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Herdt,R.W.; Te,Amanda; Barker,Randolph

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9. ABSTRACT
Assuring adequate food has been a priority objective of the governments of LDCs in Asia and of people concerned about Asia. This paper examines the rice situation in the region and the prospects for its future. It has three parts: the first section discusses the current level of food consumption in the region and the changes that have occurred in that production from 1952 to 1972; the second section examines the sources of growth of rice production; the third section discusses a model used for projecting future growth in rice output and provides some estimates of the investments required in order to support the continued growth of rice production at the required rate. Cereals dominate the consumption patterns in most of the countries represented. Rice contributes an appreciable fraction of total calories, especially in the mainland South Asian countries of Bangladesh, Burma, Thailand, Laos, Cambodia, and Vietnam. While food production has increased from 1.6 to over 5% per year in various countries with substantial increases coming in cereal grains, these increases have been rapid enough to keep us with demand in only a few countries. In the others there has been an increased dependence on imports, reduction of exports or upward pressure on food prices. The reasons for the decline of increase in growth rate of production seem to differ from country to country and may be due to temporary fluctuations rather than long term trends. The highly cyclical nature of irrigation investment is closely correlated with fluctuations in the benefit-cost ratio caused principally by variation in the world rice price used in calculating the benefits. The model discussed in this paper suggests a method to stabilize investment for increasing rice production at a rate sufficent to meet the anticipated demand.

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THE PROSPECTS FOR ASIAN RICE PRODUCTION

Robert W. Herdt
Agricultural Economist

Amanda Te
Research Fellow

Randolph Barker
Agricultural Economist

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AGRICULTURAL ECONOMICS DEPARTMENT
INTERNATIONAL RICE RESEARCH INSTITUTE
Los Baños, Laguna, Phil. Mailing Address: P.O. Box 933 Manila, Philippines

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THE PROSPECTS FOR ASIAN RICE PRODUCTION*

Robert W. Herdt, Amanda Te and Randolph Barker

The developing countries of Asia, excluding the People's Republic of China, contain 1.2 billion people, approximately one-third of the world's population. Assuring adequate food for these people has been a priority objective of the governments of Asia and of other people concerned about Asia. In this paper, we attempt to understand the rice situation in the region and prospects for its future. The paper has three parts: the first section discusses the current level of food consumption in the region and the changes that have occurred in that production over the period from 1952 to 1972; the second section examines the sources of growth of rice production; the third section discusses a model we have used for projecting future growth in rice output and provides some estimates of the investments that will be required in order to insure that rice production will continue to grow at the required rate.

CURRENT FOOD ADEQUACY AND RECENT TRENDS[1]

The food balance sheet approach is one of the few practical ways to measure the level of food availability on a national basis. It is a simple accounting of food production, exports, imports and stock changes

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

divided by population to give per capita availability. This is sometimes adjusted for feed, seed, and waste to give apparent consumption. Where data on stocks or stock changes are not available, averaging availability over several years results in acceptable estimates.

Figure 1 shows the apparent per capita consumption of food in two recent periods for 15 countries in Asia. 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. Table 1, however, shows that both the absolute level of consumption and the growth in per capita consumption tend to be associated with the rate of growth in per capita income. In that table, countries have been divided into two groups, with per capita calorie consumption above and below 2200, and then ranked according to the annual rate of growth in per capita income. Given the uncertain quality of the data, the relationship between the level and changes in income and consumption seems reasonably consistent.[2]

Cereals dominate the consumption patterns in most of the countries, but non-cereals are particularly important in Sri Lanka, Malaysia, and Taiwan (Fig.1). Rice contributes an appreciable fraction of total calories in all countries, and makes up an especially large portion of total calories in the mainland South Asian countries of Bangladesh, Burma, Thailand, Laos, Cambodia, and Vietnam.

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[2]The rank correlation test rejects the hypothesis of rank independence at the 5% level with $r = 0.73$.

