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FOCUSING FIELD RESEARCH ON FUTURE CONSTRAINTS TO RICE PRODUCTION

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FOCUSING FIELD RESEARCH ON FUTURE CONSTRAINTS TO RICE PRODUCTION[1/]

ABSTRACT

The dimensions of the food-population problem for Asia are reviewed and the factors contributing to the growth of rice output since 1953 are examined. Increases in yield per hectare were the dominant source of rice output growth in most countries in the 1970s as irrigation, fertilizer, and high-yielding varieties spread. The effectiveness of three strategies for increasing future production is reviewed -- price subsidization, extension to close the yield gap, and research to raise the possible yield. The expected future availability of rice and likely prices of rice production inputs suggest the types of field-oriented research that may be needed to overcome the likely future constraints to production.

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FOCUSING FIELD RESEARCH ON FUTURE CONSTRAINTS TO RICE PRODUCTION

The purpose of agricultural research is to develop technologies that help farmers produce more food, obtain higher incomes, and provide more adequate nutrition for all people. Rapid growth in population raises the largest challenge to meeting that goal. By the year 2000 rice production will have to double to meet the demand in Asia.

Incomes in Asia are rising and per capita rice consumption is higher than 10 or 20 years ago. Only in the most advanced countries of the region, such as in Japan, has per capita rice consumption declined.

The burden of increasing production will fall on research. Extension services can transmit new ideas to farmers but cannot produce the new technologies that are needed. The expected relative increase in price of fossil fuel-dependent inputs means that new systems of rice production that give high yields but use different factor proportions from those now used will have to be produced by research if the world is to meet the food needs of the 1980s and the 1990s.

THE DIMENSIONS OF THE FOOD-POPULATION PROBLEM IN ASIA

Projections made by the World Bank illustrate the dimensions of the population problem. By the year 2000, the number of rice eating people in Asia will increase by 600 million (Table 1). This will happen even though in many countries of Asia, the birth rate has declined over the past 15 years -- from 47 to 37 per 1,000 in Indonesia, from 36 to 26 in Sri Lanka, from 43 to 35 in India, and from 45 to 35 in the Philippines (IBRD 1979). This decline obviously eases the food production problem somewhat. It is, however, no cause for complacency. Taking into account these declines in birth rates and projecting ahead to a hypothetical stationary population, which would be achieved in the 21st or 22d century in various countries, the World Bank projection figures imply that the population of rice eating people in Asia would increase by about 2.0 billion.

It is difficult to comprehend these numbers, but they imply that by the year 2000, India will have nearly 50% more people, Indonesia 60% more, and Bangladesh 70% more. Populations in other countries will increase in similar proportion. If in addition to population growth one expects a modest increase of incomes, then rice production will have to increase at a 3.6% annual average rate in Asia (IFPRI 1977). If incomes grow slightly more rapidly, rice production will have to increase at 3.9%/year.

Table 1. Estimated population (million) in South, Southeast, and East Asia whose major food is rice, 1980.

Site	Total population 1980	Rice eaters 1980	Annual growth (%)	Projected no. of rice eaters[a/] Year 2000	Stationary
China	956	600	1.4	747	964
India	660	416	2.0	632	1,051
Indonesia	147	118	2.4	166	286
Japan	116	81	1.0	91	93
Bangladesh	90	81	2.7	131	301
Pakistan	80	24	3.0	42	101
Vietnam	50	45	2.2	78	134
Philippines	49	37	2.5	57	96
Thailand	48	38	2.3	55	84
Republic of Korea	38	36	1.7	46	61
Burma	35	32	2.4	46	83
Taiwan	17	12	2.1	16	21
Sri Lanka	15	14	1.7	19	27
Nepal	15	9	2.3	14	31
Malaysia	13	10	2.5	16	23
Democratic People's Republic of Korea	15	14	2.5	24	39
Kampuchea	9	8	2.9	14	33
Lao People's Republic	4	3	2.4	4	9
Total[b/]	2,365	1,584	1.9	2,205	3,488

[a/] Assuming rice eaters are in the same proportion as in 1980. Projections are by the World Bank.
[b/] Total also includes data for Hongkong, Singapore, Bhutan, Portuguese Timor, and Macao. Sources: Huke 1982, IBRD 1979.

If rice production fails to keep up with the rate of increase in demand, the burden will fall most heavily on the poorest people in the region. That is because the poorest people already have the lowest consumption levels, but they spend a higher fraction of their income on rice than do the wealthy. This is especially true in high rice-dependent countries like Bangladesh (Table 2). If the demand for rice increases faster than its supply, prices will rise and the poor will be even less able to afford adequate diets.

This problem has enormous dimensions. Even in those countries that have adequate levels of food consumption, on the average a substantial proportion of the populations have inadequate consumption levels (Table 3). According to one calculation more than 500 million Asians had inadequate

levels of caloric intake in 1960. This increased to more than 600 million in the 1970s (Reutlinger and Alderman 1980). If food production proceeds fast enough to insure that prices remain constant through 1990, the proportion of the population with inadequate diets will fall, but the absolute number will increase by about 100 million. If food prices increase by as little as 1%/year, the number with inadequate diets will increase by an additional 50 million (Reutlinger and Alderman 1980).

SOURCES OF RICE PRODUCTION GROWTH IN THE PAST DECADES

Since 1953, Asia's rice production has grown at an average rate of 2.7% -- slightly faster than population growth, but somewhat slower than the rate needed to keep up with the growth in demand (Table 4). The proportion of output growth due to yield increases and that due to area increases have varied from country to country, but, on the basis of a weighted average, have remained remarkably stable for the region as a whole. Sixty to 65% of the growth was achieved through increases in yield per unit area, the rest from expanding area.

The growth in land area comes from new land brought into production and from increases in double-cropping made possible by upgrading irrigation systems. It is impossible to separate the two sources of increased area from national level data for most countries, but based on fragmentary data it seems that increased double-cropping is the main source.

Yield increases are attributable to three sources: more fertilizer, more irrigated area, and higher-yielding, more fertilizer-responsive varieties. Data on the magnitude of changes in these factors are available. Using those data and rough rules of thumb about response to fertilizer, one can attribute yield gains to fertilizer and a residual. Table 5 shows the results of the calculations. Five-year averages are used to isolate the underlying trends because the year-to-year weather- and price-induced fluctuations are considerable. Data for years earlier than 1965 when fertilizer's contribution was minor in any case are not available. In all but 5 of the 22 periods, expansion of irrigated area accounted for the bulk of the area increases that occurred. The contribution of fertilizer to yield increases was large, but not overwhelming, and in a number of interesting cases -- the Philippines, Indonesia, Burma, and Korea in the late 1970s -- the unexplained residual was considerably larger than the contribution of fertilizer, suggesting the importance of extension-production programs in those countries.

STRATEGIES FOR INCREASING RICE PRODUCTION

One can conceive of three broad strategies that may be followed by governments in their efforts to increase agricultural production:

- price subsidies to encourage farmers to use more inputs,
- extension education programs to close the gap between possible and actual production, and
- research to increase the possible yield levels.

Rice price subsidies

Subsidies to lower the price of agricultural inputs, or to raise the price of rice for producers while keeping its sale price low for consumers, can encourage increased farm production. If the subsidies are large, however, they can become serious financial burdens on governments; for example, fertilizer subsidies were estimated to have absorbed 75% of agricultural development expenditures in 1978-79 in Bangladesh (ESCAP 1980). The usual result is their reduction or elimination. A determined government policy of subsidies can, of course, be followed, but in countries where a large fraction of income is generated within the agricultural sector there are serious limitations to the capacity to finance such subsidies.

