 6	3,346	790	2,306	0	1,681	1,455 (546)	11,345 (4,254)	1,367

Table 22. General features of farms in experiments and random sample of 60 in the same areas. Taiwan, 1977.

Item	Taichung site		Kaohsiung site	
	3 farms with complete factorial	Av of 60 farms	3 farms with complete factorial	Av of 60 farms
Farm size (ha)	1.29	0.95	0.96	1.12
Rice area (ha)	1.29	0.89	0.83	0.96
Persons per household	8.30	7.90	4.8	6.4
Persons per household engaged in farming	3.0	3.1	3.0	2.7
Income from rice as % of total income	50.38	45.06	59.22	54.65
Nonfarm income as % of total income	40.32	38.72	20.73	27.74

Table 23. Comparison of yields and inputs of farms in experiments and a random sample of 60 in the same areas. Taiwan, 1977.

Farms	Yield (t/ha)	Fertilizer (kg/ha)			Density (hills/m^2)	Manure (t/ha)
		N	P_2O_5	K_2O		
Taichung, 1st season						
3 experiment farms	4.5	128	56	101	19.37	3.8
60 survey farms	4.4	148	48	93	19.73	2.9
Taichung, 2d season						
3 experiment farms	5.4	131	42	93	19.37	4.6
60 survey farms	5.2	147	52	91	18.76	2.7
Kaohsiung, 1st season						
3 experiment farms	6.4	151	45	71	18.23	0.4
60 survey farms	6.3	155	42	101	20.46	1.1
Kaohsiung, 2d season						
3 experiment farms	3.4	101	44	74	19.89	0.5
60 survey farms	3.2	135	43	107	20.29	0.4

Technology used by farmers

Previous studies and our own experience indicate that the rice farmers in Taiwan adopt most of the new technologies. This fact is again supported in this survey. Table 24 shows the percentages of farmers who used the listed technologies on the 60 farms in each area. Among the various technologies, sane are directly related to the yield of rice (e.g., chemical technology) and some to labor saving, such as mechanical technology.

All of the sample farms cultivated the new rice varieties, and all applied chemical fertilizers, herbicides, and insecticides. Some farmers also weeded by hand. A higher proportion of farmers in Kaohsiung (60%) practiced hand weeding than in the Taichung area (33%). However, the proportion of farmers who applied manure was higher in Taichung (75%) than in Kaohsiung (21%). This may be because Taichung is the mushroom production area, in which manure is relatively abundant.

Table 24. Proportion of 60 sample farms where the specified modern rice production technologies are used. Taichung and Kaohsiung, Taiwan, 1977.

Input or practice	Taichung (%)	Kaohsiung (%)
Technology		
New variety	100	100
Direct seeding	16	0
Additional hand weeding	33	60
Group farming	27	0
Chemical technology		
Chemical fertilizer	100	100
Herbicides	100	100
Insecticides	100	100
Compost manure	75	21
Rodenticides	87	90
Mechanical technology		
Water pump	83	95
Seeding machine	24	56
Dryer	51	59
Power tiller	98	84

Farmers who did not apply the new technologies were asked why they didn't. Lack of labor was a reason for not using manure among 63% of the Taichung farmers and 48% of the Kaohsiung farmers (Table 25). About 10% of the farmers in both areas practiced no supplementary hand weeding because of labor shortage. About 70% believed that hand weeding was unnecessary after the application of herbicide.

Farmers' awareness and attitude

To examine farmers' awareness of the importance of the factors affecting rice yields in their own fields, the survey farmers were asked the question, "What factors do you think are of the first, second, and third importance for high yield?" The number of farmers giving each factor and the rank they gave are listed in Table 26. The responses were weighted by arbitrary scores of 3, 2, and 1 to the first, second, and third important factor respectively. Fertilizer was divided into two related factors: total quantity and distribution, and timing of application.

Table 25. Farmers' reasons for not using specified practices. Taiwan, 1977.

Technology	% of respondents giving each reason						
	Lack of labor	No need	Small-scale operation	Don't know	Uneconomical	Laborious	Others
			Taichung				
Direct seeding	-	-	-	89	-	11	-
Compost manure	63	-	-	-	-	-	37
Hand weeding	10	70	-	-	10	10	-
Group farming	-	-	13	37	-	22	28
Seeding machine	-	77	17	6	-	-	-
Dryer	-	-	58	10	32	-	-
			Kaohsiung				
Direct seeding	-	-	-	70	-	-	30
Compost manure	48	-	-	-	-	22	30
Hand weeding	12	72	-	-	-	16	-
Group farming	-	-	-	56	-	-	44
Seeding machine	-	50	36	-	-	-	14
Dryer	-	-	50	12	38	-	-

Table 26. Farmers' perceptions of factors affecting rice yield, survey of 120 rice farmers. Taiwan, 1977.

Factor	Taichung				Kaohsiung			
	Farmers (no.) indicating the ranking[a]			Weighted av[b]	Farmers (no.) indicating the ranking[a]			Weighted av[b]
	M	S	T		M	S	T	
Fertilizer quantity	5	29	8	13.50	16	10	8	12.66
Fertilizer timing	19	8	9	13.66	6	5	14	7.00
Manure	11	3	12	8.50	3	5	10	4.83
Density	1	4	12	3.83	2	10	10	6.00
Rodent damage	2	2	13	3.83	24	20	15	21.16
Bird damage	0	0	5	0.83	1	3	17	4.33
Insect damage	5	4	4	4.16	7	5	0	5.16
Water control	3	0	1	1.66	0	0	0	0
Climate	18	1	1	9.50	1	1	13	3.00

[a] M = most important, S = second important, T = third important.

[b] The numbers in ranking were weighted by assigning 3 to M, 2 to S, and 1 to T.

A large proportion of farmers in both areas answered that the test factors fertilizer, manure, and density were the most important factors affecting yield. Farmers ranked fertilizer as relatively more important than the other two. Farmers in Kaohsiung ranked the quantity of fertilizer more important than the timing. Farmers in Taichung tended to place greater importance on compost manure than farmers in Kaohsiung. This is consistent with the fact that Taichung farmers actually used a higher level of manure.

Factors other than inputs that affected yield were also reported. Rodents, birds, and insects were regarded to be the more important causes of damage in Kaohsiung. Climate was considered more important in Taichung.

To the question "Do you think that the present yield in your field could be increased further if the inputs were improved?", only about one-third of the 120 farmers gave a positive answer. The reasons for the present use of these inputs by farmers who said that the improvement of inputs could increase yields are listed in Table 27.

Table 27. Farmers' reasons for not using improved input level. Taiwan, 1977.

Input	Farmers (no.) Taichung	Kaohsiung	Reasons for not using
Fertilizer	3	9	Uneconomical, labor shortage
Density	9	4	Tiresome to change
Manure	2	2	Labor shortage
Insecticide	3	8	Uneconomical, labor shortage
Total	17	23	

Most of the farmers in Taiwan believe that they are using the right level of inputs under present technological and economic conditions. They believe that higher levels of inputs will not increase yields significantly.

RELATIONSHIP BETWEEN LEVEL OF INPUT USE AND OTHER FACTORS

Before the factors affecting the yield gap were studied, the hypothesis that the existing yield gaps could be reduced if the high level of inputs were used was well accepted. The agronomic analysis in the first part of our paper has confirmed the point that the designated high level of inputs increased yields by about 13% in both experimental areas. We now report on a regression analysis showing the relationship of yields reported in the survey to various levels of inputs used by the farmers. Only the first rice crop in the Taichung area showed significant effects of inputs on yield. Thus, only regression results from the 60 sample farms in the Taichung area are given in Table 28. The listed independent variables explain only 33% of the variation in yield. Furthermore, damage by natural forces was the most significant reported factor affecting yield. Among the inputs, only fertilizers and herbicides showed a significant positive effect on yield.