In most countries, approximately 2000 calories are available per capita per day. This is not far from the minimum level "required" for maintenance,[3] however, there is a wide dispersion in food availability in the countries represented. As a result, even where average availability per capita is equal to requirements, a substantial portion of the population has an inadequate diet. This is illustrated in Figure 2 reproduced from a study by Reutlinger and Selowsky (1975), which shows an estimate of per capita calorie consumption by income groups. These data indicate that 84% of the region's population consumes less than 2200 calories per day and 47% consumes less than 2000 calories per day. The result is not widespread starvation but widespread malnutrition.

Mangahas (1976) indicates that in the Philippines, the distribution of food among the population is such that in order to insure that 95% of the population would each consume no less than 2187 calories per day (The Philippine Food and Nutrition Research Council minimum standard requirement), the average consumption would have to be over 3300 calories per day. It is clear from these illustrations that providing the total population with an adequate diet is not merely a question of increasing agricultural production or achieving food "self-sufficiency." Food self-sufficiency has little meaning if a large portion of the population cannot afford an adequate diet. While this paper is concerned principally with ways to increase production, the solution to the food problem in most countries lies in a proper combination of production and distribution programs.

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[3] The Food and Agriculture Organization of the United Nations recommends a calorie level per person ranging from 2350 to 3500 depending on the amount of physical activity required by the person's occupation.

The data in Table 2 give further indications as to why per capita food availability has not increased more rapidly. They show the annual rates of growth of food production, population, and domestic demand between 1952 and 1972 as calculated by the FAO for the World Food Conference of 1974. In these data, demand is estimated on the basis of the equation:

(1) $$D = P + eY$$

where D, P, and Y represent the rates of growth of food demand, population and per capita income and e represents the income elasticity of demand for dood. The countries have been divided into three groups: (i) those whose food production has grown more slowly than population, (ii) those whose food production has kept pace with population, but grown more slowly than demand, and (iii) those whose food production has kept pace with food demand.

Nepal, Bangladesh, and Indonesia belong to the first group of low production growth. Nepal has reduced its export of cereals and the other two countries have increased their imports. Burma, India, Pakistan, and the Philippines belong to the middle group. In these countries as well as the first four, there has been an upward pressure on prices that can only be offset by imports or (in the case of Burma) by reducing exports.

The third group of countries, where the date of growth in production exceeded demand, could increase their exports (Thailand) or decrease their imports (Malaysia) or permit real food prices to drift downward, thereby benefiting consumers. (Unfortunately, this favorable picture may have been reversed in Sri Lanka by a series of bad weather years since 1972.)

These data indicate that while food production has increased from 1.6 to over 5% per year in various countries with substantial increases coming in cereal grains, these increases have been rapid enough to keep up with demand in only few countries and that in the others there has been an unavoidable increased dependence on imports, reduction of exports or upward pressure on food prices. In this context, it is important to examine the growth that has occurred to determine its sources and ask whether it can be enhanced in the future.

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

The gradual closing of the land frontier after 1960 -- more pronounced in rice than in upland crops -- necessitated a shift toward the use of modern yield increasing inputs. The speed with which this transformation can occur determines the degree to which output can keep pace with population growth and generate the food surpluses needed for agricultural development. In this section, we examine the changes in production, area, and yield of rice over the past two decades and measure the contribution of increased fertilizer and irrigation development to output growth. Then, we examine the trends and fluctuations in output and inputs to determine whether or not there appears to be a slowing of production growth rates.

Sources of output growth

The contributions of irrigation and fertilizer to output growth in rice are examined in more detail in this section. The first step is to disaggregate the contribution of area and yield in more detail. Crop area changes can arise from a change in the total land area or from a change in the area double cropped. Yield increases can be 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 (see Appendix for procedures). In calculating the contribution of fertilizer, it is assumed that 1 kg of nutrient (N, P, or K) will produce 10 kgs of grain. The contribution of new varieties can be said to be embodied in the added fertilizer made profitable by their adoption.

