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THE PROSPECTS FOR ASIAN RICE PRODUCTION

The developing countries of Asia contain more than two billion people, approximately one-half of the world's population. Assuring adequate food for these people is a priority goal of the governments of Asia and of others concerned about the region. This paper examines the prospects for meeting 1985 food requirements through increased rice production.

Chart 1 shows the apparent per capita consumption of calories in two recent periods for 15 countries in Asia.[1] Because data on stocks are not available for all countries, the average of 1963-67 is compared to the average of 1971-75. The comparison shows relatively little change in consumption levels in most countries over the eight-year period. Cereals are the principal source of food calories in most of the countries, but are less important in Sri Lanka, Malaysia, and Taiwan (Chart 1). Rice contributes an appreciable fraction of total calories in all countries and makes up an especially large portion in Bangladesh, Burma, Thailand, Laos, Cambodia, and Vietnam.

Apparent per capita food availability of approximately 2,000 calories per capita is not far below the Food and Agriculture Organization of the United Nations (FAO) estimated requirements of 2,200 for Asia. However, such a comparison underestimates the seriousness of future problems because population is expected to grow rapidly and because the distribution of food is skewed, much as is the distribution of income. Hence, a large proportion of low income Asian households is likely to have levels of food intake far below the national average. While this paper is concerned principally with ways to increase production, particularly of rice, the solution to the food problem in most countries lies in a proper combination of production and distribution programs.

SOURCES OF OUTPUT GROWTH OF RICE IN ASIA

Agricultural output can be increased through the expansion of cultivated area or through an increase in the productivity of existing land. In South and Southeast Asia prior to 1960, the expansion of land area provided the principal

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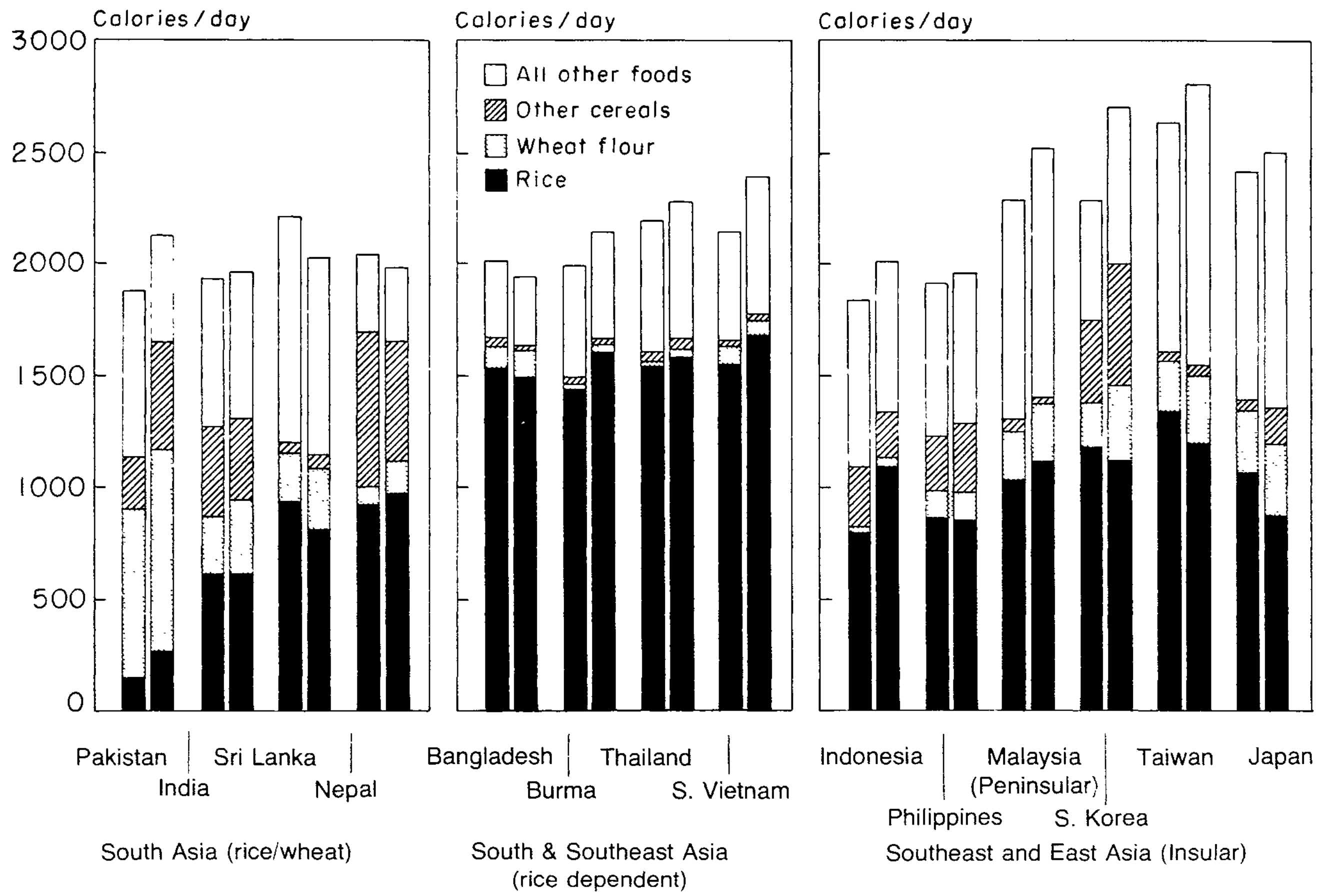
[1] The data in this section are from materials prepared by Randolph Barker and Bruce F. Johnston for the Second Asian Agricultural Survey of the Asian Development Bank.

CHART 1.—APPARENT PER CAPITA DAILY CALORIE CONSUMPTION, 1963-67 AND 1971-75



source of output growth. New lands were opened up at a pace roughly in keeping with the growth of the agricultural labor force.