We tried three regressions to explain the interfarm variation in the factors affecting farmers' levels of inputs: one to explain per hectare total input expenditure (Table 29), one for fertilizer fees (Table 30), and another for compost manure (Table 31).

The rice price farmers received in the previous season was considered an indicator of expected profitability in rice production.

Table 28. Regression results of rice yield on inputs. Taichung, Taiwan 1977, first season.

Input	Coefficient[a]	Standard error
Labor availability (% of family labor)	1.85	7.60
Manure (kg/ha)	0.02	0.03
Insecticide (NT$/h)	-0.04	0.13
Herbicide (NT$/ha)	1.32:*	0.95
Fertilizer (kg/ha)	1.44**	0.69
Density (cm^2)	0.01***	1.71
Damage reported (dummy)	-1239	308
Intercept	5195	1433
F	3.55	
$\bar{R}^2$	0.33	

[a] *** = significant at 1%.
** = significant at 5%.
* = significant at 10%.

Table 29. Estimated coefficients in equations explaining total expenditure of rice production (NT$/ha) by 60 farmers. Taichung and Kaohsiung, Taiwan, 1977.

Independent variable	Regression coefficients [a]			
	Taichung		Kaohsiung	
	1st season	2d season	1st season	2d season
Intercept (NT$/ha)	-4,847	37,240	23,220	29,783
	(27,180)	(24,676)	(7,575)	(9,703)
Rice area (ha)	-930.84	-2,960.77	-879.78	-1,347.42
	(1,717.32)	(3,102.94)	(841.42)	(1,061.88)
Labor availability (month/ha)	432.72***	345.23**	37.32	163.69*
	(122.74)	(205.08662)	(96.01)	(112.27)
Rice price (NT$/kg)	6,072.59*	2,545.18	1,505.13*	709.14
	(4,225.30)	(4,575.19)	(1,089.57)	(1,510.47)
Alternative income (%)	-24.94	-139.09	33.25	
	(53.77)	(116.99)	(31.64)	(55.83)
Number of practice	531.67	-761.59	102.94	-605.81
	(1,215.05)	(1,608.77)	(847.05)	(798.58)
Attitude score	-965.39	-1,103.11	661.36	-402.52
	(1,216.92)	(2,159.42)	(858.19)	(1,002.22)
F	4.15	1.41	1.04	4.11
$\bar{R}^2$	0.32	0.14	0.11	0.32

[a] Standard errors in parentheses. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Table 30. Estimated coefficients in equations explaining fertilizer expenditures (NT$/ha) by 60 farmers. Taichung and Kaohsiung, Taiwan, 1977.

Independent variable	Regression coefficients[a]			
	Taichung		Kaohsiung	
	1st season	2d season	1st season	2d season
Intercept (NT$/ha)	8,564	4,431	3,169	2,840
	(2,791)	(2,110)	(915)	(1,340)
Rice area (ha)	4.88	-310.62	-108.65	10.83
	(177.64)	(285.29)	(102.00)	(175.18)
Labor availability	21.05**	7.89	4.77	36.15***
(month/ha)	(12.63)	(17.53)	(11.63)	(15.49)
Rice price (NT$/kg)	-681.71*	74.38	213.21*	-43.84
	(434.71)	(391.16)	(131.72)	(203.28)
Alternative	-6.25	-4.57	-3.23	9.91
income (%)	(5.61)	(10.00)	(3.832	(7.87)
Number of practice	-115.66	-46.79	-154.28	-116.71
	(125.02)	(137.54)	(102.42)	(108.01)
Attitude	-7.80	-163.12	-143.65*	172.78
score	(124.93)	(184.62)	(103.81)	(135.24)
$\underline{F}$	1.41	0.95	2.02	4.28
$\underline{R}^2$	0.14	0.10	0.19	0.33

[a]Standard errors in parentheses. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Alternative income, which is measured by the percentage of income from sources other than rice to total family income, was the second factor. This was hypothesized to be negatively related to input levels. Labor availability, measured by family labor available for rice production, was the third. Since the farmers in our survey never mentioned difficulties concerning inputs and credit availability those were not included. Two dummy variables for mushroom and livestock production were included in explaining the use of manure. The two were thought to be related to the sources of raw materials in processing compost manure.

Surprisingly, not much of the variation in the three dependent variables could be explained by the listed factors. R^2 values of all sets of equations were no more than 33%. Since the significant factors varied with season and area, no consistent conclusions could be drawn. Nevertheless, judging from its relatively frequent significance, labor availability appears to be one of the most important factors among those examined. The price of rice and alternative income were the second most significant factors. As expected, mushroom production had a positive and significant effect on the use of manure.

Table 31. Estimated coefficients in equations explaining manure use (chin/ha) of 60 farmers. Taichung and Kaohsiung, Taiwan, 1977.

Independent variable	Coefficients[a]			
	Taichung		Kaohsiung	
	1st season	2d season	1st season	2d season
Intercept (chin/ha)	22,205	28,906	1,505	−678
	(15,882)	(19,406)	(9,472)	(2,952)
Labor availability (month/ha)	116.48*	60.96	60.80	4.11
	(78.30)	(162.90)	(115.98)	(30.48)
From mushroom (ping)	30.25***	50.95*	-	-
	(18.36)	(36.54)		
From livestock (NT$)	-0.02	0.20	0.05*	0.02
	(0.05)	(0.17)	(0.03)	(0.02)
Rice area (ha)	1,318.92	-1,293.09	−1,240.79	−117.31
	(1,042.51)	(2,480.22)	(1,498.11)	(372.49)
Alternative income (%)	-56.48*	−12.78	−45.95	−22.87*
	(36.34)	(95.05)	(40.98)	(16.54)
Rice price (NT$/kg)	−2,487.90	−4,151.83	330.82	228.35
	(2,456.94)	(3,636.30)	(1,302)	(424.67)
Number of practice	-	-	2,640.94***	387.09**
			(995.87)	(213.11)
Attitude score	−572.83	255.10	−1,210.02	0.83
	(716.07)	(1,707.02)	(1,008.62)	(265.98)
F	2.02	0.62	1.58	1.85
R^2	0.21	0.08	0.18	0.20

[a] Standard errors in parentheses. *** Significant at 1%, ** Significant at 5%, * Significant at 13%.

The results remind us that the farmers in Taiwan are engaging in a wider variety of enterprises than rice production alone. As the economic environment changes, nonagricultural jobs comprise a larger proportion of their activities. This is reflected in the finding that, on the average, more than half of farm family income comes from nonfarm activities. We are convinced that the diversity of income sources leads to the complex behavior of farmers in making decisions about farm inputs. Thus, it will be difficult to use a simple model to find the factors affecting input level.

SUMMARY

This project covered the first and second rice crops of 1977. To determine the regional variation in the yield gap and the factors affecting rice yield, two sites in the central and southern

parts of Taiwan were selected for the experiments. One site represented a major production area and the other, a high production potential area.

In selecting the test factors, the technology of both cash inputs and noncash inputs were considered. Two of the three factors in the 1975 experiment -- insecticides and weed control or herbicides -- were dropped. The three factors in the 1977 experiments were chemical fertilizer, planting density, and manure.

Summary of results

The average yield gap varied by region and season. Average yield gap over the two crops was 0.60 t/ha in the Kaohsiung area and 0.75 t/ha in the Taichung area. The yield gap was 0.70 t/ha for the first rice crop and 0.60 t/ha for the second, averaged over the two areas. The yield gap in the first rice crop was quite stable and similar in both areas with an average of 0.7 t/ha; that in the second rice crop ranged from 0.5 t/ha in Kaohsiung to 0.8 t/ha in Taichung.

The three factors - fertilizer, density, and manure - affected rice yield. As in the previous study, fertilizer was the most important, contributing 43% to the yield gap.