Following the above format, we examined the sources of output growth in the Philippines for the past two decades (Table 3). In the earlier period, the major contribution to increased production was irrigation (double cropping and improved average land quality) which accounted for 1.83 of a total 2.41% annual growth. Land area expansion and fertilizer were not important. In the latter period, the contribution of land area became negative due principally to the decline in upland rice. The contribution of irrigation became even more important with the area double cropped more than off-setting the decline in net area. Fertilizer accounted for an output increase of 1.47% per annum. Given the small size of the "residual" in both time periods, fertilizer and irrigation seem to account for nearly all of the yield gain.

Mellor (1976) has undertaken a similar analysis of food grains in India, although his input classification is somewhat different (Table 4). Nevertheless, there is a striking similarity both in magnitude and sources of output growth for rice in the Philippines and for food grains in India. The expanded use of fertilizer after 1965 led to an increase in annual growth in production.

The analytical procedures and assumptions used in the Mellor study were used to estimate the contribution of land, irrigation, and fertilizer input to growth in production in seven Asian countries which experienced a growth in rice production in excess of 2% per annum in the period since 1965 (Table 5). The countries have been ranked according to the annual rate of production growth. The proportion of increased production is divided between area and yield. Area change is subdivided into irrigated and unirrigated (rainfed lowland and upland). Yield growth is subdivided into the proportion due to fertilizer (assuming 1 kg of N, P, or K produces an additional 10 kg of paddy) and a residual.

In five of the seven countries -- Pakistan, Sri Lanka, Indonesia, the Philippines, and India -- the major source of output growth is due to an increase in yield per hectare. In four of these five countries (all but Sri Lanka), level of fertilizer input tripled from about 7 to 8 kg NPK/ha to 20 to 25 kg NPK/ha (Appendix Table 1). In Sri Lanka, the fertilizer level also tripled from 25 to 72 kg/ha, but the absolute increase in the amount of fertilizer applied was almost 50 kg/ha or more than double that of the other four countries, causing the especially large contribution of fertilizer to output growth in Sri Lanka.

The sources of growth in Malaysia and Thailand stand in sharp contrast to the pattern experienced in the other five countries. The most significant development in Malaysia was the expansion of irrigated area accounting for almost 2/3 of added production. This was the result principally of the development of the Muda River irrigation system which increased the acreage of rice double cropped. By contrast, Thailand is the only country to follow the traditional pattern of increasing output by expanding rainfed rice area. The low rate of change in unirrigated area in the other six countries suggests that expansion of irrigated area takes principally the form of additional double cropped area.

Trends and fluctuations in production

Analysis of sources and pattern of growth are invariably confounded by short-run fluctuation in output that are related to changes in weather and other factors. These fluctuations have considerable impact on rice prices and hence on the welfare of consumers, particularly that large body of Asian consumers whose incomes are too low to afford an adequate diet. But of even more paramount concern at the moment is the possibility that trend in production has slackened off following an initial spurt provided by the introduction of the new technology in the late 1960s.

In order to examine this question in more detail, we plotted rice yields in a number of countries, grouping them according to the pattern they displayed in Figure 3. 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. In the period since 1965, however, several Asian countries registered yield increases in excess of 2% narrowing the gap (Figs. 3a and 3b). Rates of yield 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 of rice yields has again accelerated.

Indonesia, Sri Lanka, and Pakistan all show rapid increase in yields in the late 1960s followed by a fall of yields in recent years (Fig. 3b). The other countries show little sustained increase, but occasional small jumps from time to time (Fig. 3c).

In Table 6, we have divided the last decade into two periods, 1965-70 and 1970-74, in order to identify the change in growth of output and inputs. Rice production and change in irrigated and unirrigated area 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 pattern of growth in output and in the specified inputs showed considerable variability from country to country just as in the case of the yield trends. In Pakistan, Sri Lanka, India, and Thailand there was a slackening of the production growth rate in the early 1970s compared to

the late 1960s. The annual rate of growth in production changed very little in Indonesia and the Philippines between the two periods, but has increased in Bangladesh and Burma in the 1970-74 period.