Popular opinion notwithstanding, governments have limits to their capacity to generate funds. Taxes are the most obvious source. If a large fraction of the total economy is agricultural, then either agriculture will be taxed to subsidize itself, or the other sector will be taxed to subsidize agriculture. Because most countries are trying to encourage development of the nonagricultural sector, they generally avoid taxing it heavily. A second source of funds is deficit financing, sometimes accomplished by borrowing from the general public and at other times by increasing the money supply. Borrowing from the general public is difficult in a developing economy, because income levels are low. The more usual course is the creation of money, which leads to inflation. The deliberate pursuit of a policy that encourages inflation is counterproductive because it results in higher prices, the very evil that was being avoided through subsidies.

Of course, governments may subsidize one commodity while taxing another and thereby avoid inflationary pressures. This may be justified on the basis that the subsidized commodity is a necessity and the taxed one a luxury.

Another factor to be considered is the effectiveness of price subsidies. Price subsidies, whether designed to lower the price of an input like fertilizer or to raise the price of a product like rice, increase the incentive to use inputs in production. This is illustrated in Figure 1. The price lines (P) show the ratio of the price of input to the price of output and the curve shows the impact of the input on the yield, or output. If producers wish to use inputs in an economic way they will operate at the tangency points X_2,

Table 2. Relationship of income and quantity of rice and rice products consumed, Bangladesh, India, and Korea.

Bangladesh (1968-69, rural)		India (1964-65, national)		Korea 1964	
Income per capita (1968 Rs/mo)	Monthly rice consumption (kg/household)	Income class (1964 Rs/mo)	Annual rice consumption (kg per capita)	Income class (1964 won)	Annual rice consumption (kg per capita)
22.7	47.2	<11.9	50.6	<72	74.4
29.8	58.4	12-15.9	51.7	72-96	100.9
35.6	63.3	16-18.9	51.8	96-120	124.6
39.4	64.8	19-21.9	61.3	120-144	129.8
41.7	65.2	22-28.9	62.8	144-168	134.8
48.9	72.6	29-43.9	63.6	168-192	148.1
94.5	74.9	>44	87.2	>192	164.3

Sources: Alamgir and Berlage (1973) for Bangladesh, NCAER (1969) for India, Pak and Han (1969) for Korea.

Table 3. Selected indices of calorie deficiency of Asia based on income distribution data, 1960s to 1990s.

Site	Per capita calorie intake as a % of requirements, mid-1960s	Share of population with calorie deficits			
		Mid-1960s	1973	Projected to 1990: Constant food price	Projected to 1990: 1% annual increase in food prices
Indonesia	83	80	66	30	37
Pakistan	89	75	67	35	40
Philippines	84	74	70	54	57
India	88	70	72	60	64
Sri Lanka	100	60	62	44	49
Thailand	100	54	49	17	20
Malaysia	101	54	34	14	16
Korea	103	40	25	0	1
Asia: millions of persons		540	613	643	707

Source: Reutlinger and Alderman (1980).

Table 4. Annual growth rates of rice production in Asia[a] (Source: USDA 1979).

Site	1978-80 production (thousand t)	1953-63		1963-73		1972-79	
		Output growth rate	% from yield	Output growth rate	% from yield	Output growth rate	% from yield
China	140,500	2.54	85	2.86	59	2.82	71
India	74,989	3.37	55	2.15	67	2.46	72
Indonesia	26,443	1.79	39	4.38	67	3.80	67
Bangladesh	18,318	1.29	79	2.80	20	1.97	71
Thailand	16,500	2.25	55	4.89	55	2.96	25
Vietnam	10,468	1.71	n.a.	1.13	n.a.	-0.05	n.a.
Burma	9,940	4.18	35	1.02	75	3.0[illegible]	68
Korea, Republic of	7,607	4.81	69	2.11	87	4.[illegible]7	87
Philippines	7,272	3.89	24	4.89	76	5.39	85
Pakistan	4,893	3.00	19	7.24	72	4.95	4
Taiwan	3,258	3.99	100	1.80	100	0.40	100
Nepal[b]	2,027	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Malaysia	1,942	3.93	45	5.10	29	2.59	-26[c]
Sri Lanka	1,885	5.65	0	4.25	62	4.99	4
Asia	347,115	1.62	60	1.62	62	1.73	64

[a]Calculated from 5-year averages centered on the years shown, except for the last 2 columns which use 2-year averages. [b]n.a. = data not available. [c]Yields declined over the period.

X_1, X_0, given price ratios P_2, P_1, P_0. This illustrates one of the limitations of price subsidization. If farmers are operating with X_2 level, it may relatively be inexpensive to subsidize to P_1 level and increase output from Y_2 to Y_1. But to get to Y_0 level, inputs have to be totally subsidized, and even then, the increased output from Y_1 to Y_0 is small.

The other side of the argument on price subsidies should, however, also be recognized. Many of the macroeconomic policies followed by governments depress the prices of agricultural products and increase the prices of agricultural inputs, especially relative to other economic sectors. These policies have an effect opposite to those discussed above -- they drive the use of inputs down. Government monopoly purchases of rice may have this effect if, at the same time, imports are controlled. In countries producing an exportable surplus, government control over exports or export taxes, like Thailand's rice premium, decrease production incentives.

Extension to close the gap

A second policy strategy that might be followed is to promote a greater effort to get proven rice production technologies adopted by farmers, and raise the yields of the lowest-yielding farmers to make them closer to those of the highest-yielding farmers.

Research on the constraint to high yields in farmers' fields, done in 6 countries between 1974 and 1977, demonstrated that yields could be increased by about 1 t/ha, but that in many cases it would not be to the farmers' economic advantage to use the high-input, maximum-yield technology that gave the yield increase (Table 6). Only at 3 of the 10 research sites was it possible to achieve a benefit-cost ratio of 1.4 or greater on the increased level of inputs needed to raise yields in the wet season. At the 7 other sites, even at those where yield increases were as high as 1.8 t/ha, the economic return was not attractive, on the average. The yield increases were highly variable within a given site and, therefore, risky, making it even more unlikely that farmers would use the high input levels.

Table 5. Percentage points of the annual compound growth rate in rice production attributed to irrigated area, nonirrigated area, yield increases from fertilizer, and residual yield increases, Asia, 1965-79.

Site	Period[a]	Average growth rate	Percentage points in growth rate attributable to[b]					
			Total area	Irrigated area	Nonirrigated area	Yield	Fertilizer	Residual
Bangladesh	1967-72	-0.1	0	0	0	-0.1	0.2	-0.3
	1972-77	2.8	0.8	0.2	0.6	2.0	0.5	1.5
Burma	1967-72	1.1	0.3	0.4	-0.1	0.8	0.2	0.6
	1972-77	2.5	0.7	0.3	0.4	1.8	0.3	1.5
India	1967-72	3.1	0.7	0.5	0.2	2.4	1.2	1.2
	1972-77	2.9	0.9	0.4	0.5	2.0	0.7	1.3
Indonesia	1967-72	4.8	1.4	1.9	-0.5	3.4	1.5	1.9
	1972-77	6.4	1.6	1.6	0	4.8	1.7	3.1
Korea, Republic of	1967-72	2.4	-0.3	1.3	-1.6	2.7	1.7	1.0
	1972-77	5.4	0.5	0.4	0.1	4.9	0.5	4.4
Malaysia (West)	1967-72	7.9	6.3	5.3	1.0	1.6	1.1	0.5
	1972-77	2.1	3.6	0.7	2.9	-1.5	-0.6	-0.9
Pakistan	1967-72	5.9	0.4	0.4	0	5.7	0.2	5.3
	1972-77	5.2	4.5	4.5	0	0.7	1.1	-0.4
Philippines	1967-72	3.1	0.6	0.6	0	2.5	1.9	0.6
	1972-77	5.4	1.3	0.6	0.7	4.1	0.5	3.6
Sri Lanka	1967-72	5.3	2.4	2.5	-0.1	2.9	3.4	-0.5
	1972-77	1.5	0.2	0.5	-0.3	1.3	-0.7	2.0
Taiwan	1967-72	-0.1	-0.8	0.9	-1.7	0.7	-2.6	3.3
	1972-77	1.0	0.3	0.2	0.1	0.7	3.5	-2.8
Thailand	1967-72	2.1	3.3	0.7	4.3	0.1	-1.3	-1.2
	1972-77	3.0	3.3	n.a.	n.a.	0.4	-0.7	-0.3

[a] Five-year averages centered on the years indicated, thus 1967 is the average of 1965-69, etc.
[b] n.a. = data not available.