The effect of four management packages (M_2 to M_5) other than farmers' practices (M_1) on the yield was also tested in 1977. M_4 offered the highest yield in both seasons: 7.4 t/ha for the first rice crop, and 4.8 t/ha for the second. The comparable figures at farmers' levels were 6.5 t/ha for the first crop and 4.3 t/ha for the second. The yield of the first rice crop was higher in Kaohsiung than in Taichung, but that of the second crop was lower. In the first season M_1 and M_4 were 6.8 t/ha and 8.4 t/ha in Kaohsiung, and 6.2 t/ha and 6.7. t/ha in Taichung. In the second season M_1 and M_4 gave 3.1 t/ha and 3.5 t/ha in Kaohsiung, and 5.6 t/ha and 6.2 t/ha in Taichung.

The prices of inputs used for economic analysis in 1977 did not significantly differ from 1976 prices. One of the constraints - manure – had no market price; so imputed price estimates based on labor used in producing manure, were used. Two sources were used: our survey data, referred to as "high"cost (case I), and PDAF data, referred to as "low"cost (case II). The calculated cost structure showed that labor accounted for more than 70% of the total costs at farmers' levels. Cost of manure was the second highest expense. But, without application of manure at various levels, the proportion of wages in total costs declined to about 50%.

The profitability of the four management packages was usually less than that of the farmers' inputs, whether with high cost or low cost for manure. Nevertheless, the yields of some packages were higher than those of the farmers' levels. The cost of manure and its influence on overall costs should be studied further.

The second crop in 1977 appeared to be much less profitable than the first crop at both sites. Packages M_2 to M_5 in Kaohsiung showed a great loss for the second rice crop, but showed a profit in the first. In Taichung all packages with high cost for manure showed a loss in both seasons. Some with low cost for manure showed a profit.

When the separate contributions of inputs for different sites and seasons were compared, it was observed that it was more profitable to apply the high level of fertilizer on the first crop at Kaohsiung. For the second crop, fertilizer was more profitable at Taichung. The average value increased tremendously over that of additional costs (Table 20).

The contribution of high density planting was more profitable in the first crop than the second at both sites. The net gains were equivalent to, or even larger than, those from chemical fertilizer. The increased costs of high levels of manure significantly exceeded the increased values of output, even with a low price for manure (case II).

The representativeness of experimental farms in each area was high. When the general features of the experimental farms and the ordinary farms were compared, the two sets of averages were found to be similar.

This study reinforces the belief that the rice farmers of Taiwan readily adopt most new technologies. Only about one-thirdof the 120 farmers believed that their yields would increase if the inputs were improved. Their main reason for not using same inputs was labor shortage. A large proportion of farmers regarded the three constraints in the experiments as important factors affecting rice yield. Among these three, fertilizer was considered to be the most important.

The attempt to determine through a linear regression model the socioeconomic factors that are related to the farmers' input levels was not successful. The selected socioeconomic factors explained only 33% of the variation in farmers' inputs. However, availability of labor and profitability appeared most frequently as significant factors in the equations. This seems to agree with the perception of the farmers.

CONCLUSION

Some trends emerge from the farm data in both the experiments and the survey.

Most farmers in Taiwan believe that they are using the right levels of inputs under present technological and economic conditions. They believe that there is little to be gained from using higher levels of inputs, especially inputs that require labor. This is supported by analysis of the experimental data.

The farmers in Taiwan are engaging in more diversified enterprises. Nonagricultural jobs constitute a large proportion of their activities: average income from nonfarm sources is more than half of the farm family income. We are convinced that the diversity of income sources leads to complex farmers' behavior in decision making concerning farm inputs. A simple model cannot bring out the factors affecting input level.

In calculating profitability of the tested packages, the cost of manure, whether high or low, was the detrimental factor. Since this was estimated for both cases, we suggest a study of the physical effect of manure on the improvement of soil condition and the effect of dispersion fertility. The yield effect of manure in Taichung was 0.11 t/ha on the first crop and 0.27 t/ha on the second and in Kaohsiung, 0.18 t/ha on the first crop and 0.20 on the second. The prolonged effect of manure application on rice yield was noted as the yield increase of the second rice crop was larger than that of the first at both sites. The economics of producing manure is another dimension for research.

Although rice yield, as well as rice production, has increased tremendously, it appears to have reached its limit under the present technological and socioeconomic conditions in Taiwan.

This study reveals another dimension for consideration: the noncash technology, or density, that increases the rice yield significantly. Technologies that are costly to society but cost the farmer nothing (e.g., improved varieties) offer hope for yield increases.

Appendix A. Physical and chemical characteristics of soil of farmers' fields. Taicuhng, Taiwan, 1977.[a]

Farm no.	Mechanical composition				Chemical characteristics				
	Sand (%)	Silt (%)	Clay (%)	Texture	Organic matter (%)	Available P_2O_5 (ppm)	Exchange-able K_2O	pH	CEC[a] (meq/lOOg)
1	37	37	27	Loam	4.01	72.6	86	5.73	12.76
2	25	41	35	Clay loam	2.72	102.1	94	5.52	16.48
3	31	45	25	Loam	2.52	71.6	92	5.30	13.74
4	19	45	37	Silty clay loam	2.78	75.4	90	5.15	16.78
5	25	44	32	Clay loam	2.20	67.7	102	5.85	13.11
6	24	45	32	Clay loam	2.52	71.6	106	5.30	7.83
7	28	42	31	Clay loam	2.46	132.3	99	5.30	16.66
8	31	41	29	Clay loam	2.46	112.6	134	5.20	13.95
9	24	44	33	Clay loam	2.52	54.7	80	5.20	15.80
10	28	42	31	Clay loam	2.52	74.0	99	5.12	13.00

[a]soil analysis done by the Soil Department, National Chung-Hsing University.

Appendix B. Physical and chemical characteristics of soil in farmers' fields. Kaohsiung, Taiwan, 1977.[a]

Farm no.	Mechanical composition				Chemical characteristics				
	Sand (%)	Silt (x)	Clay (%)	Texture	Organic matter (%)	Available P_2O_5able (ppm)	Exchange-K_2O	pH	CEC[a] (mes1100g)
1	13	47	40	Silty clay 1oam	2.20	119.9	106	6.34	10.96
2	15	49	36	Silty clay loam	2.20	280.7	99	5.95	9.96
3	9	47	44	Silty clay	1.75	99.6	98	7.10	14.44
4	21	56	23	Silty loam	1.55	157.5	84	5.05	6.23
5	19	57	24	Silty loam	2.20	132.3	84	5.00	7.24
6	23	51	26	Silty loam	3.37	102.1	78	5.75	11.29
7	13	45	42	Silty loam	3.43	84.6	168	5.95	12.16
8	13	50	38	Silty clay loam	2.85	134.7	126	5.40	16.46
9	13	47	40	Silty clay loam	2.59	117.5	110	5.71	11.42
10	23	45	32	Clay loam	2.14	102.1	74	5.18	9.55
11	13	51	36	Silty clay loam	2.20	147.4	120	4.98	8.84
12	16	46	39	Silty clay loam	2.72	157.9	126	5.79	8.43

[a]Soil analysis done by the Soil Department, National Chung–Hsing University.

Appendix C. Amount of fertilizer, planting density, and compost used by farmers. Taiwan, 1977 first crop season.