The reasons for the decrease or increase in growth rate of production seem to differ from country to country. For example, the sharp decline in Pakistan is accompanied by a slackening in growth of irrigated area, fertilizer, and modern varieties. In India, however, despite the decline in production growth rate, annual additional area devoted to modern varieties has increased. The decline in output growth in Sri Lanka is accompanied by an increase in the average annual increment of both fertilizer and modern varieties. Conversely, an increase in the annual compound growth rate in Bangladesh and Burma has been accompanied by a decrease in average annual increment of fertilizer.

These results suggest that the change in production growth that we observe in the early 1970s compared to the late 1960s may be due to temporary fluctuations rather than long term trends. The sources of growth, especially in recent years are, of course, affected by the generally bad weather in 1972 and the fertilizer and energy crises in 1973 and 1974.

The effect of these short term fluctuations on world price can be seen in Fig. 4. In that graph, the price of rice exported from Thailand (the major Asian rice exporter) is shown together with world rice production the previous year and a steady rate of growth in demand. Analysis of the data shows that on the average over the period a 1 million ton reduction in world rice production was accompanied by a $8/ton increase

in the export price of Thai 5% rice.[4] These price fluctuations lead to a peculiar response by governments and international lenders like the World Bank who evaluate the costs and benefits of rice production investments on the basis of world rice prices. When rice prices and hence benefits are high, investment is high and when rice prices are low, investment is low. Figure 5 illustrates this for the Philippines in the case of irrigation. The highly cyclical nature of irrigation investment is closely correlated with fluctuations in the benefit-cost ratio caused principally by variation in the world rice price used in calculating the benefits. Hence, an indirect effect of price fluctuation is to induce fluctuation in food production investment.

This kind of fluctuation in food production investment also occurs in the construction of fertilizer manufacturing plants, resulting in wide swings in fertilizer prices. We argue that a steady growth of fertilizer and irrigation would be a preferable situation. The next section of the paper discusses a model that may be used to indicate the necessary investment for increasing rice production at a rate sufficient to meet anticipated demand.

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[4] A regression equation fitted to the data in the graph show:

$$P_t - P_{t-1} = 67.23 - \underset{(2.87)}{8.25}\,(Q_{t-2} - Q_{t-1}) - \underset{(0.42)}{0.21}\,(W_{t-2} - W_{t-1}) \quad R^2 = 0.48$$

Where P = price, Q = world rice production, W = world grain production except rice; values in parentheses are "t" values. Data were 1960/61 to 1974/75.

FUTURE GROWTH IN 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, the expected magnitude of imports, and the need for action to change trends, A number of such studies are available.

In mid-1960s, the FAO began work on its "Indicative World Plan" for agriculture. This document has become the basis for the more recent projections of foodgrain production to 1985 summarized in Table 7. All three projections were made by projecting past rates of growth of output. Demand was projected by an equation like (1), using the United Nations medium population projection, assuming a modest rate of income growth and using the FAO's income elasticities of demand.

The projections of the International Food Policy Research Institute (IFPRI, 1976), the Asian Development Bank (1977), and the World Bank (Hadler, 1976) differ somewhat in absolute levels because of differences in countries and crops included, different income projections, and differences in using milled rice or paddy as the basis for calculations. Despite these differences, all three studies indicate that a gap between 25 (World Bank), and 40 (IFPRI) million tons foodgrains will exist between production and demand in the region by 1985 (for example, see Fig. 6).

These deficits are projected to occur with 2.2% (World Bank) and 2.8% (IFPRI) annual rates of growth of output, respectively. The ADB supply projection is higher, but demand also grows faster resulting in a projected deficit.

If rice output grows at a rate within this range it will approximate its growth over the past 15 years. What kind of changes in agricultural resources devoted to rice will be required to insure such a rate of growth?

A model of rice output growth

To answer this question, we developed a simple aggregate model of rice output growth for South and South East Asia[5] that includes land, fertilizer, irrigation, technological change, and the investment cost associated with each source of growth. The model begins from the base year of 1974 and projects to 1985. It permits us to determine what investment would be required to obtain different rates of output increase.