In a detailed analysis of constraints data for Nueva Ecija, Philippines, the yields and practices of 25% of the experiments where farmers' treatments gave low yields were compared to those of the 25% of the experiments where farmers' treatments gave the highest yields (Fig. 2). In the wet season, the researcher's inputs raised yields substantially on only 1 out of 8 of the low-yield farms, and raised yields modestly on most of the high-yield farms. For the irrigated dry-season crop, the high inputs raised yields in almost every case. The low-yield farms applied significantly lower levels of fertilizer in both seasons and significantly lower levels of insecticide in the wet season (Table 7).

We estimated a functional relationship between the managed inputs and environmental factors, then used that relationship to explain the difference between the low- and high-yield farms (Mandac and Herdt 1979). The differences in input levels and their interactions accounted for only about 25% of the explained yield difference in the wet season and about 50% in the dry season (Fig. 3). Thus, a major part of the yield difference between groups was due to typhoons and differences in solar radiation, insects, and diseases -- factors beyond the farmers' control.

These data from research on constraints to high yields in farmers' fields suggest that there is relatively little scope for economically increasing yields through the more intensive application of known technologies, especially in the wet season. There appears to be somewhat more possibility in the dry season. That is, farmers rapidly and rather completely exploit technology that is appropriate and that gives higher profit than their existing technology.

Further support of the view that farmers are rapid adoptors of appropriate technology is suggested by the data on adoption of modern varieties, for example, the case of Indonesia. The first modern varieties were introduced in the late 1960s. By 1971-72, they and similar varieties were being grown on 25% of Indonesia's rice area. When serious brown planthopper outbreaks threatened Indonesia's crop in 1974, the government made resistant varieties available. They rapidly spread to cover 25% of the area by 1976. When a new brown planthopper biotype threatened the crop, even newer varieties were released and covered 50% of the area within 3 years (Bernsten et al 1982).

The fact that farmers are observed to effectively use and rapidly adopt profitable available technology indicates that we cannot expect a great jump in production to accompany new programs of extension. It suggests that for most conditions, there is only a small unexploited yield gap that

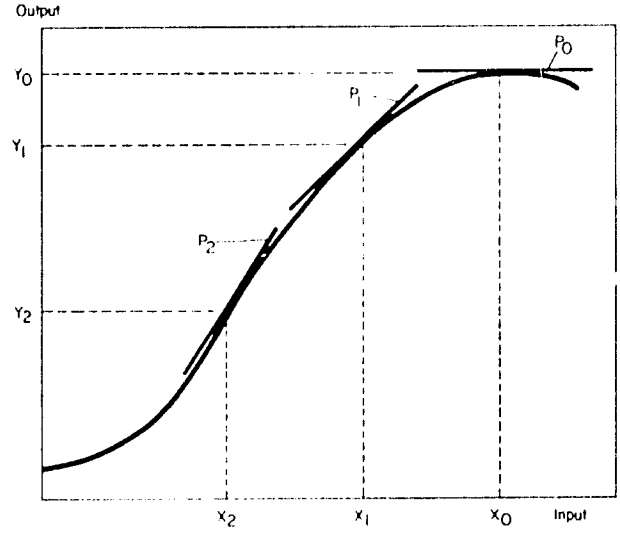


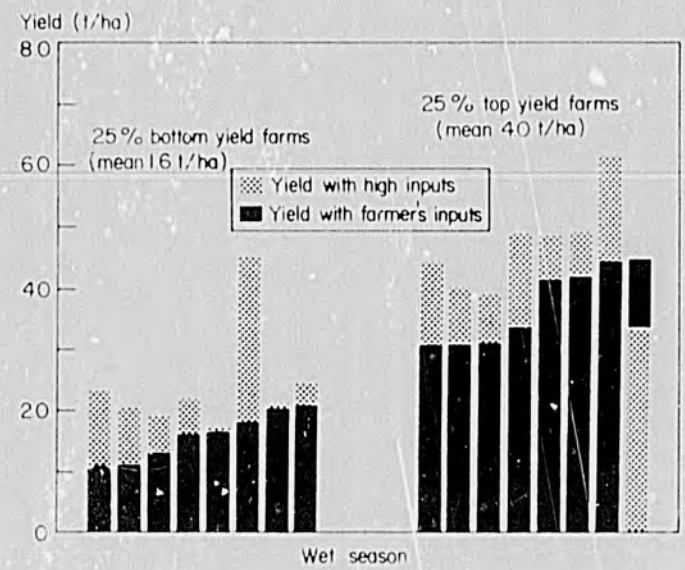
Fig. 1. Relationship between price ratios of input and output and optimal level of input application.

Table 6. Economic comparisons of farmers' and high levels of test inputs in constraints experiments in farmers' fields, 1974-77 wet seasons.

Site	Trials (no.)	Yield gap (t/ha)	Increased output value ($/ha)	Increased input cost (US$/ha)	Increased profit (US$/ha)	B:C on increased inputs
Joydebpur, Bangladesh	52	0.91	143	39	104	3.7
Subang, Indonesia	8	1.00	122	66	56	1.9
Nueva Ecija, Philippines	29	1.10	143	104	39	1.4
Dry zone, Sri Lanka	17	0.89	168	140	28	1.2
Laguna, Philippines	41	1.77	209	183	26	1.1
Iloilo, Philippines	23	1.30	156	151	5	1.0
Central Plain, Thailand	18	1.20	134	160	-25	0.8
Taiwan, China	9	0.40	130	161	-31	0.8
Yogyakarta, Indonesia	14	0.39	56	88	-32	0.6
Camarines Sur, Philippines	27	0.51	61	136	-75	0.5

Source: Herdt 1979.

can be tapped by intensified excension education. The critical role of extension will increase, however, as technology becomes more complex and more difficult to understand. Farmers need to understand why they are being advised to follow certain practices and to be able to judge the value of that advice for their own conditions.



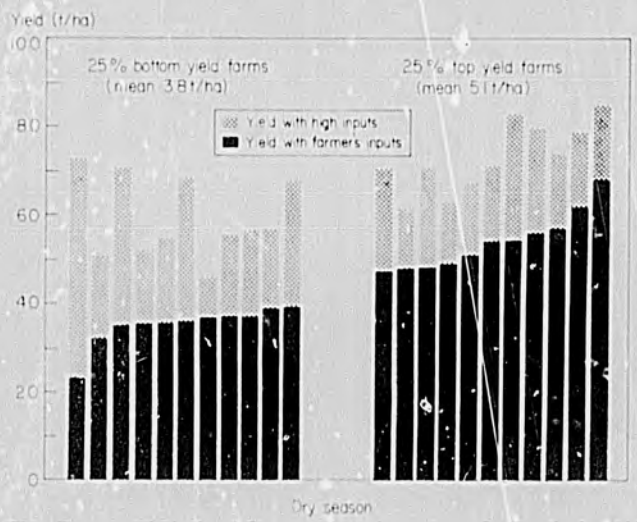


Fig. 2. High- and low-yield farms, by season, Nueva Ecija, 1974-77. Figures in parentheses are mean yields with farmer's inputs.

Research to raise the possible yield

The limitations associated with price subsidies and extension suggest the critical need for research to raise the level of possible yields. The evidence of the past 20 years supports the importance of this role. It was after the development of fertilizer-responsive rice varieties that yield increases became the main source of output growth. Insect-resistant varieties made it possible to sustain the gains made through the introduction of fertilizer-responsive varieties. The challenge to rice researchers now is to anticipate the conditions that will prevail by the end of the 1980s so that appropriate new technology to meet the biological, physical, social, and economic constraints of the future will be available when needed.