The gradual exhaustion of idle land and closing of the land frontier after 1960—more pronounced for rice than for upland crops—necessitated a shift toward increased double cropping and the use of modern yield-increasing inputs. The speed with which this transition can be effected in the future will determine the degree to which output can keep pace with population growth and generate the food surpluses needed for agricultural development. In this section, the changes in production, area, and yield of rice over the past decades are examined and the contribution of increased fertilizer and irrigation development to output growth is measured. The trends and fluctuations in output and inputs are then examined to determine whether or not there has been a slowing of production growth rates.

Yield and Area Effects

The first step in examining the contributions of irrigation and fertilizer to past output growth is to disaggregate the contribution of area and yield. Crop area changes arise from changes in the total land area or from changes in the area double cropped. Yield increases are partitioned into increases due to a higher proportion of the area irrigated and to a higher use of yield-increasing inputs, such as new seed and fertilizer. In calculating the contribution of fertilizer, it is assumed that 1 kilogram (kg) of fertilizer nutrient produced 10 kg of paddy (rough or unhulled rice). The contribution of new varieties is assumed to be embodied in the added fertilizer made profitable by their adoption.

Following the above method, the sources of output growth in seven Asian countries were disaggregated for the post-1969 period (Table 1). The countries have been ranked by their annual rate of production growth. Area change is divided into irrigated and unirrigated. Unfortunately, available data were not robust enough to distinguish the double-cropped area. Yield growth not attributable to fertilizer use is shown as a residual that reflects the influence of increased irrigated acreage, more timely water application, improved drainage, and desalinization.

Trends and Fluctuations in Production

Analysis of sources and patterns of growth are invariably confounded by short-run fluctuations in output that may mask changes in longer-term trends. Of paramount concern at the moment is the possibility that such fluctuations may obscure a slackening of the growth in production following an initial spurt provided by the introduction of the new technology in the late 1960s.

In order to examine this question, rice yields in a number of countries were plotted and the countries were grouped according to the pattern they displayed. Malaysia, the Philippines, Korea, and Taiwan have all had a rather steady and prolonged growth in yields. In the mid-1950s, rice yields in Korea and Taiwan were twice the level being obtained in most South and Southeast Asian countries. By the mid-1960s, the differential was even greater because of the more rapid yield increase in Korea and Taiwan. Since 1965, however, several Asian countries have registered yield increases in excess of 2 percent per year. Rates of

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 (*percent*)	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

*Data are from the International Rice Research Institute, *Research Highlights for 1976*, Los Banos, Philippines, 1977, p. 79.
[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 due to higher proportion of irrigated area.

increase in Korea and Taiwan were substantially lower during the 1965-72 period than in the previous decade, suggesting that a ceiling was being approached. In Korea, however, beginning in 1973, the introduction of a new generation of high-yielding varieties, obtained by crossing Indica and Japonica varieties, significantly raised the yield ceiling and the rate of growth or rice yields again accelerated. Indonesia, Sri Lanka, and Pakistan all showed rapid increase in yields in the late 1960s followed by a fall of yields in recent years. The other countries show occasional small increases from time to time but little sustained improvement.

In Table 2, data for the last decade are shown separately for 1965-70 and 1970-74 in order to identify any possible change in growth of output and inputs. Rice production and change in irrigated and unirrigated areas are reported in the table in terms of annual compound growth rate over the designated periods. Growth in fertilizer and modern varieties (MV) are reported in annual increments, since the level of both was close to zero in 1965.

The reasons for the decrease or increase in the growth rate of production seem to differ from country to country. In Pakistan the sharp decline was accompanied by a slackening in growth of irrigation, fertilizer, and MVs. In India, however, the rate of growth of production declined even though the area devoted to MVs increased more rapidly. The decline in output growth in Sri Lanka was accompanied by an increase in the average annual increment of both fertilizer and MVs. Conversely, an increase in the annual compound growth rate of production in Bangladesh and Burma was accompanied by a decrease in average annual increment of fertilizer. Thus, the change in production growth that was observed in the early 1970s compared to the late 1960s may be due to temporary fluctuations resulting from the generally bad Asian weather in 1972, and the sharp price fluctuations of 1973 and 1974. Until data from additional years become available, however, no firm conclusions about the post-1970 trends are warranted.

FUTURE GROWTH OF FOOD PRODUCTION IN ASIA

There have been a number of attempts to determine whether future food availability in Asia will be "adequate" to meet future demand. Such studies are to some extent academic because when the target year arrives, the amount of food that will be consumed must obviously be available from some source. Projections are useful though for indicating whether current supply trends will meet current demand trends and, if not, the expected magnitude of imports and the need for action to change trends. A number of such studies are available.

In the mid-1960s the FAO began work on its "Indicative World Plan" for agriculture. This document has become the starting point for similar projections by other groups. Three recent projections of foodgrain production to 1985 are summarized in Table 3. The FAO projections were made by adjusting past rates of growth of output to expected feasible levels.

The projections of the International Food Policy Research Institute (IFPRI) (*6*), the Asian Development Bank (*1*), and the World Bank (*5*) differ somewhat in absolute levels because of differences in countries and crops included, income projections, and in using milled rice or paddy as the basis for calculations. Rates