The model works as follows:

1) The geographic land area available for rice production is assumed constant through 1985, but the distribution of that land among the major types of rice culture is determined based on projections of irrigation investment.

2) The proportion of each type of land in modern and traditional varieties is projected based on historical trends and on investment in research and extension.

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[5]See Table 8 for the countries included in the model.

3) The fertilizer available for rice production and the investment necessary to produce that fertilizer is determined based on historical trends and budgeting studies of fertilizer investment.

4) The fertilizer used per hectare of each type of rice is determined based on fertilizer response functions, total fertilizer availability, area in each type of rice, and the assumption 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) Technological change affects the response functions used in steps 4 and 5.

The basis for the data and relationships used in each part of the model are discussed below.

Land in rice. The geographic area devoted to rice production in the study countries has probably increased very little in the past decade except in Thailand and on the outer islands of Indonesia. As shown above, some countries including the Philippines, have had a decrease in the net area devoted to rice production. It is impossible to get accurate regionwide 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 double cropped area which are made possible through irrigation. About 30% of the gross irrigated area has two rice crops in 1974. It is possible that this proportion could increase, but to be conservative we assume it is constant throughout. As irrigation increases, land is switched from the rainfed category to the irrigated category. Total area increases as irrigated area increases because 30% of the irrigated area is double cropped.

Changes in varieties. For purposes of this model, riceland is classed as irrigated, rainfed and upland-deepwater. Irrigated and rainfed areas are further divided into area planted to modern and traditional varieties, giving five types: irrigated modern varieties (IMVI), rainfed modern varieties (IMVR), irrigated traditional varieties (TVI), rainfed traditional varieties (TVR), and upland and deepwater which are all assumed to be traditional (ULDW). Good statistics are not available on the existing area planted to these types, but farm surveys have invariably shows a close association between irrigated area and modern varieties, and an equally close relationship exists on an inter-country basis. Table 9 shows the area irrigated and planted in MVs during the 1963-1973 period. We project that modern varieties will cover 90% of the irrigated riceland in 1985.

Modern varieties are also grown on rainfed land. For example, in the Philippines modern varieties covered 64% of the rainfed lowland

and 80% 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 modern varieties is assumed to reach 30% by 1985.

Irrigation growth. The amount of irrigated land is one of the policy variables determined externally for the projections model. The resulting costs are determined by the model. Several recent studies of irrigation costs and coverage are available. Kikuchi's (1975) study of Philippine irrigation system construction between 1949 and 1975 showed construction costs (converted to 1975 constant prices)[6] on river diversion systems of $304/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. 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.

Kikuchi (1975) hypothesized that costs of new irrigation would continue to increase because the more suitable irrigation locations had been constructed first, and the remaining sites would continue to entail higher costs.

Nakahara (n.d.) reviewed irrigation projects financed by the Asian Development Bank (ADB) and World Bank in Asia between 1965 and 1974. His primary focus was on the costs of projects. Eight irrigation construction projects financed by the World Bank irrigated a total of 1,071,900 ha

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[6]Converted using the index of international inflation reported by Nakahara (n.d.).

at a capital cost of $587 million, a cost per hectare of $548. Twenty-four ADB financed projects that irrigated a total of 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 had no explanation for the difference in cost between the two organizations 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/ha to $1300/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. We have used $1000 and $1300 as low and high per hectare investment in our 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. Ex-post, the projects usually show much more modest benefits. In our analysis, we make the benefits of irrigation dependent on the level of fertilizer and modern varieties, as discussed below. The minimum yield benefit of irrigation is 0.7 t/ha, increasing to 1.5 t/ha, depending on the technology level.