Table 7. Comparison of mean farmer's input levels, soil factors, climatic factors, and pest incidence between low- and high-yielding farms on which yield constraints experiments were run, Nueva Ecija, Philippines, 1974-77 (Source: Mandac and Herdt 1979).

Factor	Wet season[a]		Dry season[a]	
	Low yield	High yield	Low yield	High yield
$N + P_2O_5 + K_2O$ (kg/ha)	42	81	90	147*
Insect control (₱/ha)	50	133	136	171
Weed control (₱/ha)	35	56	144	115
Seedling age (days)	43	37	31	29*
Seasonal rainfall (mm)	100	59	89	14*
Solar radiation (kcal/cm^2) [b]	11	18*	22	23
Typhoon (av no.)[c]	4	1*	1*	0*
Drought, late (meq/100 g)	2	5	0	2
Soil CEC (meq/100 g)[d]	32	42*	30	31
Stem borer[e]	5	5	11	7*
Bacterial leaf blight[f]	2	0*	0	0
Bacterial leaf streak	5	0*	0	0

[a] The asterisks show significant differences between the low- and high-yield groups within a season, at the 5% level, using a t-test. [b] Measured 45 days before harvest. [c] Crops were at the vegetative stage when the typhoons struck. Even during the dry seasons, typhoons caused the large difference in rainfall between the low- and the high-yield classes. [d] Other soil factors that were measured but were not significantly different were % clay, % sand, % silt, pH, total N, organic matter, extractable P, and exchangeable K. [e] Other insects that were monitored and found to be not significantly different between groups were the whorl maggot, brown planthopper, green leafhopper, and leaffolder. [f] Other diseases monitored and found to be not significantly different between groups were tungro, grassy stunt, and sheath blight.

Price policy and extension are sometimes suggested as the answers to socioeconomic constraints, whereas research is viewed as the solution to biological and physical constraints. However, one cannot really separate economic from biological constraints. Research provides the technology that makes previously uneconomic production profitable. This can be illustrated by Figure 4.

In region I of the diagram, research constraints are overriding. There the benefit-cost ratio (B:C) on inputs used in rice production is below zero -- there is no economically suitable technology, so

additional research is needed to discover a suitable technology. Of course, there is no guarantee that such a suitable technology will be discovered, but in the area near the boundary of region I and II, there may be a possibility.

In region II, technology exists but is not adopted. Apparently, the technology has a positive B:C because it is being recommended for adoption but for some reason is not accepted by many farmers. In region III, the technology is adopted, perhaps on a wide scale, but yields are still low. In this region, the B:C is apparently high enough to generate adoption, but the resulting yields are disappointing to researchers or extension workers.

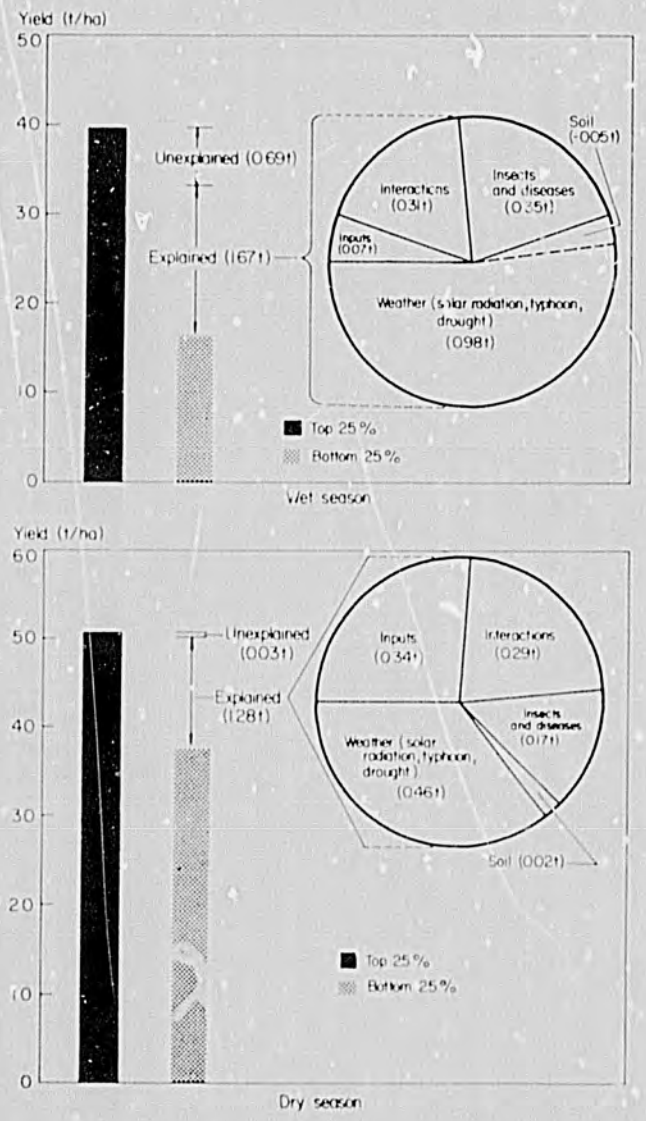


Fig. 3. Accounting for differences between low- and high-yield farms, wet and dry seasons, Nueva Ecija, Philippines.

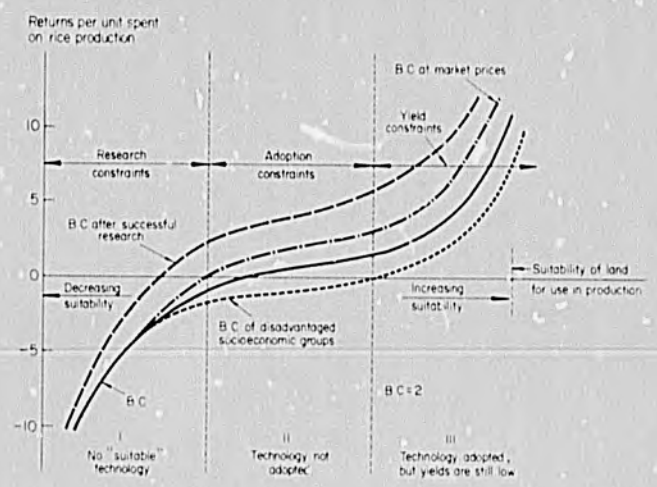


Fig. 4. Relationship of three types of constraints to the suitability of land for rice production and the benefit-cost ratio (B:C) obtained from inputs used in rice production.

One may view successful research as the process of shifting the B:C function upward so that in a given situation returns are increased. This will, at the same time, change the range of research, adoption, and yield constraints. Market imperfections that may bear more on particular socioeconomic groups may be viewed as operating so as to reduce B:C. Thus, more attractive prices can substitute for new technology and vice versa to a limited extent, but the major gains from research come from devising new technologies that exploit relatively cheap inputs to change the production systems and shift upward the returns per unit expenditure on production (or keep returns from falling).

PROJECTING INPUT AVAILABILITY AND PRICES

The main inputs used in rice production are land, labor, water, fertilizer, pesticides, and animal or mechanical power. Increased rice production can be achieved either by increasing all resources at the same rate or by selectively increasing the use of some resources more rapidly than others. If certain resources are expected to become scarce more rapidly than others, i.e. increase in relative price, it is obviously preferable to increase their use less rapidly than resources that will become more abundant.

Labor

The number of laborers will swell as populations continue to grow in developing Asian countries. The availability of agricultural laborers depends on the growth rate of nonagricultural employment and the proportion of the labor force in the agricultural and nonagricultural sectors. One can express the relationship mathematically by noting that the growth rate of the total labor force (Z)

is a weighted average of the rate in the two sectors: $Z = ax + (1-a)y$. Defining X as the growth rate in nonagriculture, and y as the growth rate in agriculture, $y = (Z - ax)/1-a$.