TABLE 2.—ANNUAL GROWTH IN PRODUCTION, IRRIGATED AREA, FERTILIZER PER HECTARE, AND AREA IN MVS, 1965-70 AND 1970-74*

	Annual compound growth rates (*percent*)						Average annual increment			
	Production		Irrigated land		Other land		Fertilizer (*kg NPK*/ha)		Area in modern varieties (*percent of rice area*)	
Country	1965-70	1970-74	1965-70	1970-74	1965-70	1970-74	1965-70	1970-74	1965-70	1970-74
Pakistan	10.65	1.66	2.10[a]	0.65[a]	0	0	2.73	1.33	7.32	0.92
Sri Lanka	7.39	0.94	2.93[b]	n.a.[e]	2.72[b]	n.a.[e]	5.50	20.40	1.67	12.55
India	3.20	0.83	1.56	n.a.[e]	0.33	n.a.[e]	2.28	1.05	2.42[f]	3.75
Thailand	2.61	0.93	0.85	0.62	3.02	0.04	0.78	-0.23	0.20[g]	1.52
Indonesia	4.92	4.71	2.89[c]	2.53[c]	-0.64	-4.36	2.37	4.41	3.70[h]	7.35
Philippines	3.59	3.99	4.51	1.30	-2.54	1.45	2.31	1.66	10.06	2.80
Bangladesh	0.73	1.73	12.72[d]	5.73[d]	0.05	-0.49	0.45	-.02	0.92	2.50
Burma	0.49	2.28	2.02	3.87	-0.61	0.40	0.61	0.40	1.0[i]	0.65

*Production, total area, and yield data are from U.S. Department of Agriculture, except for Indonesia and Thailand which are from national sources. Irrigation data are from national sources. Fertilizer data are estimated from the Food and Agriculture Organization of the United Nations, *Fertilizers: An Annual Review*, Rome, various years. For a more detailed explanation of sources of irrigation and fertilizer data, see A. C. Palacpac, "World Rice Statistics," Agricultural Economics Department, International Rice Research Institute, Los Banos, Philippines, April 1977. Modern varieties data are from D. Dalrymple, *Development and Spread of High Yielding Varieties of Wheat and Rice in Less Developed Nations*, U.S. Department of Agriculture, Washington, D.C., August 1976.

[a] Assume 100 percent of rice area is irrigated.

[b] 1965-69

[c] This includes rainfed area.

[d] This refers to "Boro" crop area.

[e] Data are not available.

[f] 1964-70

[g] 1968-70

[h] 1967-70

[i] 1966-70

of growth are projected to range from 2.2 percent (World Bank) to 2.8 percent (IFPRI), or approximately the average rate of increase in production from 1960 to 1975. The rest of this paper attempts to determine what changes will be required in resources devoted to rice production in order to achieve such a rate of growth.

A Model of Rice Output Growth

A simple aggregate model has been developed to specify the relationships between growth of the output in South and Southeast Asia and changes in land, labor, fertilizer use, irrigated area, and technology. From this formulation it is possible to specify the investment cost associated with each of these sources of production growth. The model begins from the base year of 1974 and projects to 1985. It is not intended to represent the situation in each country, rather the country data are used as components of regional totals. The objective is to suggest the magnitude of regional investment that would be required to obtain alternative rates of output increase.

The model works as follows:

1. The geographic land available for rice production is assumed to be constant through 1985, but the distribution of cost of that land among the major types of rice culture, including the amount of double-cropped land is based on projections of irrigation investment. Labor supplies are assumed not to be limiting.
2. The proportion of each type of land in modern and traditional rice varieties is based on historical trends and on investment in research and extension.
3. The amount of fertilizer available for rice production is based on best available estimates of past allocation. The investment necessary to produce the fertilizer demanded is based on budgeting studies of fertilizer investment (*11*). Imports are an alternative source of supply.
4. The fertilizer used per hectare of each type of rice is based on fertilizer response functions, total fertilizer availability, area in each type of rice, and the assumptions of efficient allocation to various types of rice.
5. Yields of each type are determined from the fertilizer used and the response functions, and total production is determined from yields and area of each type.
6. Technical change affects the response functions used in steps 4 and 5.

Attention is focused on the change in the level of investments needed to achieve stated constant rates of growth in output. The computational model utilizes annual fertilizer, irrigation, land area, and other data. These levels grow over the projection period, but in this presentation the focus is on the rates of change and the average annual investment required over the entire projection period of ten years.

Similarly, no account is taken of the time lag involved in the investment process. It takes three to five or more years to complete fertilizer or major irrigation projects. Many such projects have been and are presently being constructed in the region. Those under construction will provide part of the output needed in the late 1970s. Those started in the late 1970s will provide output for the 1980s. The issue that the analysis deals with is the relative investment that will be required for the next 10 years in order to match the growth achieved over the last 20 years.

TABLE 3.—ALTERNATIVE SETS OF CEREAL GRAIN PRODUCTION PROJECTIONS AND RATES OF GROWTH FOR SELECTED ASIAN COUNTRIES*

	IFPRI[a]			ADB			World Bank		
	1969-71 (million metric tons)	1985-86	Rate (percent)	1970-74 (million metric tons)	1985	Rate (percent)	1974 (million metric tons)	1985	Rate (percent)
India	101.7	133.5	1.8	111.5	152.2	2.4	80.7	106.1	2.5
Bangladesh	11.1	13.1	1.1	16.8	21.7	2.0	11.7	13.9	1.6
Pakistan	10.5	22.3	5.0	11.5	15.4	2.2	11.2	17.2	3.9
Indonesia	15.6	23.3	2.7	24.5	31.8	2.0	18.3	27.5	3.7
Philippines	5.4	8.7	3.2	7.3	10.8	3.0	6.2	9.5	3.9
Thailand	11.0	18.4	3.4	15.4	20.2	2.1	11.5	16.5	3.3
Sri Lanka	—	—	—	1.5	2.0	2.2	1.2	1.7	3.2
Burma	—	—	—	8.3	11.2	2.3	5.7	6.4	1.1
Nepal	—	—	—	—	—	—	2.5	2.8	1.0
Other Asia	9.3	10.9	1.1	—	—	—	—	—	—
Total	164.8	230.2	2.2	196.8	265.3	2.3	149.0	201.6	2.8

*Data are from the International Food Policy Research Institute (IFPRI), *Meeting Food Needs in the Developing World: The Location and Magnitude of the Task in the Next Decade*, IFPRI Research Report No. 1, Washington, D.C., February 1976; Asian Development Bank, *Asian Agricultural Survey 1976*, Manila, Philippines, 1977, preliminary; and S. Hadler, "Developing Country Foodgrain Projections for 1985," Bank Staff Working Paper No. 247, World Bank, Washington, D.C., November 1976.