Farms (no.)	Variety	Amount of fertilizer applied (kg/ha) N	P_2O_5	K_2O	Time of split applications of N (no.)	Planting density (hills/m^2)	Compost or manure (kg/ha)
			Taichung site				
1	Taichung 181	126	54	72	3	26.00	0
2	Taichung 181	134	43	96	4	17.36	0
3	Taichung 181	126	36	96	4	17.36	0
4	Taichung 181	126	43	72	3	17.36	10,000
5	Tainan 5	151	43	72	3	18.26	2,400
6	Tainan 5	118	36	72	4	26.00	7,000
7	Taichung 181	134	43	72	4	18.26	2,700
8	Tainan 5	126	40	48	3	17.36	2,500
9	Tainan 5	134	43	72	3	18.26	0
10	Taichung 181	149	27	60	5	17.36	0
Av		132	41	73	3.6	19.36	2,460
			Kaohsiung site				
1	Tainan 5	65	72	45	4	16.67	0
2	Kaohsiung 139	107	36	120	4	16.67	0
3	Tainan 5	92	36	162	3	15.87	0
4	Taichung Sen 3	95	43	120	3	22.45	0
5	Kaohsiung 139	88	29	132	3	19.75	0
6	Tainan 6	92	43	84	4	19.75	0
7	Kaohsiung 53	84	72	156	4	19.75	0
8	Kaohsiung 139	137	63	209	3	20.58	0
9	Kaohsiung 139	76	86	240	4	22.45	0
10	Kaohsiung 139	91	40	72	4	17.81	0
11	Kaohsiung 139	127	36	240	3	18.52	0
12	Tainan 6	105	30	83	3	17.36	0
Av		97	49	139	3.5	18.97	0
Av	(2 sites)	114.5	45	106	3.55	19.165	1,230

Appendix D. Amount of fertilizer, planting density, and compost used by farmers. Taiwan, 1977 second crop season.

Farm no.	Variety	Amount of fertilizer applied (kg/ha) N	P_2O_5	K_2O	Time of split applications of N (no.)	Planting density (hills/m^2)	Compost or manure (kg/ha)
				Taichung site			
1	Tainan 5	107	60	64	3	23.39	0
2	Tainan 5	100	40	85	4	17.36	0
3	Tainan 5	110	40	80	3	17.36	0
4	Tainan 5	110	50	70	3	17.36	6,186
5	Tainan 5	126	97	88	3	18.26	2,255
6	Tainan 5	105	90	78	3	27.43	5,892
7	Taichung 181	120	65	50	4	18.26	6,186
8	Tainan 5	112	40	82	3	17.36	2,750
9	Tainan 5	115	60	72	3	18.26	0
10	Taichung 181	100	52	80	5	17.36	0
Av		111	59	75	3.4	19.24	2,327
				Kaohsiung site			
1	Tainan 5	84	72	120	3	18.99	0
2	Kaohsiung 139	73	36	120	4	20.58	0
3	Tainan 5	78	36	120	3	20.58	0
4	Kaohsiung 139	80	36	60	3	20.58	1,874
5	Hsinchu 61	113	29	120	3	19.75	0
6	Tainan 6	140	121	108	3	22.22	4,949
7	Taichung Sen 3	86	40	160	4	19.75	0
8	Kaohsiung 139	91	31	157	3	22.45	0
9	Kaohsiung 139	158	72	160	4	20.58	0
10	Kaohsiung 139	115	36	126	4	19.75	0
11	Tainan 5	123	45	130	3	20.58	0
12	Tainan 5	42	18	60	3	17.36	0
Av		99	48	120	3.3	20.26	569
Av	(2 sites)	105	54	97	3.4	19.79	1,448

REFERENCES CITED

Department of Agriculture and Forestry, Provincial Government of Taiwan. 1977. Taiwan Agricultural Yearbook 1977.

Economic Planning Council, Executive Yuan, Republic of China. 1977. Taiwan statistical data book 1977.

Kuo, Yi Chung, Carson Wu, and Cheng Chang Li. 1977. Rice production in Taiwan's agriculture. Pages 177-202 in The International Rice Research Institute. Constraints to high yields on Asian rice farms: an interim report.

Provincial Department of Agriculture and Forestry (PDAF). Survey of production costs of crops in Taiwan.

Taiwan Provincial Food Bureau. Taiwan food statistics book.

Wu, Carson, Kung-Hsien, and Yu-KangMao. 1976. Interregional comparative advantage of rice production in Taiwan. Food research institute studies. 15(2): 233-256.

An Overview of the Constraints Project Results

Robert W. Herdt

Research on constraints to high yields on farmers' fields has been under way since 1974 in a number of locations in Asia. The research projects have followed the general approach outlined in the methodology paper in this volume, but there have been substantial individual variations on the theme. Nonetheless, it is still possible to summarize the empirical findings of the research and to identify the areas for further work.

Project objectives. It is useful to begin with a statement of what the yield constraints project did and did not attempt. It did attempt to evaluate the performance of the currently available high-yielding rice technology in farmers' fields in which at least some components of the technology had been adopted. It focused on yield per unit area, asking what the potential yield was, what the farmer's actual yield was, and what explained the difference or yield gap between the two. The explanation had two aspects: (1) the added biological or physical factors (inputs) that resulted in higher yields; (2) why the farmers were not using the inputs at a level and in a way that would result in the potential yield being achieved. For convenience these two aspects are called "biophysical constraints" and "socioeconomic constraints."

The constraints project did not attempt to explain the adoption of new technology, although that issue was touched upon to sane extent in considering the levels of inputs (like fertilizer) used by farmers. The constraints project did not attempt to explain or identify the constraints to rice production imposed by circumstances beyond the control of farmers -- the policies of government, weather, soil conditions, water available in the irrigation canals, and other similar factors. Finally, the constraints project did not attempt to explain the existing level of land use intensity or to explore how intensity could be increased through engineering or technological innovations.

Summary of results. Thus, the project had a narrow focus on the yield gap and the factors explaining it. Anticipating the results discussed in the balance of this paper, the research showed the

existence of a yield gap of 0.9 t/ha in the main rice-growing wet season and a slightly higher gap (1.3 t/ha) in the dry season, averaged across all study areas. The average gap for a study area varied from 0.4 t/ha to 2.2 t/ha. Fertilizer, insect control, and weed control were tested in many trials. The research showed that higher levels of fertilizer and insect control than farmers were using contributed equally to raising wet season yields, and in the dry season high fertilizer levels contributed more than half to the gap. In all but one location, the average benefit: cost ratio of the additional inputs required for the high yield level was less than 1.5:l in the wet season, averaging 1.2:l across all locations. The situation was slightly better in the dry season, with the benefit-cost ratio exceeding 1.5:l in half of the locations, averaging 1.6:1 across all locations.

This is not surprising, because in general the high inputs were designed to maximize yields, and maximizing profits and yields ate two different objectives. In a number of locations intermediate levels of inputs and profits were tested. Analyses of these data suggest that while a gap may exist, it would be economically irrational to recover the gap in the wet season. Benefits in the dry season are somewhat greater, but the factors explaining why farmer were not attempting to achieve that economically preferrable yield varied widely from one location to another, depending on the specific circumstances. In general, however, it is possible to conclude from the research that the yield gap is rather small, quite variable, and probably explainable by factors other than the reluctance of farmers to adopt the technology.

It is clear from an examination of this volume that a large number of researchers were involved in the project. IRRI encouraged and coordinated the efforts of those involved, but the actual research was conducted by the authors of the papers and their associates. Research was conducted in 10 locations in 6 countries of Asia. It was planned in 1974, in many areas was under way in 1975, but in some not until 1976.

The yield gap. Four hundred ten trials were conducted under wet season conditions resulting in an average yield of 3.6 t/ha using farmers' inputs and 4.5 t/ha using high inputs, thereby demonstrating an average yield gap of 0.9 t/ha. Table 1 shows the average results from each area, arranged according to the size of the measured yield gap.

The yield gap in 5 locations was small, averaging from 0.4 to 0.6 t/ha. Two of these 5 locations had very low farmers' yields -- Subang, Indonesia and the dry zone, Sri Lanka. A third area, Camarines Sur, Philippines, had intermediate farmers' yields. in these three areas, it was not generally possible to raise yields substantially above the farmers' low level by using only

Table 1. Number of wet season trials by year and average yields in constraints experiments in farmers' fields. 6 Asian countries, 1974–1977.