Table 8 shows data on the labor force for some Asian countries. The agricultural labor force in all the developing countries of the region will continue to grow between 1 and 1.9%/year. Only Korea, Taiwan, and Japan, which have a major part of their labor force in the nonagricultural sector and which have rapid growth in the demand for nonagricultural labor, will have a decrease in the labor force in agriculture.

Land

The data seen earlier in Table 5 showed that land provided only one-third of the rice output growth in the past few decades. It will likely provide even less in the future, because the unused lands of Asia either are remote from population centers, require large investments for settlement, or have problem soils for which productive agricultural techniques are unknown. Of course, the problem soils provide an opportunity for research to create valuable resources out of less valuable ones. If inexpensive techniques of cultivation, or new varieties that can exploit such areas, can be developed, then they will add to the available supply of land.

One other source of available, inexpensive land is the land presently used to grow only one crop of rice per year. With long-duration rice varieties only one crop could be grown because of moisture limitations. With modern short-duration varieties, however, another crop of rice or a nonrice crop can be grown with the same length of growing season. Technologies that permit greater cropping intensity will effectively increase the supply of land, but the physical availability of land is likely to remain nearly fixed.

Energy, fertilizer, and power

Most farmers in developing countries use relatively small amounts of fossil fuel energy directly in production. In some countries there has been a recent turn toward the use of machinery for land preparation and for threshing but this is still the exception rather than the rule. However, energy is a major input in fertilizer production, and as shown above, fertilizer has been an important source of rice output growth in the 1970s. Energy costs, especially those of crude oil, are expected to rapidly increase in the foreseeable future.

It is not clear how much the rising costs of energy will drive up fertilizer prices. This is because many of the new urea plants use natural gas that would otherwise be burned at the well head. Thus, world prices of urea are projected by the World Bank unit that makes such projections (personal communication, World Bank) to increase more slowly than rice, and much more slowly than crude soil. However, there is no general agreement on this, and fertilizer prices may increase more rapidly than projected.

It is clear that fertilizer will have to be an important source of future rice output growth, and any increased efficiency that can be achieved in its use will be important.

Water

Control of water through irrigation has provided a major source of rice output growth over the past several decades. Irrigation and drainage improve yields and extend the area on which rice production can be sustained. The modern rice technology developed over the past 15 years is more productive in the dry season with irrigation than in the wet season with rainfall. Irrigation has been identified as a major source of future growth in rice production (Colombo et al 1978).

Table 8. Growth rates of the total labor force, its nonagricultural portion, and the resulting residual rate of growth in the agricultural labor force, Asia, 1970-2000.

Site	Growth rate of labor force 1970-77	Growth rate of labor force 1977-2000	Growth rate of nonagricultural force[a] 1970-75	% of force in nonagriculture 1977	Resulting growth in agricultural force 1977-2000
Thailand	2.5	2.3	3.5	23	1.94
Pakistan	2.4	2.8	4.1	42	1.86
Philippines	2.1	2.6	3.5	49	1.74
Bangladesh	2.3	2.7	6.3	22	1.68
Burma	1.4	1.9	3.8	45	1.46
India	1.7	1.9	3.1	27	1.46
Indonesia	2.0	1.9	3.3	40	0.97
Malaysia	3.6	3.0	4.8	56	0.71
Korea, Republic of	2.9	1.9	5.4	55	-2.38
Taiwan	1.9	1.6	4.4	66	-3.84
Japan	1.3	0.8	2.4	86	-9.03

[a] Growth rate in urban population used as a proxy. Calculated from data in IBRD (1979).

The data showing sources of output growth do not fully reveal the role of dry season yields that seem to have contributed significantly to the average yield increases obtained in many countries. In Malaysia, yields of dry season rice have increased from below those of the main-season crop and are now above those of the main-season crop (Fig. 5). The same is true in the Philippines (Fig. 6). In Bangladesh and eastern India, the dry season crop produced significantly higher yields than the main-season crop. Research supports the same finding. At IRRI and many other research stations dry season yields are generally higher than wet season yields.

The cost of water control is likely to become one of the most limiting factors to increasing rice production in the future because irrigation is extremely energy intensive, and energy costs may rise sharply. Irrigation can be provided through construction of river diversion or high dam storage systems that utilize gravity to deliver the water, or through pumps that lift water from deep wells or rivers and creeks. Construction of irrigation systems uses labor and capital. Capital takes the form of tractors (which consume large amounts of fuel), cement, steel, sand and gravel that is washed and moved using trucks, and other energy-intensive inputs. The pumps and water conveyance systems are likewise energy intensive.

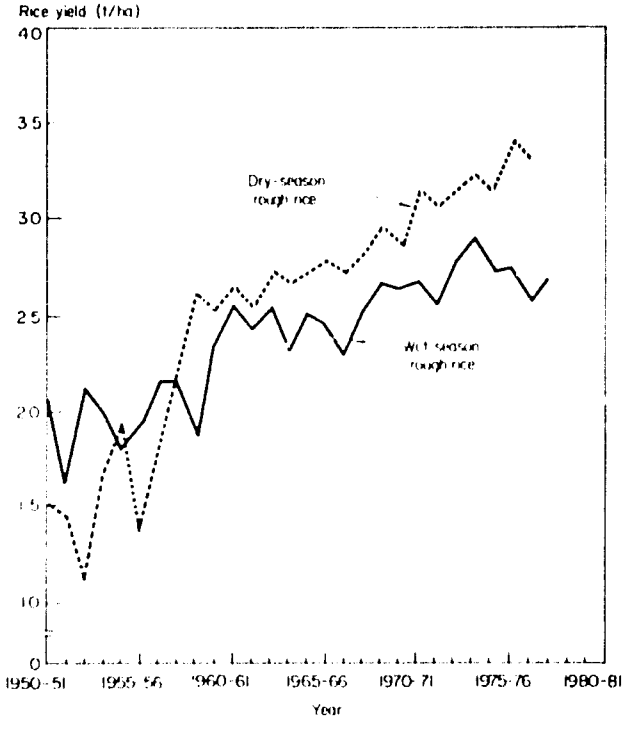


Fig. 5. Dry and wet season rice yields in West Malaysia, 1950-51 to 1977-78.

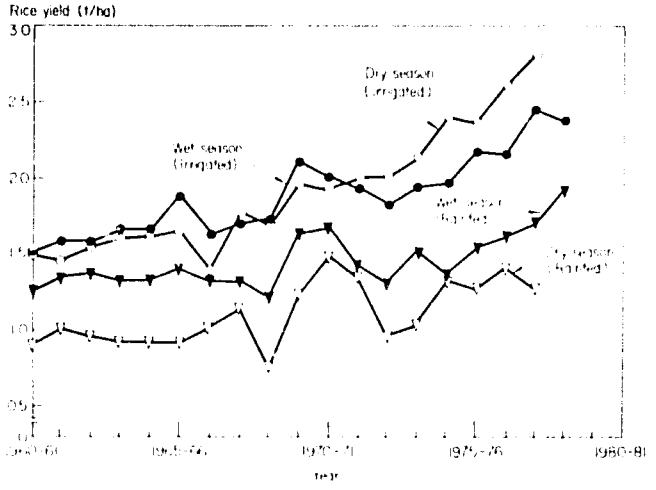


Fig. 6. Rice yield on irrigated and rainfed farms, Philippines, 1960-61 to 1978-79.

A study of 10 irrigation systems in the Philippines contrasted the cost structure of gravity and pump systems (Table 9). Gravity and surface-pump systems had much lower investment costs than deep well pumps, but the ratio of labor to energy used in their construction was similar. The pump systems, however, used much higher levels of energy for operations -- up to 20 times the energy/ha of gravity systems. Their total cost of operation, when computed on an annual basis that included both investment and operations costs, showed shallow pump systems nearly three times as expensive as gravity systems, and deep well pumps twice as expensive as shallow lift pumps.