[a]Cereals production in India includes pulses in IFPRI data; rice in milled rice equivalent, not paddy.

The data and relationships used in each part of the projections are discussed below.

Land in rice.—The geographic area devoted to rice production in the countries under study has probably increased very little in the past decade except in Thailand and the outer islands of Indonesia. Some countries, including the Philippines, have actually had a decrease in the net area devoted to rice production. It is impossible to obtain accurate regional data on the net (geographic) area because most countries report the total area planted or harvested, so that double-cropped areas are counted twice. However, if one subtracts irrigated area from total area, the remainder was about constant from 1965 to 1974.

Net land area devoted to rice is assumed to remain fixed at the 1974 level until 1985. Growth in total land is attained through increases in the double-cropped area which are made possible through irrigation. About 30 percent of the gross irrigated area had two rice crops in 1974. This proportion could increase, but as a conservative assumption it is held constant throughout. As irrigation investment occurs, land is switched from the rainfed category to the irrigated category. An alternative projection technique might be to have irrigation investment upgrade the quality of irrigated land to increase the proportion of double-cropped land without decreasing the rainfed area. This may be a more realistic assumption for some countries, but the former is better for others and appears to be adequate for the region. Total rice area increases as irrigated area increases because 30 percent of the irrigated area is double-cropped.

Labor's contribution.—The labor available for rice production will continue to grow throughout the projection period. Most estimates of labor's impact on production are derived from cross-sectional production function studies which include the actual labor used in production on different types of production units. These probably overestimate the response of output to the increased inputs of labor.

Changes in varieties.—Rice land is classed as irrigated, rainfed, upland, and deepwater. In the model, irrigated and rainfed areas are further divided into area planted to modern and traditional varieties. Because the prospect for yield-increasing technology for upland and deepwater areas is limited and of the same magnitude, they are treated as a single class. Thus, the model has five land types: irrigated modern varieties (MVI), rainfed modern varieties (MVR), irrigated traditional varieties (TVI), rainfed traditional varieties (TVR), and upland and deepwater which are both assumed to be traditional (ULDW). Good statistics are not available on the existing area planted to these types, but farm surveys have invariably shown a close association between irrigated area and MVs, and an equally close relationship exists on an inter-country basis. Table 4 shows the area irrigated and the area planted in MVs during 1963-73. MVs are expected to cover 90 percent of the irrigated rice land in 1985.

MVs are also grown on rainfed land. In the Philippines MVs covered 64 percent of the rainfed lowland and 80 percent of the irrigated area in 1975-76. In most other countries, MVs are currently planted on only a small fraction of the rainfed land. As better adapted varieties are developed MVs will spread to rainfed areas. The proportion of rainfed area planted to MVs is assumed to reach 30 percent by 1985.

TABLE 4.—AREA, IRRIGATION, MODERN VARIETIES, AND FERTILIZER USED IN RICE PRODUCTION IN SOUTH AND SOUTHEAST ASIA, 1963-74*

Country	Total rice area (thousand ha)			Irrigated rice area (thousand ha)			Modern varieties area (thousand ha)			Fertilizer applied to rice (thousand nutrient tons)		
	1963-67	1968-72	1973-74	1963-67	1968-72	1973-74	1963-67	1968-72	1973-74	1963-67	1968-72	1973-74
India	35,886	37,333	38,302	13,413	14,498	—	894	5,539	10,249	279	715	869
Bangladesh	9,311	9,745	9,900	500[a]	910[a]	1,106[a]	34	513	1,515	20[b]	43[b]	50[b]
Indonesia	7,249	8,078	8,625	5,739	6,616	7,220	0	1,039	3,270	64	167	285
Thailand	6,153	6,941	7,398	1,706	1,780	1,819	0	108	425	22	52	49
Burma	5,019	4,958	5,143	667	737	858[c]	3	177	292	6	21	29
Philippines	3,159	3,183	3,544	1,102	1,374	1,447	392	1,556	2,217	24	61	83
Pakistan	1,373	1,523	1,624	1,373[c]	1,523[c]	1,624[c]	2	547	634	11	33	41
Malaysia	399	515	587	167	375	442[d]	65	161	219	19	32	49[e]
Sri Lanka	597	627	574	359	403	—	0	73	360	15	33	65
Total	69,146	72,903	75,697	25,026	28,216	30,035[f]	1,290	9,713	19,181	460	1,157	1,520
Growth rate (*percent*)	—	1.1	1.1	—	2.4	1.8[f]	—	38.9	19.4	—	18.5	7.8
Seven country total[g]	32,663	34,943	36,821	11,254	13,315	14,516	496	4,101	8,572	166	409	586
Growth rate (*percent*)	—	1.3	1.5	—	3.4	2.5	—	42.2	21.1	—	18.0	10.3

*Production, total area, and yield data are from U.S. Department of Agriculture, except for Indonesia and Thailand which are from national sources. Irrigation data are from national sources. Fertilizer data are estimated from the Food and Agriculture Organization of the United Nations, *Fertilizers: An Annual Review*, Rome, various years. For a more detailed explanation of sources of irrigation and fertilizer data, see A. C. Palacpac, "World Rice Statistics," Agricultural Economics Department, International Rice Research Institute, Los Banos, Philippines, April 1977. Modern varieties data are from D. Dalrymple, *Development and Spread of High Yielding Varieties of Wheat and Rice in the Less Developed Nations*, U.S. Department of Agriculture, Washington, D.C., August 1976.

[a]Data are for the rice planted to Boro rice, which is irrigated.

[b]Assumed equal to 32 percent of total fertilizer, the corresponding figure for India.

[c]All rice in Pakistan is assumed to be irrigated.

[d]Based on an estimate of the growth in net irrigated area.