Location	Wet season trials (no.)				Yield (t/ha)		
	1975	1976	1977	Total	Farmers'	High	Gap
Subang, Indonesia	-	4[a]	24	28	1.4	2.0	0.6
Dry zone, Sri Lanka		12	20	32	2.9	3.4	0.5
Camarines Sur, Philippines	6	6	27	39	3.9	4.5	0.6
Yogyakarta, Indonesia	3	3	35	41	4.7	5.1	0.4
Taiwan	3	16	18	37	5.0	5.6	0.6
Joydebpur, Bangladesh	3	20[b]	29[c]	52	2.9	3.8	0.9
Nueva Ecija, Philippines	11	9	37	67[d]	3.4	4.5	1.1
Laguna, Philippines	20	13	6	49[d]	3.6	5.4	1.8
Iloilo, Philippines		7	23	30	3.8	5.0	1.2
Central Plain, Thailand	6	6	20	35[e]	4.0	4.9	0.9
All	52	96	219	410[f]	3.6	4.5	0.9

Sources: Papers in this volume and the *Interim report.*

[a]20 simple trials were conducted in addition to these, but they involved the high level of only one factor.

[b]Includes 9 aus season trials and 11 aman season trials.

[c]Includes 11 aus season trials and 18 aman season trials.

[d]Includes 10 trials in 1974.

[e]Includes 3 trials in 1974.

[f]Includes 23 trials in 1974.

inputs that could be applied on farmers' fields by the researchers. In Yogyakarta, Indonesia and Taiwan, farmers' wet season yields were quite high (about 5 t/ha), and there the high levels of inputs failed to raise yields further. Farmers in these two areas were already using high inputs and getting high yields.

In 5 other locations the wet season yield gap was 0.9 tlha or more, up to 1.8 t/ha in Laguna, Philippines. Among these 5 locations, Joydebpur, Bangladesh had the lowest farmers' yield of 2.9 t/ha, while the other sites had farmers' yields between 3.4 and 4.0 t/ha. The trials in Laguna showed a yield gap of 1.8 t/ha, which was 0.6 tlha higher than any other location.

The wet season trials show that the average potential farm yield was 0.9 t/ha higher than the actual farmers' yields in the test areas. The correlation between the level of the farmers' yield and the yield gap was zero. There was considerable variability in the yield gap across locations.

Table 2. Number of dry season trials by year and average yields recorded in constraints experiments in farmers' fields. 6 Asian countries, 1974-1977.

Location	Dry season trials (no.)				Yield (t/ha)		
	1975	1976	1977	Total	Farmers'	High	Gap
Dry zone, Sri Lanka		11	20	31	2.5	2.9	0.4
Subang, Indonesia		24	40	64	3.8	4.4	0.6
Taiwan		3	34	37	6.6	7.3	0.7
Joydebpur, Bangladesh		6	23	29	3.5	4.6	1.0
Iloilo, Philippines		2	17	19	3.9	5.3	1.4
Yogyakarta, Indonesia	2	2	35	39	4.8	6.1	1.3
Camarines Sur, Philippines	3	5	20	28	4.0	5.8	1.8
Central Plain, Thailand	7	6	26	39	4.2	6.1	1.9
Laguna, Philippines	9	12	19	46[a]	4.5	6.5	2.0
Nueva Ecija, Philippines	3	9	28	40	4.6	6.8	2.2
All	24	80	262	372[a]	4.3	5.6	1.3

Sources: Papers in this volume and the *Interim report.*

[a]Includes 6 trials in 1974.

Dry season constraints experiments were conducted on 366 farmers' fields in the 10 locations between 1975 and 1977. Farmers' yields averaged 4.3 t/ha, and yields with the high inputs were 5.6 t/ha, for an average yield gap of 1.3 t/ha (Table 2).

In 3 locations the yield gap was small; about 1/2 t/ha. In the dry zone of Sri Lanka and Subang, Indonesia, both farmers' yields and the yield gap were low, indicating that the technology applied could not overcome the constraints. Taiwan also showed a small gap, but in that case it was because the farmers were already close to the potential yield. All three of these locations showed the same general results in the wet season.

In 3 locations the yield gap was about 1 t/ha. Joydebpur, Bangladesh had farmers' yields of 3.6 t/ha, with a yield gap of 1.0 t/ha, while the other two locations, Iloilo, Philippines and Yogyakarta, Indonesia, had somewhat' higher farmers' yields and slightly larger yield gaps.

In the remaining 4 locations the yield gap was approximately 2 t/ha, and in all cases the average farmers' yields were 4 t/ha or higher. These areas demonstrate the largest unrealized potential for yield increases, even though they already had fairly respectable yield levels.

There was a positive correlation between farmers' yields and the yield gap (r = .17) in the dry season data than in the wet season. Also, the average dry season gap of 1.3 t/ha was somewhat larger than the average wet season gap. With the exception of the dry zone of Sri Lanka, in every case the yield with high inputs was higher in the dry season than in the wet season, with an average difference of 1.1 t/ha between the seasons. The dry season yield gap was also larger than the wet season gap everywhere but in the dry zone of Sri Lanka.

Biophysical constraints. The constraints experiments have been designed to enable the analyst to separate the yield gap into the components attributable to each of the variable test factors used in the experiments. In each location, the researchers decided before the experiment which farmer practices or input levels should be changed in order to achieve higher yields than what farmers were achieving. That is, researchers tried to identify the unused or inadequately applied factors that would give higher yields. These factors were then used as the test factors in the experiments. Each participating research group was urged to choose the factors that appeared to be most limiting in their situation. Two to four factors were generally chosen. A larger number would have made the experiment too cumbersome for convenient use in farmers' fields.

Fertilizer and insect control were the most frequently used test factors. Others included weed control, variety, plant spacing, land preparation, organic manure, and various separate fertilizer elements. Tables 3 and 4 show the locations at which each factor was tested and the effects of the three most frequently used factors.

The experimental design permits a direct allocation of the total yield gap to each of the test factors, where interaction among test factors is not significant (De Datta et al 1978). In most seasons and locations interactions were found to be insignificant; so the contribution of each major factor to the gap could be calculated. The wet season contributions, shown in Table 3, do not in sum equal the yield gap in Table 1 for the following reasons: there is usually a residual that is not attributable to individual factors; the total gap in Table 1 is calculated from complete factorial, mini-factorial and supplemental trials, but the supplemental trials cannot be used to determine separate contributions to the gap.

A total of 272 wet season experiments can be used to determine contributions. Fertilizer was a test factor in all 272 trials and contributed an average of 0.4 t/ha to the wet season yield gap (Table 3). High insect control was tested in 254 trials. It also contributed an average of 0.4 t/ha to the yield gap. High weed control, tested in 229 trials, contributed 0.1 t/ha toward overcoming the gap.

Table 3. Average wet season contributions of test factors in constraint: experiments in farmers' fields. 6 Asian countries, 1974–1977.

Location	Trials (no.)[a]			Contribution (t/ha) to the gap			Other factor, tested[b]
	F	W	I	Fertil-izer	Weed control	Insect control	
Joydebpur, Bangladesh	35	20	35	0.51	0	0.24	S (6)
Yogyakarta, Indonesia	14	6	14	0.24	0.10	0	
Subang, Indonesia	8	0	8	0.15	n.t.[c]	0.95	L (4)
Dry zone, Sri Lanka	32	32	32	0.13	0.10	0.14	T (12)
Taiwan	15	3	3	0.38	0.20	0.10	T,M(12)
Centra1 Plain, Thailand	15	15	9	0.42	0.14	0.23	
Laguna, Philippines	49	49	49	0.72	0.24	0.91	
Nueva Ecija, Philippines	54	54	54	0.32	0.06	0.51	L (10)
Camarines Sur, Philippines	27	27	27	0.12	0	0.07	
Iloilo, Philippines	23	23	23	0.63	0.33	0.43	
Av	272	229	254	0.40	0.13	0.42	

[a]Refers to the number of trials from which the contributions of individual factors (F = fertilizer; W = weed control; I = insect control) were calculated. This is less than the number in Table 1 because some trials had a simple design that could not be used for calculating contributions.