In his study of irrigation systems in Malaysia, Taylor (1982) found that the construction cost, as well as operation and maintenance cost, of pump systems was higher than that of gravity systems, although the differences were smaller than those in Table 9. He did not allocate costs to their labor and capital components.

The impact of future price increases on irrigation costs can be illustrated as follows. Assume energy costs increase 150% between 1978 and 1985. Assume capital costs increase at half that rate. It is likely that rice prices and labor prices will increase at about the same rate, but more slowly than capital. If this happens, the annual cost per hectare of gravity irrigation will increase from US$41 to US$71 whereas the annual cost of shallow pump irrigation will increase from US$114 to US$225/ha and the annual cost of deep well pumps will be double that at around US$450/ha. The latter will amount to 56% of the value of a 4 t/ha rice crop!

Clearly, farmers will be unable to pay such costs. Unless these expenses are subsidized by governments, farmers will use irrigation to grow higher-value crops or seek ways to economize on the costs of water for rice production.

SYSTEMS APPROPRIATE TO LIKELY FUTURE CONSTRAINTS

Population and agricultural labor force will continue to grow in most Asian countries. Energy costs will continue to rise. Land will not become more plentiful.

Some implications of these likely changes may be drawn by considering the key functions in rice production (Fig. 7). It is obviously essential that the crop be established, that it grow, and that it be harvested. Farmers do crop establishment and harvest, and seek to control fertility, water, weeds, and insects or diseases. The sun provides the energy to make the plant system function. Certain activities contribute to several functions. Regardless of the future course of events, these functions will have to continue to be performed if rice is to be produced.

There are alternative ways in which these various functions can be performed. Examination of data on costs and labor used for rice production in 3 countries shows that human labor inputs range from 87 days/ha in the Philippines to 278 days/ha in Bangladesh (Table 10). Animal labor is much higher in Bangladesh than in the Philippines. Machinery is used for land preparation and postharvest operations in Central Luzon, but not in Bangladesh. Fertility control is obtained by chemical fertilizer in Central Luzon, but animal manures are used in Bangladesh. Inputs of chemical fertilizer, measured in kg of rough rice[2]/ha, are highest in Malaysia. Inputs for water control are also highest there. Farmers studied in the Philippines and Malaysia used about the same amount of capital for insect control, about three times as much as in Bangladesh.

Two generalizations can be derived from these data:

1. Land preparation, fertility control, and water control are the three largest users of inputs in all systems.

2. Where machinery is not used in land preparation and harvesting, a large amount of human and animal labor is used. This is explained in part by the relative factor prices -- labor is relatively inexpensive in Bangladesh and relatively expensive in the Philippines.

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[2]/No adequate direct intercountry comparisons of capital use is possible because each country uses different currency and their exchange rates are set by government policies. The solution adopted here is to express input use in terms of kg of rough rice equivalent per hectare by dividing the monetary value by the rough rice price. This measure also reflects government policies on those rice prices, but it is directly comparable across countries.

One cannot, however, claim that any of the systems uses significantly lower levels of total inputs than any other system. Indeed, the Philippine and Bangladesh systems seem to illustrate two extremes of conventional technology. One uses low energy and high human time and the other higher energy and low human time. A true alternative would use less of both energy and time to produce the same output.

Clearly, finding such an alternate technology is not a simple or obvious process of combining available resources in a slightly different pattern than now used. The future will bring radically higher costs for energy-intensive inputs, and I believe radically new systems of rice production must be developed to reduce the use of such inputs. Such systems will be developed only if there is imaginative thinking about all the functions involved in production -- they will not result by experimenting with slight modifications of existing systems. There is need to examine and understand why each operation is carried out, and then devise alternative ways to achieve the same result, as opposed to modified ways to execute a current operation.

Land preparation

The activities involved in land preparation absorb a major part of the labor and power (energy) inputs used in production. Land preparation provides a suitable transplanting medium, promotes the decomposition of organic matter, promotes water conservation through minimizing percolation, and helps control weeds. Are there viable alternatives to the land preparation methods now in widespread use? Can rice be established with zero tillage? If so, what alternatives to control weeds are available? Many countries have had experience with direct seeding of rice, but this has been done largely on puddled soil -- a practice that saves little of the inputs required for conventional crop establishment. Radically new systems are needed to reduce the level of inputs for this operation.

Water control

Even with current energy prices water control absorbs a large share of costs. As researchers seek ways to productively utilize land during the dry season the high cost of water will become an increasing constraint. In current systems, water serves three functions -- it aids in land preparation, it helps control weeds, and it helps rice plants grow well and produce high and stable yields. To what extent can other inputs be substituted for water? Can we develop rices that will give high yields under less than saturated soil moisture conditions? How much water and cost will be saved if rice fields are allowed to dry out during the cropping season?

Evidence from the 1974, 1975, 1976, and 1977 International Upland Rice Yield Nursery shows that drought-resistant rices can, indeed, be developed.

Table 9. Investment and operation and maintenance costs attributable to labor and energy for 3 types of irrigation in 10 systems in the Philippines (Source: Moya et al 1980).

Items	Labor and overhead (US$000)	Direct energy (US$000)	Material and machinery (US$000)	Cost (US$)/ha Labor	Energy[a]	Total
			Investment costs			
Gravity systems (4)	191.07	[b]	329.47	195.87	337.87	533.74
Surface pump systems (3)	83.20	[b]	111.60	187.87	252.00	439.87
Deep well pumps (3)	101.33	[b]	137.87	645.33	878.00	1523.33
			Annual operations and maintenance			
Gravity systems	3.87[c]	0.53	2.93	4.00	3.47	7.47
Surface pump systems	9.60[c]	21.07	2.40	21.73	47.47	69.20
Deep well pumps	4.00	10.80	1.07	25.47	75.33	100.80
			Annualized total cost[d]			
Gravity systems	15.87	0.53	23.73	16.27	24.93	41.20
Surface pump systems	16.93	21.07	12.13	38.53	75.47	114.00
Deep well pumps	12.00	10.80	11.87	76.40	144.40	220.80

[a] Direct energy and materials and machinery. [b] Included under materials and machinery. [c] Direct labor cost plus 50% of "repairs" costs. [d] Computed assuming 6% interest, a 60-year life for dams, 30-year life for canals, and 15-year life for pumps and engines.

Table 10. Labor and capital inputs used per hectare in rice production in the Philippines, Malaysia, and Bangladesh, 1979.

	Land preparation	Crop establishment	Fertility control	Water control	Weed control	Insect control	Harvest, postharvest
			Central Luzon, Philippines[a]				
Days labor	19	22	2	10	6	2	26
Days animals	6	1	0	0	0	0	0
Machinery (kg rough rice)	430	0	0	41	0	0	88
Chemicals (kg rough rice)	0	0	262	0	25	61	0
Seed (kg rough rice)	0	83	0	0	0	0	0
			West Malaysia[b]				
Days labor	16	55	3	10	20	5	80
Days animals[c]	4	0	0	0	0	0	0
Machinery (kg rough rice)	251	0	0	313[d]	0	0	0
Chemicals (kg rough rice)	0	0	330	0	0	54	0
Seed (kg rough rice)	0	46	0	0	0	0	0
			Bangladesh[e]				
Days labor	52	76	10	2	62	2	74
Days animals	44	0	17[f]	0	0	0	0
Machinery (kg rough rice)	0	0	0	47	0	0	0
Chemicals (kg rough rice)	0	0	59	0	0	9	0
Seed (kg rough rice)	0	48	0	0	0	0	0

[a] Source: IRRI 1979 wet season loop survey. [b] Source: Taylor (1982). [c] Attributed 80% of land preparation costs to machinery. [d] 5% of construction cost plus operation and maintenance. [e] Source: Bangladesh Ministry of Agriculture and Forests, Agro-economic Research Unit (1980). [f] Value of animal manures converted to equivalent value of workdays.