[e]Projected at 20 percent of total fertilizer for the country; projected from two previous periods when it was 30 percent and 23 percent.

[f]Projected growth rate of 9 percent in countries for which data are available, compared to 18 percent.

[g]Bangladesh through Malaysia.

Irrigation.—The amount of irrigated land is a policy variable determined externally which directly results in a major investment cost. Several recent studies of irrigation costs and coverage are available. Kikuchi's study of Philippine irrigation system construction between 1949 and 1975 showed construction costs (converted to 1975 constant prices)[2] on river diversion systems of $304/hectare (ha) on 7,170 ha for systems constructed during 1949-55; $413/ha on 13,970 ha constructed during 1956-65; and $513/ha on 18,747 ha constructed during 1966-74 (8). These river diversion systems are generally small projects with construction periods of one to three years. In 1975 a high dam storage system with a command area of 80,000 ha was completed at an average cost of $1,280/ha. It had a construction period extending over five years, with full irrigation capacity reached after two years of operation.

Kikuchi hypothesized that costs of new irrigation would continue to increase because the more suitable irrigation locations had been utilized first, and the remaining sites would be less suitable and hence entail higher costs.

Nakahara (9) reviewed irrigation projects financed by the Asian Development Bank (ADB) and World Bank in Asia between 1965 and 1974. His primary focus was on costs. Eight projects financed by the World Bank irrigated 1,071,900 ha at a capital cost of $587 million, a cost of $548 per hectare. Twenty-four ADB-financed projects that irrigated 322,171 ha had a total project cost of $429 million (in 1975 prices), for an average capital investment cost of $1,330/ha. Fifty percent of the investment costs were foreign costs. Nakahara did not explain the difference in cost between the two sets of projects, but they may reflect economies of scale and different construction years. On the basis of Kikuchi's and Nakahara's data, there is a range of $550 to $1,300/ha between the low and high estimates of capital costs for new irrigation. It is likely that future costs will be at the upper end of this range because most of the lower cost sites are already developed so $1,000 and $1,300 are used as low and high investment cost per hectare in the projections.

The benefits of irrigation are related to the level of production technology used in the command area. Feasibility studies of irrigation projects usually assume very high yields after irrigation which assures a favorable benefit-cost ratio. However, micro-studies that compare irrigated and nonirrigated areas usually show more modest increases in yield. In this analysis, the yield benefits of irrigation are made dependent on the level of fertilizer and MVs, as discussed below. The minimum yield benefit of irrigation is 0.7 tons/ha, increasing to 1.5 tons/ha, depending on the technology level. In addition, irrigation increases the area devoted to rice through double cropping.

Fertilizer demand and investment cost.—Fertilizer application is a major source of additional rice output. Since the introduction of MVs, the amount of fertilizer applied to rice has increased rapidly; between 1963 and 1967 fertilizer applied on rice increased by nearly 20 percent annually and between 1968 and 1973 by nearly 8 percent. In the early 1970s, fertilizer on rice amounted to one-third of the total fertilizer used in the countries of the region. Farm-level research shows a considerable scope for higher yields from more fertilizer, especially where it is presently being applied to rice in the dry season (7). There is a limit, of course, to the amount of fertilizer that can be applied profitably.

Projections of fertilizer use between 1975 and 1980 are based on demand projections by the National Fertilizer Development Center of the Tennessee Valley Authority (TVA) (*11*). TVA projects a 12 percent annual rate of increase in fertilizer use in South and Southeast Asia in 1975, declining gradually to 9 percent in 1980. This trend has been extended through 1985 when use would be growing at 8 percent annually. An alternative projection uses a 12 percent rate declining to a 9.5 percent annual increase in 1985.

The fertilizer can alternatively be obtained by importing it from the developed countries or the Middle East. Two cost levels are used: a low price of $150/ton and a high cost of $250/ton of urea. Fertilizer imports may be preferred by smaller countries of the region. Under a perfect market equilibrium assumption, the cost of imported fertilizer and the cost of domestically produced fertilizer would be equal. But because of the market imperfections related to entry and knowledge, it is likely that fertilizer could be produced by nationalized firms at a lower cost than that of imports. Part of the cost reduction might be acceptance of less than the 20 percent return on investment assumed necessary in the TVA studies, acceptable by nationalized firms in the social interest.

Constructing an ammonia-urea production unit of the latest technical design, using low cost ($0.10/1,000 cubic feet) natural gas as a feedstock producing 495,000 tons of urea per year, entails a capital investment ranging from $187 to $190 million (1975 dollars, with allowance for a moderate cost increase through 1978) (*11*, p. 86). In such a unit, urea can be produced for approximately $100/ton under TVA assumptions. A 20 percent return on investment in addition to costs of production (which include depreciation) would increase the gate sale price to $175/ton. Feedstock costing $0.25/1,000 cubic feet would increase production cost to $103/ton, and high cost gas at $0.50/1,000 cubic feet would increase it to $109/ton.

The investment for a complex capable of producing 340,000 metric tons of triple superphosphate (TSP) (46 percent P_2O_5) per year ranges from $78 to $183 million (including cost escalation to 1978). The production cost of TSP from such a complex ranges from $138 to $253/ton depending on the price of sulphur and phosphate rock. With a return on investment of 20 percent, TVA estimates a gate sale price of between $184 and $332/ton (*11*, p. 99).

Fertilizer application rates and yield.—One may project output increases from fertilizer availability by using the "rule of thumb" that one kilogram of fertilizer yields 10 kilograms of paddy as in the analysis of sources of output growth. However, that approach does not reflect the complementarity of fertilizer, irrigation, and new varieties, nor does it recognize that a linear response to fertilizer cannot be expected to continue indefinitely. Traditional varieties respond less to fertilizer than modern varieties, and both respond more when irrigated. In most countries the area planted to modern varieties is irrigated, thereby removing some of the potential drought stress that usually occurs under rainfed conditions. Farmers apply more fertilizer per hectare on modern than on traditional varieties.