[b]These factors were tested in only a few locations. The number of trials is in parentheses. S = sulphur; L = land preparation; T = depth and spacing of transplanted seedlings; M = organic manures; V = variety.

[c]n.t. = not tested.

Fertilizer was 2 test factor in 187 dry season trials (Table 4). Its average contribution to the gap in those trials was 0.9 t/ha. A high level of insect control contributed an average of 0.6 t/ha to the dry season yield gap in 193 trials. Weed control was tested in 169 trials and contributed an average of 0.2 t/ha to the yield gap.

Inadequate fertilizer in the dry season is clearly the most important among the measured yield constraints, and insect control is second. In the wet season, the two factors are equally important, but both make smaller contributions than during the dry season. The contribution of the high level of insect control was more variable than the contribution of high fertilizer. High

Table 4. Average dry season contributions of test factors in constraints experiments in farmers' fields. 6 Asian countries, 1974–1977.

Location	Trials (no.)[a]			Contribution (t/ha) to the gap			Other factors tested
	F	W	I	Fertilizer	Weed control	Insect control	
Joydebpur, Bangladesh	29	29	23	0.51	0.16	0.10	
Yogyakarta, Indonesia	10	8	8	1.02	0.40	0.18	
Subang, Indonesia	4	0	44	0.30	n.t.	0.70	L (4)
Dry zone, Sri Lanka	16	16	16	0.14	-0.08	0.10	T (11)
Taiwan	15	3	3	0.42	0.20	0.10	T, M(12)
Central Plain, Thailand	21	21	7	1.44	0.35	0.30	V (8)
Laguna, Philippines	33	33	33	1.02	0.17	0.93	
Nueva Ecija, Philippines	28	28	28	0.98	0.26	0.85	
Camarines Sur, Philippines	20	20	20	1.21	0.25	0.71	
Iloilo, Philippines	11	11	11	1.27	0.24	0.28	
Av	187	169	193	0.88	0.21	0.57	

[a] See footnotes to Table 3.

insect control had a coefficient of variation (cv) of 73 and 113 in the dry and wet seasons compared with a cv of 58 and 80 for fertilizer in the dry and wet seasons.

The high levels of weed control tested in the experiments increased yields by an average of 0.2 t/ha in 169 dry season trials and by 0.1 t/ha in 229 wet season trials. These relatively small contributions may be explained by any of the following reasons: farmers did an adequate job of controlling weeds on their fields; the farmers may have had inadequate control, but the "high" weed control tested did no better job than the farmers'; weeds may not have been an important problem in the experimental fields; and farmers may have taken extra care to remove weeds because of the presence of the researchers.

Socioeconomic constraints. The experiments showed that in many cases it was possible to raise rice yields in farmers' fields in Asia by 1 t/ha or more. The purpose of the study of socioeconomic constraints is to explain why farmers are not taking advantage of that yield potential.

The explanation for why farmers do not use the high level of weed control seems fairly obvious. The additions to output are small, probably so small that they do not appear to be worthwhile. In

only 6 out of 32 cases did the increased yield from high weed control exceed 300 kg/ha, and in 4 out of 32 cases the yield was lower with "high" weed control than with farmers' low weed control (Tables 3 and 4). Farmers are unlikely to be impressed by these small yield gains (5% of their yield levels), even without considering the relative costs of the high and existing systems.

The high levels of fertilizer and insect control, on the other hand, raise yields by 3 or 4 times as much as the high weed control and require a rigorous economic analysis to determine whether they would be economically attractive. Most of the experiments were not designed to permit the fitting of a production function that could be used to estimate optimal levels of input application. In some cases, where the experiments were large and the design was more complex than usual, data could be pooled across locations and years to permit such an analysis (see Nueva Ecija chapter). However, it is possible to subject the data from all experiments to a budgeting analysis to determine how economically attractive the high input levels were.

Table 5 shows the budgeting analysis of 239 wet season trials for which data were available. Because of variation in the design of experiments not all of the trials listed in Tables 1 and 2 could be included in the economic analysis. In the subset of 239 wet season experiments subjected to economic analysis the farmers' yields averaged 3.5 t/ha and the yield gap averaged about 1 t/ha. The value of increased rice output was calculated at prevailing local prices for each location, and in the Philippine sites was reduced by the prevailing *share-based* harvesting and threshing costs. Local currencies were converted to US$ at the rates prevailing in 1975 – 77, shown in a footnote to Table 5. The high inputs increased yields by 0.4 t/ha and output value by US$50/ha or more in all wet season cases.

The cost of the high inputs averaged 40% more than what farmers were spending on the same inputs. In some cases the difference was much greater. For example, in the central plain of Thailand, the high inputs cost 6 times as much as farmers spent. In Laguna, Philippines, the high inputs cost 3.6 times as much.

In 4 locations the use of the high inputs in the wet season, on the average, resulted in a *reduction* of net benefits to farmers. That is, the added input costs exceeded the value of added yields. In Yogyakarta, Taiwan, the central plain of Thailand, and Camarines Sur, farmers would not be attracted to the high levels of inputs for the wet season because their own practices were more profitable. In the remaining 6 locations the high inputs resulted in increased profits. On the average, in those 6 remaining locations each $1.00 invested in buying inputs returned $1.50, or a net benefit of $0.50 for each extra dollar invested. In Joydebpur, the rate of return was substantially higher.

Table 5. Economic comparisons[a] of wet season yields with farmers' and high levels of test inputs in constraints experiments in farmers' fields. 6 Asian countries, 1974–77.

Location	Trials (no.)	Yield (t/ha)[b] Farmers'	Yield (t/ha)[b] Gap	Increased output[c] value ($/ha)	Input cost ($/ha) Farmers'	Input cost ($/ha) Increase to high	Increased net benefits from high ($/ha)
Joydebpur, Bangladesh	52	2.8	0.9	143	35	39	104
Yogyakarta, Indonesia	14	5.4	0.4	56	92	88	-32
Subang, Indonesia	8	3.0	1.0	122	132	66	56
Dry zone, Sri Lanka	17	2.8	0.9	168	80	140	28
Taiwan	9	4.9	0.4	130	834[d]	161	-31
Central Plain, Thailand	18	3.7	1.0	134	26	160	-25
Laguna, Philippines	41	3.8	1.8	209	51	183	26
Nueva Ecija, Philippines	29	3.5	1.1	143	73	104	39
Camarines Sur, Philippines	27	3.4	0.5	61	52	136	-75
Iloilo, Philippines	23	3.5	1.3	156	51	151	5
All	239	3.5	1.0	141	85	118	23

[a]Exchange rates used: Bangladesh US$l.00 = Tk14; Indonesia US$l.00 = Rp415; Sri Lanka US$l.00 = Rs8; China US$l.00 = NT$38; Thailand US$l.00 = B20; Philippines US$l.00 = P7.30.

[b]Yields may differ from corresponding data in Tables 1 and 3 because different numbers of experiments are included in that table and this one.

[c]In Philippine sites, harvesting costs are taken account of but not in other locations.

[d]Includes labor cost of farmers' practices.