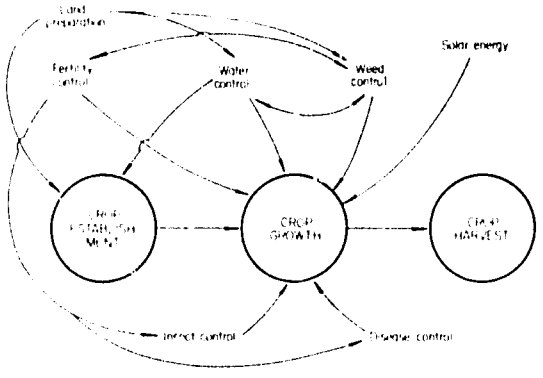

Fig. 7. Key functions in rice production.

When yields of rices in those trials are plotted against the moisture index (I_m) or the long-term average rainfall of each site, a clear pattern emerges (Fig. 8). The average yields of all entries (Y) is positively related to moisture availability, as would be expected. The yield of the local check (LC) is almost unrelated to moisture stress, i.e. local checks are highly stable where there is drought. The yield of the two highest yielding varieties (Y') at each site responds positively to added water, but also outperforms the local checks of all levels of moisture, demonstrating that better performing rices can be developed for droughty areas (O'Toole and Novero, unpubl.).

Research on the impact of drought at the time of flowering provides convincing evidence of the impact severe water stress has at that time (Cruz et al 1981). Given that the most economically efficient use of water on rice is at the time of flowering, there is a premium on the ability of groups of farmers to organize their rice fields so that all the fields served by a single irrigation turnout flowered within a short time. Thus, research like that being conducted by IRRI's Irrigation Water Management Department to tell us how to efficiently organize farmers and the techniques that can be used to get them to organize themselves should have a high pay-off (IRRI 1980b).

Weed control

Input cost data seem to indicate that relatively few inputs are used in weed control. However, when one recognizes that a major function of both land preparation and water is to control weeds it becomes apparent that a large fraction of total resources are used for this purpose.

Can lower-cost, more effective weed control systems be developed? Suppose chemical weed control techniques that would reduce the use of energy for irrigation by half can be developed. Suppose further that the costs of water and weed control chemicals will in the future more fully reflect their energy input. Table 11 illustrates the result of a technology that would use one-half the water and five times the chemicals used in conventional systems where weed control is accomplished by keeping standing water in wetland rice fields. The energy used in the present system is about twice as much as the amount projected in the possible alternative. The main problem is the development of a weed control system adequate to deal with the weeds in the absence of standing water. This is a major challenge for technology development.

Fertility control

Fertility control makes up a large fraction of current rice production costs. It is the one input that can be easily increased through direct policy action, and rates of fertilizer application in most rice producing countries are still far below the maximum profitable level that might be achieved with various improvements in management. On the other hand, the price of fertilizer is likely to increase rapidly in the future.

With present techniques a considerable fraction of the fertilizer applied to rice is lost and not used by the rice plant. The prodectivity of fertilizer, especially urea, can be improved by proper placement and timing of applications within conventional puddled soil systems but practical methods to place the fertilizer beneath the soil surface still must be developed. What would happen to fertilizer productivity in nonpuddled irrigated rice? Would incorporation of topdressed fertilizer improve its productivity in a nonpuddled system? Do farmers apply their fertilizer at a later date than agronomists believe is optimal because of their desire to slow weed growth?

Research on alternatives to ordinary prilled urea has been going on for some time, organized under the INSFFER network. A summary of the results of the first 3 years' data from that work indicates that although there is some promise that sulfur-coated urea or urea supergranules can increase fertilizer efficiency, there is great variability in the results, particularly in the wet season (Table 12). More research on identifying situations in which such materials are worthwhile and on the reasons for observed variability is needed.

Alternative biological sources of nitrogen and other plant nutrients should be investigated with the recognition that only under exceptional conditions do Asia's rice farmers have 5 cm of standing water in their fields throughout the season. It must also be recognized that most rice fields dry out completely at least once a season. Can legumes provide an appreciable amount of fixed nitrogen in such fields? How can such contributions be maximized?

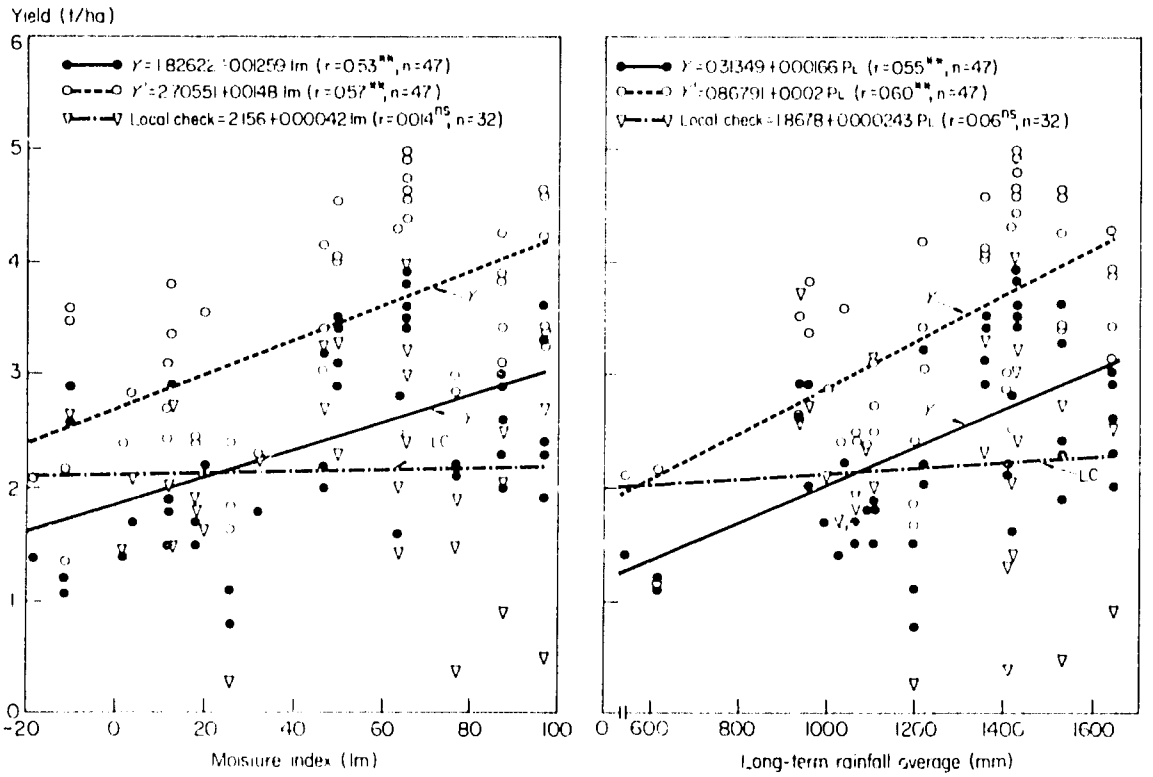

Fig. 8. Relationship of yield of International Upland Rice Yield Nursery (IURYN) entries 1974, 1975, 1976, and 1977 and Thornthwaite moisture index (Carter and Mathers 1966) and long-term rainfall (Thornthwaite Associates 1963) for the growing season at each site. Y = mean yield of all varieties (n = 25) at a site. Y' = mean of two highest-yielding varieties at a site; local check = locally adapted variety grown with same agronomic practices at IURYN entries (O'Toole and Novero, unpublished).

Table 11. Calculated energy tradeoff between water and herbicides in wetland rice production (coefficients from Kuether and Duff).