Response functions relating rates of fertilizer application to yield in each combination of variety and moisture control incorporate the influence of variety and irrigation as well as the influence of fertilizer. Barker, Bennagen, and

Hayami (2) have fitted the functions of the form:

$$Y_I = \alpha_I + \beta_I F_i - \gamma_I F_i^2 \qquad (1)$$

where Y_I refers to MF 1, Y_2 to MVR, Y_3 to TVI, and Y_r to TVR to national farm survey data in the Philippines and experiment station data adjusted by observed differences between survey and experimental data. It is assumed that upland and deepwater rice are not responsive to fertilizer. Coefficients used in the model, slightly modified from those found by Barker et al. are:

	α	β	γ
MVI	2,200	18	.09
MVR	1,400	15	.11
TVI	2,000	11	.13
TVR	1,400	9	.16

When values of the F_i are known for a particular year, production can be estimated. Under the assumption of market equilibrium, the marginal productivity of fertilizer applied to each type of rice will be equal to the ratio of the price of fertilizer to the price of rice. If there is not enough fertilizer to permit this, the model assumes that what fertilizer is available will be so allocated among the four possible uses as to make the marginal product in terms of rice—a—the same in each. This gives:

$$a = \frac{d\,Y_i}{d\,F_i} = 18 - 0.18\,F_1 = 15 - .22\,F_2 = \text{etc.} \qquad (2)$$

It is assumed that the total amount of fertilizer used, $\Sigma F_i A_i$ where A_i = the area planted with each technique, will equal the total amount of fertilizer available, $\hat{F}$, giving

$$\hat{F} = F_i A_i \qquad (3)$$

If the area in each type of planting (A_i) and the total amount of a fertilizer available are known, Equations (2) through (3) can be solved for a, and for total rice production. Equation (2) is solved for the F_i in terms of a. Substitution in Equation (3) gives the value of a. Substituting this back in Equation (2) gives values for the F_i. When these are substituted in Equation (1), yields per acre are obtained for each situation, and these, with the known areas, given total rice production.

Investment in research and extension.—The conventional economic explanation of technological change is that it arises from a change in the production function (*12*). This could be interpreted, in this case, as the difference between Equations (1) and (3) or between (2) and (4). The modern varieties give a greater yield response to fertilizer. The advantage was created largely through the investment in rice research between 1960 and 1970. Spreading this innovation was achieved through extension investments made between 1965 and 1975.

Present rice research is focused on a wide range of topics including insect resistance, problem soils, and drought, as well as fertilizer efficiency, so it is impossible to devise a "realistic" technique for reflecting the impact of successful future technological change. A simplified way of looking at the future impact of investment in rice research and extension is to assume that it will continue to shift the fertilizer response functions. If it is agreed that investment in rice research and extension between 1960 and 1970 caused the observed change in the fertilizer response function between Equations (1) and (3), it took an investment of $350 million to generate and spread the present modern varieties that resulted in response functions with two-thirds higher marginal productivity capable of effectively using more than twice as much fertilizer. One could conservatively estimate that $100 million investment might lead, over time, to a 15 percent higher marginal productivity. This is the assumption made here.

Investment in research may be more constrained than investment in other sources of growth. The amount one can effectively invest in research is limited to some moderate proportion of previous research. Even building the capacity for research by training additional researchers is a time-consuming process (3), which can itself limit the amount of growth that can be obtained from this source.[3] Also, a certain amount of research investment is needed to maintain current levels of productivity. Hence, the 15 percent in marginal productivity will only be generated by $100 in addition to current (maintenance) research investments.

Model Verification, 1963-67 to 1968-72

In order to verify the projections model, the actual levels of inputs used by the countries of the region for the five-year average periods 1963-67 and 1968-72 were used to estimate production (Table 5). Land, irrigation, modern varieties, and fertilizer on rice were derived for the five-year average periods centered on 1965 and 1970 and for the two-year average of 1973-74. It was assumed that the modern varieties were planted only on irrigated land in 1963-67, that 95 percent of the modern varieties area was irrigated in 1968-72, and 90 percent of the modern varieties area was irrigated by 1973-74. The areas of upland and deepwater rice were assumed to remain constant. Data on irrigated rice area were not available for 1973-74 for all countries, but in the seven countries for which irrigation data were available, irrigated rice area grew 75 percent as rapidly between 1968-72 and 1973-74 as it had in the previous five-year period. Assuming the same proportional rate for all countries gave the 1.8 percent rate of irrigation growth used for the second validation period.

Estimated and actual output.—Under these assumptions and using the data in Table 5, the model estimates an average annual level of output of 112.1 million metric tons of rice (paddy) compared to reported average actual production as estimated by the U.S. Department of Agriculture of 111.1 for 1963-67 (*10*). The model estimates 1968-72 output as 130.2 compared to reported output of 129.5 million metric tons. Model estimated output for 1973-74 is 143.4 compared to reported output of 142.9 million metric tons.

The shadow price ratio of fertilizer (nutrient) and rice (paddy) implied by the model exceeds 6.5 for both verification periods. Market price ratios in most

[2] Converted using the index of international inflation reported by Nakahara (9).