In the dry season the high level of inputs increased net benefits in 9 out of 10 locations (Table 6). In about half of the sites farmers spent more on their inputs in the dry season than in the wet, but in half the sites the opposite was true. Increased output averaged 0.4 t/ha more in the dry season than in the wet and, as a consequence, the average increase in net benefits was higher in

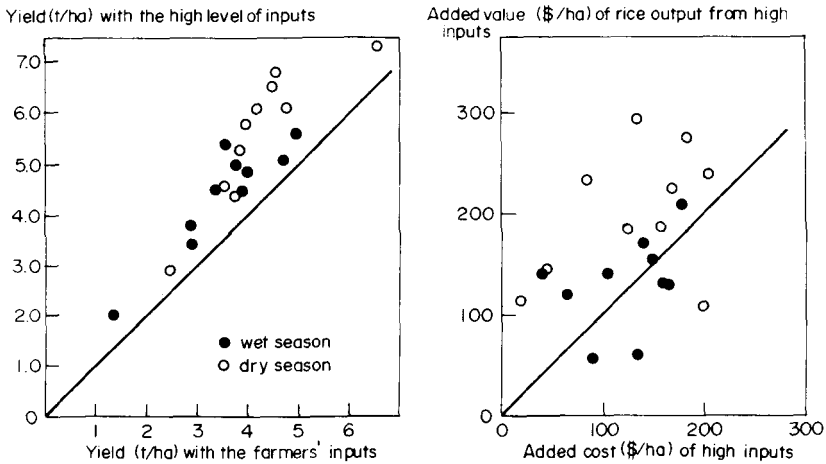
Table 6. Economic comparisons[a] of dry season yields with farmers' and high levels of test inputs in constraints experiments in farmers' fields. 6 Asian countries, 1974–77.

Location	Trials (no.)	Yield (t/ha)		Increased output value ($/ha)	Input cost ($/ha)		Increased net benefits from high ($/ha)
		Farmers'	Gap		Farmers'	Increase to high	
Joydebpur, Bangladesh	29	3.6	0.9	145	77	47	98
Yogyakarta, Indonesia	12	4.2	1.6	236	90	84	152
Subang, Indonesia	44	4.0	0.7	115	14	19	96
Dry zone, Sri Lanka	17	3.9	0.6	108	63	201	-93
Taiwan	8	5.9	0.6	186	755	124	62
Central Plain, Thailand	17	3.9	2.1	225	41	171	54
Laguna, Philippines	28	4.4	2.0	274	81	188	86
Nueva Ecija, Philippines	19	4.6	2.3	294	111	134	160
Camarines Sur, Philippines	20	3.5	2.1	242	57	207	34
Iloilo, Philippines	11	3.8	1.6	187	58	182	4
All	205	4.0	1.4	192	87	119	73

[a]See footnotes to Table 5.

the dry season in 7 locations. In the 9 locations where net benefits were increased Over the farmers' levels by the high level of inputs in the dry season, a $1.00 investment in the high inputs led to a $1.80 return or an average net benefit of $0.80 for each extra dollar invested. In four locations, Joydebpur, Yogyakarta, Subang, and Nueva Ecija the B:C ratio exceeded 2:1.

Figure 1 summarizes the results obtained. On the left side the yield with high inputs is plotted against the yield with farmers' inputs. The vertical distance above the line shows the yield gap, which is positive in every case. On the right side the economics of the gap is summarized. Points below the line are locations where the farmers' practices were more profitable than the "high" practices.



1. Yield gap and economics of the yield gap in wet and dry seasons, average of one of 10 locations in 6 Asian countries, 1974–77.

It appears that, while a modest yield gap exists in the wet season, it is not economically attractive for farmers to apply the high rates of fertilizer and insect control that would be needed to close the gap because the return is negative or the rate of return on added inputs is low. The gap is larger in the dry season and in most cases it is economically attractive to use the high inputs.

Most of the individual papers in this volume carry the economic analysis one additional step and evaluate the costs and benefits of each of the separate inputs. Although the exercise is not carried out for all trials, the available data are summarized here because they are illuminating.

Table 7 shows the added costs and returns for fertilizer and insect control in the wet season. The high level of insect control usually entails a much greater increased cost over the farmers' levels than the high level of fertilizer. This is partly because farmers apply relatively more fertilizer than insect control and partly because the expenditure on insect control needed to achieve maximum yields is relatively higher than the expenditure on fertilizer needed for maximum yields. As a result, the high level of insect control added more to costs than it did to returns in 6 out of 10 locations in the wet season. The high level of fertilizer decreased net returns in 3 out of 10 locations, but on the average added $20/ha to net returns, with an average B-C ratio of 1.7:l.

The pattern of results for the dry season is similar to the wet but is somewhat more favorable because the added yield contributed by

Table 7. Added cost and added return ($/ha)[a] of the tested high level of fertilizer and insect control in wet season constraints experiments in farmers' fields. 6 Asian countries, 1974–77.

Location	Trials (no.)	Average increase ($/ha) of high level compared to farmers' level					
		Fertilizer			Insect control		
		Cost	Net return	B:C	Cost	Net return	B:C
Joydebpur, Bangladesh	20	23	68	3.96	7	24	4.43
Yogyakarta, Indonesia	14	35	-12	0.66	43	-42	0.02
Subang, Indonesia	8	19	-10	0.47	27	93	4.44
Dry zone, Sri Lanka	32	9	15	2.67	53	-27	0.49
Taiwan	12	23	49	3.13		n.t.[b]	
Central Plain, Thailand	17	63	23	1.37	135	-103	0.24
Laguna, Philippines	41	15	59	4.93	160	-34	0.75
Nueva Ecija, Philippines	39	35	7	1.20	81	-10	0.88
Camarines Sur, Philippines	20	52	-56	-0.08	76	-43	0.43
Iloilo, Philippines	23	45	17	1.38	95	52	1.55
All	226	30	20	1.67	86	-16	0.81

[a] Currencies converted at the rates shown in footnote to Table 5.

[b] Factor was not tested.

high inputs was greater in the dry season than in the wet season (Table 8). In one case the high fertilizer reduced net benefits, but in nearly all other locations it raised net returns by a substantial amount, averaging $71/ha. The average B–C ratio on high fertilizer compared with farmers' fertilizer was 2.6:l. High insect control, on the other hand, reduced net returns in 6 cases and barely covered its cost on the average, yielding a B–C ratio of 1.2:l.

This breakdown by inputs shows that in the dry season the application of higher levels of fertilizer appears to give a sufficiently high return above added costs to generate a strong incentive for its use. But high insect control is not sufficiently attractive to expect farmers to use it except under certain conditions. Thus, the economic analysis indicates that the main profitable opportunity for increasing yields exists in the dry season through the use of researchers' fertilizer levels instead of farmers' fertilizer levels. The individual papers address this question within their own context.

Impact of the institutional setting. Considerable attention has been given in the literature to the potential impact of institutions tenure, credit limitation, and relative prices as factors

Table 8. Added cost and added return ($/ha) of the tested high level of fertilizer and insect control in dry season constraints experiments in farmers' fields. 6 Asian countries, 1974–77.

Location	Trials (no.)	Average increase ($/ha) of high level compared to farmers' level					
		Fertilizer			Insect control		
		Cost	Net return	B–C	Cost	Net return	B–C
Joydebpur, Bangladesh	29	31	42	2.35	5	10	3.00
Yogyakarta, Indonesia	10	63	121	2.92	22	3	1.14
Subang, Indonesia	4	36	8	1.22	4	-4	0
Subang, Indonesia	40[a]	n.t.[b]			7	60	9.57
Dry zone, Sri Lanka	16	50	-24	0.52	95	-77	0.19
Taiwan	12[a]	24	68	2.83	n.t.		
Central Plain, Thailand	6	84	67	1.80	151	-121	0.20
Central Plain, Thailand	10[a]	33	135	5.09	n.t.		
Laguna, Philippines	18	18	113	7.28	170	-74	0.56
Nueva Ecija, Philippines	19	38	124	4.26	87	34	1.39
Camarines Sur, Philippines	20	82	68	1.83	116	-34	0.71
Iloilo, Philippines	11	66	62	1.94	109	-79	0.28
All	195[a]	45	71	2.58	65	12	1.18

[a] Fertilizer or insect control but not both, were tested in these cases. The total number of trials for fertilizer was 155 and that for insect control was 173.

[b] Factor not tested.

depressing farmer incentives. The economic analysis reported above was conducted using the prices that farmers in each area reported as the prevailing prices in those areas. The above analysis has not recognized the impact of institutions, cost of credit, or tenure conditions other than land ownership. However, it is clear that such factors are important in the decision–makingof farmers.