	Present system	Possible alternative
	Inputs	
Water pumped (m^3)[a/]	3000	1500
Fuel for pumping (liters)	150	75
Hand weeding (days)	10	5
Herbicide (kg a.i.)	1	5
Herbicide application (no.)	1	5
	Energy equivalents	
Fuel energy	$5654 \text{ J} \times 10^6$	$2827 \text{ J} \times 10^6$
Energy embodied in pump	$941 \text{ J} \times 10^6$	$470 \text{ J} \times 10^6$
Energy embodied in herbicide	$110 \text{ J} \times 10^6$	$550 \text{ J} \times 10^6$
Total fossil	$6705 \text{ J} \times 10^6$	$3847 \text{ J} \times 10^6$

a/ Morooka et al (1979) show 2,000-6,000 m^3/ha per crop used to supplement rainfall at Los Baños; 17 m^3 water pumped/liter of fuel. Kuether and Duff (1979) show much lower level of fuel used per hectare. This table uses an intermediate level.

Table 12. Frequency distribution of differential response of sulfur-coated urea (SCU) and urea supergranule (USG) relative to prilled urea, two N rates, by season, in INSFFER trials, 1975-79.

Yield relative to prilled urea	Cases (no.)				Frequency (%) of cases			
	Low N rate		Medium N rate		Low N rate		Medium N rate	
	SCU	USG	SCU	USG	SCU	USG	SCU	USG
	Wet seasons (n = 91)							
Better	17	21	37	27	19	23	41	30
No difference	72	69	52	61	79	76	57	67
Worse	2	1	2	3	2	1	2	3
	Dry seasons (n = 45)							
Better	19	11	20	16	42	24	45	36
No difference	24	31	24	28	53	69	53	62
Worse	2	3	1	1	5	7	2	2

Source: De Datta and Gomez (1981).

Insect and disease control

Researchers concerned with insect and disease control may have an advantage over those concerned with other problems because there is a great diversity of methods to control these pests. Chemical control, which requires high energy inputs, is only one option. Integrated pest control, which uses biological conservation of natural enemies, host resistance, cultural control, and other innovations has much promise. Still, the research job needed to design optimal insect pest management strategies is immense.

Consider the issue of synchronized planting, a cornerstone of almost any prescription for insect control. In an experiment comparing weekly planting of rice grown without insecticides to the growing and harvesting of rice twice a year, the continuous planting system had no greater insect problem than the conventional field (Fig. 9). The continuous production system had higher levels of natural enemies that apparently kept the insects in check (IRRI 1980a).

There are many unanswered questions in the pest control area. Why do farmers, even those in advanced areas, consistently underapply insecticides -- in terms of recommended levels of active ingredients per hectare -- (Marciano et al 1981)? Would the use of ultralow-volume sprays be practical? Are insecticides reasonable and practical for use by most Asian farmers? Would systems that minimize standing water in rice fields encourage or discourage the buildup of insects and diseases? What is the future for products developed from botanical sources? What kinds of manufacturing and sales systems are practical for such products?

Machinery and land intensification

In light of the likely increase in the labor-land ratio, it seems that technologies to more effectively utilize more labor per hectare would have an advantage in most developing Asian countries. Such technologies may be grouped in two classes:

- those that use more labor by intensifying its use with existing cropping patterns; and
- those that absorb more labor by increasing the number of crops grown per year.

One seems to be faced with the dilemma that certain farm machinery may be needed to increase the crops grown per year but at the same time it may reduce the labor used per crop. Research can help identify which effect certain types of machinery actually have. For example, in Central Luzon, Philippines, cropping intensities have increased considerably over the past 15 years. The use of tractors for land preparation has also increased, whereas the use of threshers has fluctuated. Examination of the data in Table 13 shows that the use of tractors is positively associated with increased land use intensity whereas the use of threshers is negatively associated with increased intensity. The use of threshers has increased rapidly in certain places in Iloilo where double-cropping of rice has also increased. Research in the area shows, however, that 63% of the rainfed farms with threshers did not increase their cropping intensity after adopting threshers. In addition, farmers with threshers and two crops/year had more than a week longer turnaround time than farmers who used traditional threshing techniques (Juarez and Duff 1980).

Table 13. Chi-square test of independence between frequency of double-cropping, method of threshing, and method of land preparation, farms in IRRI's Central Luzon loop survey for 1966, 1970, 1974, and 1977.

Technology	Observed % of farms in each category and chi-square statistics							
	1966		1970		1974		1979	
	Single cropped	Double-cropped	Single cropped	Double-cropped	Single cropped	Double-cropped	Single cropped	Double-cropped
				Threshing method				
Manual (%)[a]	7	16	12	18	26	24	12	37
Machine (%)[a]	75	2	67	3	38	12	39	12
Chi-square [b]	53.8**		39.2**		6.2*		27.0*	
				Land preparation power				
Animal (%)	75	12	47	18	40	12	24	9
Tractor (%)	7	7	32	3	24	24	23	43
Chi-square	9.4**		2.9^{ns}		3.7^{ns}		27.4**	

[a] Threshing method for first crop. [b] **The hypothesis that the two factors are distributed independently is rejected at the .01 level; * at the .05 level.

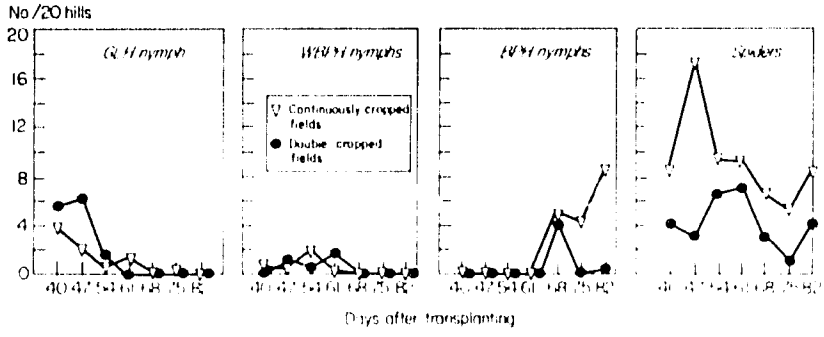

Fig. 9. Population fluctuations of green leafhoppers (GLH), whitebacked planthoppers (WBPH), brown planthoppers (BPH), and spiders in continuously cropped and double-cropped fields of IET3877. IRRI, 1979 wet season (IRRI 1980c).

Some machinery can be used to do tasks that could not otherwise be done -- for example the simple IITA rotary punch planter appears to be adapted to direct seeding of grain legumes following rice harvest without the need for land preparation. Small wind-powered irrigation pumps that will provide one or two supplemental irrigations to dryland crops following rice are another example of nonlabor-displacing machinery that requires more developmental research.

RICE RESEARCH FOR THE 1980s

Effective rice research for the 1980s will have to face up to the realities of a world where energy is much more expensive than in the past. The strategy fertilize and irrigate, which worked in the 1960s and 1970s, will be difficult in the 1980s. Irrigation and fertilizer will continue to be important for high yields, but research will contribute to farm and national welfare in a way appropriate for the future if it seeks to:

- Develop more efficient ways to use irrigation water and fertilizer to enable farmers to continue to reap the high yields now possible; and
- Continue seeking solutions to the insect and disease problems that accompany high-yielding, intensive production practices.

In addition, to meet the challenges for areas still not adequately served by new technology, research must:

- Pay much more attention to increasing wet season yields, especially in rainfed areas like eastern India, northeastern Thailand, the aus and aman crops of Bangladesh, and the main-season crop of Malaysia.
- Develop fertility sources that provide adequate nutrients without high inputs of fossil fuel energy.
- Develop component technologies for a broad range of radically different systems of production.
- Evaluate technologies much more within multifactor experimental designs -- e.g. tillage vs herbicides vs water vs weeding vs variety.
- Recognize that, for most developing Asian countries, substitutes for land are vitally important, but substitutes for labor result in a transfer of earnings from one class to another without increased output.
- Develop ways to understand the social systems that control the allocation of water and affect the possibilities for synchronized rice production.

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