TABLE 5.—ESTIMATION OF COSTS ASSOCIATED WITH INCREASED INPUT USE FOR INCREASED RICE PRODUCTION ACHIEVED, NINE ASIAN COUNTRIES, 1963-67 TO 1968-72

(in U.S. dollars unless indicated otherwise)

Input	Cost range	Average annual increase	Unit cost for: Capital investment	Unit cost for: Current cost	Annual capital investment: Domestic	Annual capital investment: Foreign	Annual additional current costs: Domestic	Annual additional current costs: Foreign	Total five-year period: Total	Total five-year period: Domestic	Total five-year period: Foreign
Irrigated land	Low	638,000 (*ha*)	1,000		319	319	6	0	3,280	1.685	1,595
Irrigated land	High	638,000 (*ha*)	1,300	20	415	415	12	0	4,330	2,255	2,075
Fertilizer, urea	Low	232,000 (*tons*)[b]	0	150[c]	0	0	0	35	525	0	525
Fertilizer, TSP	Low	77,000 (*tons*)	0	250[c]	0	0	0	19	285	0	285
Fertilizer, urea	High	232,000 (*tons*)	0	250[c]	0	0	0	58	870	0	870
Fertilizer, TSP	High	77,000 (*tons*)	0	350[c]	0	0	0	27	405	0	405
Fertilizer, urea	Low	0.47 (*units*)[d]	187(*m*)[e]	60[f]	0	87	7	7	649	105	544
Fertilizer, TSP	Low	0.23 (*units*)[g]	78(*m*)[e]	132[e]	0	18	5	5	190	75	165
Fertilizer, urea	High	0.47 (*units*)	190(*m*)[e]	70[f]	0	89	8	8	685	120	565
Fertilizer, TSP	High	0.23 (*units*)	133(*m*)[e]	243[f]	0	30	9	9	435	150	285
Research, extension	–	–	43(*m*)[e]	0[h]	33[i]	10	0	0	215	165	50

[a]The additional amount must be cumulated so that the five-year total of the additional current costs equals: in the first year, the first year addition; in the second year, the second year addition plus the first year addition, and so forth.

[b]Annual increase of 139,000 nutrient tons converted to urea and TSP assuming three-fourths of fertilizer is urea, one-fourth is TSP.

[c]All fertilizer is imported in these cases.

[d]One ammonia-urea production unit will produce 495,000 tons urea per year. About one every two years would meet the needs.

[e]*m* = million

[f]Cost per ton of producing the fertilizer, excluding capital depreciation and interest, assumed half domestic, half foreign.

[g]One TSP production complex with phosphate rock grinding and sulphuric acid plant will produce 340,000 tons of TSP per year with investment cost ranging from $78 to $133 million. See Tennessee Valley Authority, National Fertilizer Development Center, *An Appraisal of the Fertilizer Market and Trends in Asia*, Muscle Shoals, Alabama, 1975, p. 99.

[h]Assumed to be entirely an investment.

[i]Arbitrary breakdown between domestic and foreign.

countries were 4.0 or lower during the period. This suggests that on the average for the region the rate of fertilizer applied to rice was below the equilibrium level and that profitable scope existed for further output increases from higher rates of fertilizer.

Investment levels.—Given the growth in irrigated land, fertilizer, research, and extension over the period, one may wish to know the investment costs such inputs entailed. The data problems of determining actual investment costs are great because of the number of different data sources, the differences in gestation lags for similar investments in different countries, and violent price changes that occurred during the period. By abstracting from these events and using the standardized irrigation and fertilizer investment costs discussed above, it is possible to calculate the implied investments that must have been made in order to achieve the increased irrigation and fertilizer that occurred during the verification period. The actual pattern of investment and benefits over time are highly complex. The procedure used was to aggregate over five-year periods and to determine the average annual investment for each period.

The investment cost of the agricultural growth actually achieved between 1963-67 and 1968-72 was calculated as in Table 5. All costs are shown in U.S. dollars at constant 1975 prices. Because of the range in investment costs that exists in the data, a low and high estimate for each alternative is shown. With imported fertilizer, the total investment required to generate the increased rice output from the sources identified in the model ranged between $4,305 million and $5,820 million for the five-year period, 1965-70. Using the domestic fertilizer plant construction alternative the cost ranged from $4,334 million to $5,665 million. Average annual investment would average $861 million to $1,133 million.

Projections from the Model, 1985

Table 6 shows the results from the model. The first two lines give results of the verification, V1 with data for 1963-67 to 1968-72 and V2 with data for 1968-72 to 1973-74. The annual rates of growth of irrigated area and fertilizer are supplied as inputs to the model and the rate of rice production and the ratio of fertilizer prices to rice prices results. A number of other results, not shown because of lack of space, have been generated from the model, including the rates of fertilizer application on each type of rice, rice yields, and annual investment cost by input. The annual average investment requirements are calculated from the increased inputs and the investment requirement data. As indicated above, rice production projected by the model is very close to reported production, differing by less than 1 percent in each verification period.

In runs 1, 2, and 3, the irrigated area was assumed to increase at 1.5, 2.0, and 3.0 percent annually. Fertilizer use grows at 12 percent in 1974 then gradually declines to a rate of 8 percent annual growth in 1985. In run 4, irrigated area grows at 3 percent and fertilizer demand grows slightly more rapidly than projected by TVA. Runs 5 and 6 assume that farmers' fertilizer productivity is increased 30 percent through research and extension.

Runs 1 through 3 show the effect of different rates of irrigation expansion with the base rate of fertilizer growth and constant technology. With a 1.5 percent

TABLE 6.—PROJECTED RATES OF INCREASE OF IRRIGATION, FERTILIZER, AND TECHNOLOGY[a], AND ASSOCIATED OUTPUT GROWTH, AND INVESTMENT REQUIRED, SOUTH AND SOUTHEAST ASIA 1974-85

	Inputs to the model		Outputs of the model					
					Annual investment (*million U.S. $*)			
					Low costs		High costs	
Run number	Irrigated area (*percent/year*)	Fertilizer (*percent/year*)	Production (*percent/year*)	Implied nitrogen to rice shadow price	Imported fertilizer	Domestic fertilizer	Imported fertilizer	Domestic fertilizer
Verification								
V1[b]	2.4	18.5	3.0	6.6	861	866	1,164	1,133
V2[b]	1.8	7.8	2.8	6.9	715	742	768	773
Projections with inputs increased								
1	1.5	12-8[c]	1.6	1.4	1,072	960	1,530	1,237
2	2.0	12-8	1.8	1.8	1,252	1,140	1,768	1,475
3	3.0	12-8	2.3	2.6	1,641	1,529	2,256	1,963
4	3.0	12-9.5	2.4	0.8	1,754	1,619	2,435	2,080
Projections with improved technology and inputs								
5	1.5	12-8	2.5	5.5	1,272	1,160	1,730	1,437
6	3.0	12-8	3.0	6.8	1,841	1,729	2,456	1,963

[a] MVs covered 6 percent of irrigated rice land in 1963-67, 33 percent in 1968-72, and 57 percent in 1973-74. They are assumed to cover 90 percent of irrigated and 30 percent of rainfed land by 1985.