Value of rough rice and cost of urea fertilizer represent the relative incentive to use modern technology (Table 9). The ratios of these factors vary greatly across the locations studied. In the Philippines it takes 1.7 kg of paddy rice to purchase one kg of urea, in Thailand 1.5 kg, in Indonesia 1.2 kg; in Sri Lanka it takes only 0.7 kg and in Taiwan only 0.5 kg. These different ratios directly affect the incentives farmers have to use inputs and therefore affect the yield gap. Figure 2 illustrates the effect. In those areas where the cost of urea relative to rice is high, the yield gap attributable to fertilizer is also high, especially in the dry season. In the areas where it takes less than 0.8 kg of

Table 9. Prices and interest rate on credit, distribution of farms by tenure and share tenancy conditions in constraints sites. 6 Asian countries, 1977.

Location	Prices ($/kg)		Prevailing interest rate on loans (%/yr)		Distribution of farms by tenure (%)[b]			Prevailing share tenure (% of tenant	
	Paddy	Urea	Private	Institutional[a]	Owner	Fixed rent	Share rent	Output	Input
Joydebpur, Bangladesh	0.15	0.11	100	9	70	1	20	50[d]	10
Yogyakarta, Indonesia	0.15	0.18	n.a.[c]	12	65	5	30	50	10
Subang, Indonesia	0.14	0.18	n.a.	12	50	15	28	50	10
Dry zone, Sri Lanka	0.19	0.13	n.a.	10	60	20	20	50	5
Taiwan	0.32	0.16	13	10	100	0	0	-	–
Central Plain, Thailand	0.11	0.16	24	12	62	31	7	67	10
Laguna, Philippines	0.14	0.24	50	13	7	64	27	50	5
Nueva Ecija, Philippines	0.15	0.24	50	13	9	84	3	50	5
Camarines Sur, Philippines	0.14	0.24	50.	13	10	66	20	75	10

[a] Government – backed or sponsored credit programs.

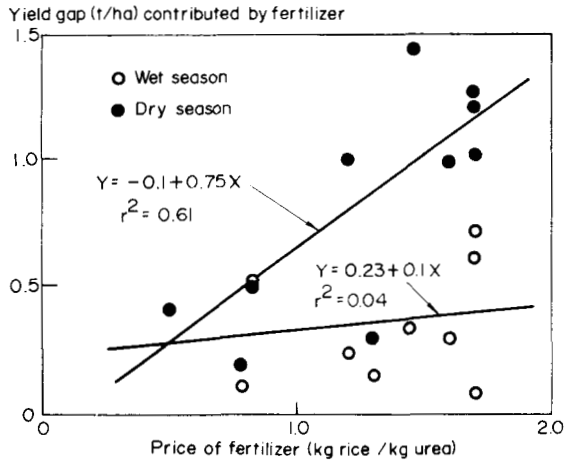
[b] The difference between the total and 100 is accounted for by farms with some land under 2 or more tenures.

[c] n.a. = information not available or credit not generally available from this source.

[d] Prevailing practice in Aus. In T. Aman 67% of output commonly goes to the landlord; so the tenant is left with 33%.

rice to buy 1 kg of urea the yield gap attributed to fertilizer is 0.5 t/ha or less. The correlation is much less in the wet season (r = .04) than in the dry (r = .65) when the disincentive effect of high fertilizer cost is apparent.

In addition to the disincentive of high – cost fertilizer, in most study areas farmers who borrow from private credit sources are faced with interest rates of 50% per year or more. Those who are also tenants paying for their land on a share basis in which they



2. Relationship of real price of fertilizer to the yield gap contributed by fertilizer.

give 25% to 50% of output to the landlord and pay for all the inputs have a further disincontive to use fertilizer. Table 10 shows the effective real price of urea - the production that would be needed to pay for one kg of urea -- in each location under the prevailing prices and institutional arrangements identified in Table 9.

Owners who are self-financedmust pay the fertilizer prices shown in the first column. Those using institutional credit that is available in most countries at an interest rate of 9 to 12% per year have slightly higher effective fertilizer prices. Those farmers who rent their land on a share basis in which the landlord pays none of the input cost such as prevails in Joydebpur, Yogyakarta, Subang, central plain of Thailand, and Camarines Sur end up paying substantially higher effective prices for their fertilizer. If the share tenants also borrow money from private credit sources, they may in the end pay up to three times as much for urea as the stated price, as in Joydebpur, Bangladesh. Such high effective prices would have a strong disincentive effect.

Fortunately, only about 30% of the sample farmers report being under the kind of disincentive tenure terms that result in such high effective fertilizer prices. However, any combination of high-interest-rate private credit or disincentive share tenure will result in reduced incentives to use fertilizer. These reduced incentives will mean that "gross" B C ratios such as shown in Tables 7 and 8 must be 2 or 3 rather than just being "over 1" in order to give an incentive for high input use.

Table 10. Effective real price of urea in kg of rice for farmers with different prevailing institutional arrangements in areas with constraints studies. Asia, 1977.

Location	Kg of rice needed to pay for 1 kg of urea with the stated conditions				
	Owner self-financed	Owner Institutional credit	Owner Private credit	Share-tenant Institutional credit	Share-tenant Private credit
Joydebpur, Bangladesh	0.73	0.77	1.09	1.53	2.19
Yogyakarta, Indonesia	1.20	1.27	n.a.[a]	2.54	n.a.
Subang, Indonesia	1.29	1.37	n.a.	2.73	n.a.
Dry zone, Sri Lanka	0.68	0.72	n.a.	0.72	n.a.
Taiwan	0.50	0.53	0.54	0.53	n.a.
Central Plain, Thailand	1.45	1.54	1.62	2.30	2.43
Laguna, Philippines	1.71	1.82	2.14	1.82	2.14
Nueva Ecija Philippines	1.60	1.70	2.00	1.70	2.00
Camarines Sur, Philippines	1.71	1.82	2.14	2.43	2.86

[a]n.a. = not available.

CONCLUSIONS AND IMPLICATIONS

The research showed the existence of a yield gap of 0.9 t/ha in the main Asian rice-growing season (wet) and a slightly higher gap (1.3 t/ha) in the dry season averaged across all study areas. The yield gaps varied from 0.4 t/ha to 2.2 t/ha across study areas. Levels of fertilizer and insect control higher than farmers' levels contributed equally to raising wet season yields, while in the dry season high fertilizer contributed more than high insect control. The average benefit-cost ratio of the additional inputs

required for the high yield level was not high enough to make high fertilizer or weed control attractive in the wet season, but in the dry season higher fertilizer gave substantially increased profits.

This research thus indicates that relative prices of rice and fertilizer, both of which are controlled by all Asian governments, have a major effect on the use of fertilizer. Low rice: fertilizer prices create an opportunity to increase yields through the application of higher levels of fertilizer, but this opportunity will only be realized if fertilizer prices are lower or rice prices are higher.

More important, perhaps, are the implications for research on insect control. The amount: of rice being lost to insects is substantial, but it appears that current technology is too costly. This finding, reported early in the project, has stimulated rice entomologists in Asia to seek lower-cost, more effective methods of insect control.

Finally, the overall weight of the evidence examined suggests that it is relatively easy to account for the dramatic gap between what is technically possible and what has been achieved: what is technically possible is more modest than most observers admit; the economics of substantially higher yields is not attractive; the costs associated with the credit and tenure arrangements that often prevail in developing countries make higher input use totally unattractive for some farmers. Thus, the available technology is being used to its potential. If further growth is to be realized, continued development of technology must be combined with institutional reforms that make current technology more attractive to users.

REFERENCES CITED

De Datta, S. K., K. A. Gomez, R. W. Herdt, and R. Barker. 1978. A handbook on the methodology for an integrated experiment - survey on rice yield constraints. International Rice Research Institute, Los Baños, Philippines.

International Rice Research Institute (IRRI). 1977. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Philippines.