[b] These are the verification runs: V1 covers the 5-year period, 1963-67 to 1968-72, and V2 covers the 3-1/2 year period, 1968-72 to 1973-74.

[c] Fertilizer applied to rice grows at 12 percent per year in 1974; that rate declines gradually to 8 percent per year by 1985.

annual increase in irrigation, output grows at 1.6 percent. A 2.0 percent annual increase in irrigation pushes output growth to 1.8 percent per year, while a 3.0 percent rate of irrigation increases output growth to 2.3 percent. All three rates of growth of output are below the observed rates of output growth during the verification periods, and all entail substantially higher rates of annual investment for irrigation and fertilizer. Because of the large investments and scarce real resources (engineering talent) needed for irrigation construction, it is unlikely that the irrigated area could grow much more rapidly than 3 percent per year. At these rates the increased irrigated area and the accompanying double cropping together with fertilizer would result in rates of production growth more or less consistent with those in Table 3.

This projection assumes the existence of enough land suitable for irrigation to permit the projected rates of increase. A country-by-country evaluation of the reasonableness of that assumption would be required to evaluate it. In some countries, the actual irrigation investment might be used to improve existing systems, resulting in higher yields and more double cropping, but that mechanism is not included in the model.

The use of fertilizer in the first three runs makes a substantial contribution to output, but the scope for any greater contribution is limited because the additional fertilizer made available during the period pushes the per hectare rates to levels where the marginal productivity of fertilizer is very low. In fact, the implied fertilizer to rice shadow price ratio is 2.6 or below, a lower level than it has been historically in most Asian countries.

Run 4, which has higher growth rates of fertilizer use, shows the futility of trying to push rice growth only through that route. The marginal productivity of fertilizer falls substantially below the levels with the first three runs and so the price necessary to induce farmers to use all the available fertilizer is about half the level of the previous runs. Such a price would entail very large fertilizer price subsidies.

CONCLUSIONS AND IMPLICATIONS

The implications of this set of projections are as sobering as the three sets reproduced in Table 3. The model's projections imply that in the absence of technological change, it will be impossible for production to grow fast enough to match population growth even with a level of annual investment twice as high as that of the past decade.[3] It is unlikely that higher rates of fertilizer or irrigated land expansion will be possible because of technical considerations. In this context, the importance of technical change becomes evident.

Technical change is expected to increase the productivity of conventional inputs like irrigation and fertilizer, but the exact relationship and mechanism is uncertain. In runs 4 and 5, it is assumed that an additional $200 million investment in research and extension per year will raise productivity as discussed above. This assumption, while based on the best available data, is highly tentative.

[3] The investment figures are shown as annual averages. The requirement in the first years of the period will be greater than in the final years. The data most accurately represent the requirements in 1980-81.

For one thing, relatively little effort has so far been made to identify and close the gap between potential and actual yields with present technology. Recent efforts to develop a methodology for measuring the gap and identifying its sources may have some payoff in this regard (7). The limited experience with the "Training and Visits" extension system being advocated by the World Bank seems to have been very favorable (4). Relatively small investments have resulted in relatively large benefits in that program. Thus, there seem to be ways of increasing the productivity of agricultural investments, but the precise path by which these increases will be achieved is unclear. Therefore, the benefits forthcoming from investments in research and extension or conversely the investment to achieve needed benefits are difficult to estimate.

It is apparent that the quality and quantity of efforts in rice research and extension have improved substantially in the past 15 years. It is possible that maintenance of efforts at this level will result in enough productivity gains to provide the needed future growth. A much safer policy would be to increase the level of effort in this area, especially in light of the high payoffs such efforts have had in the past. However, there are severely limiting constraints on the rate of expansion of research.

Expanding research and extension capacity takes trained manpower, and training manpower for scientific research work typically takes eight to ten years. An additional five years may elapse before the researcher makes a significant contribution to output. Training is costly and requires foreign exchange (such costs are not included in Table 6). It also requires a supply of individuals suitable for training. Thus, the main constraints to increasing investment in research and extension cannot quickly be removed.[4]

The most important finding of the analysis is that investment in irrigation and fertilizer at the levels considered (which are higher than historical levels) will not be sufficient to increase production by more than 2.4 percent annually. Only if the productivity of irrigation and fertilizer used by farmers on rice is increased can the rate of growth of output exceed that level. This increase in productivity can be brought about by improved management of resources with present technology—by closing the gap between potential and farmer's yields, or by raising the potential through developing better technology and adopting those improvements.

The specifics of the results are tentative because of the many assumptions. They are presented here in order to stimulate further research. Irrigation and fertilizer investments will be used for all agricultural commodities, so the analysis should be carried out for the whole sector. The regional analysis has certain advantages but must be complemented with similar national studies. National studies can use data more appropriate to their situations and thereby give more accurate indications of needed investments. It is only at the national level that the appropriate irrigation opportunities and costs can be estimated and the appropriate fertilizer response functions identified. Despite these limitations, the results indicate the relative magnitude of agricultural investments and productivity increases needed in order to produce enough rice for Asia in 1985.

[4] In some indicative calculations for Nepal, Bateson has argued that starting in 1978 as many as 20 new students per year must begin on the sequence of M.S. and Ph.D. training in order to produce the new knowledge and technology required to meet Nepal's food requirements for the year 2000 (3). This is especially difficult for Nepal which even sends its B.S. agricultural students abroad.

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