Fertilizer demand and investment cost. Fertilizer application is a major source of additional rice output. Since the introduction of modern varieties, the amount of fertilizer applied to rice has increased rapidly; between 1963 and 1967 fertilizer applied on rice increased at

nearly 20% annually and between 1968 and 1973, at nearly 8%. In the early 1970s, fertilizer on rice amounted to one-third of the total fertilizer used in the countries of the region. Micro-level studies show a considerable scope for higher yields from more fertilizer, even where it is presently being applied to rice. However, there is clearly a limit to the level of fertilizer that can be profitably applied.

Projections of the future demand for fertilizer in Asia have been conducted by the National Fertilizer Development Center of the Tennessee Valley Authority (TVA). Those projections are used as the base projection of fertilizer use between 1975 and 1980. TVA's projections show a 12% annual rate of increase in fertilizer use in South and Southeast Asia in 1975, declining gradually to a 9% rate of increase in 1980. For our projections, we have extended this trend through 1985 when use would be growing at 8% annually. An alternative projection uses a 12% rate declining to a 9.5% annual increase.

The fertilizer can be obtained either by importing it from the developed countries or by constructing fertilizer production capacity within the region. India, Indonesia, and Bangladesh are actively pursuing the latter course, with other countries having some manufacturing capacity. Fertilizer imports may be preferred by smaller countries of the region, but the production capacity will have to be created somewhere in the world.

The cost of imports will be higher than cost of production because a return on investment of 20% increases the cost of a ton of fertilizer by about 75%. Also, if countries create production capacity, their future

import needs are correspondingly reduced. Offsetting these advantages fertilizer plant construction entails a large amount of foreign exchange commitment at one time, and efficient plants are too large for most countries to fully utilize with present levels of demand.

According to published studies by the TVA of the cost of fertilizer plant construction, an ammonia-urea production uni. of the latest technical design, using low cost ($0.10/1000 ft^3) natural gas as a feedstock and producing 495,000 tons of urea per year, entails a capital investment ranging from $187 to $190 million. The calculations are in 1975 dollars, but allow for a moderate cost increase through 1978. In such a unit, urea can be produced for approximately $100/ton under the TVA assumptions. If operated commercially, a 20% return on investment in addition to costs of production would increase the gate sale price to $175/ton. Feedstock costing $0.25/1000 ft^3 would increase production cott to $103/ton, and $0.50 gas would increase it to $109/ton (TVA, p. 86).

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

Fertilizer application rates and yield. One may project output increases from fertilizer availability by using a "rule-of-thumb" like 10 kg of grain per kg of fertilizer as we have in the analysis of sources

of output growth. However, that approach does not reflect the complementarity of fertilizer, irrigation and new varieties. Traditional varieties respond less to fertilizer than modern varieties, and both respond more when irrigated than when left unirrigated. In most countries, the area planted to modern varieties is irrigated, thereby removing some of the potential drought stress that would likely occur under rainfed conditions. Farmers use higher rates of fertilizer on modern than on traditional varieties.

In order to reflect the complementary benefits of new varieties, irrigation and fertilizer, the following four fertilizer response functions, developed from research reported by Barker, Bennagen and Hayami are used:

(2) MVI: $Y_1 = 2200 + 18F_1 - 0.09\ F_1^2$

(3) MVR: $Y_2 = 1400 + 15F_2 - 0.11\ F_2^2$

(4) TVI: $Y_3 = 2000 + 11F_3 - 0.13\ F_3^2$

(5) TVR: $Y_4 = 1400 + 9F_4 - 0.16\ F_4^2$

The functions were based on national farm survey data in the Philippines, and experiment station data adjusted by observed differences between survey and experimental data. Upland and deepwater rice are assumed to be not responsive to fertilizer application.

When the levels of fertilizer, modern varieties and irrigation for a particular year are known, the resulting production that will be obtained is calculated using these functions. 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 not enough fertilizer is available to permit this, then the available supply will be applied so that its marginal product is equal on each type of rice. If one believes that one unexploited source of growth is from higher rates of fertilizer application, this implies that the present rates do not equate the marginal productivity to the price ratio. Thus, the marginal products will be equated to a constant, say a, which is the shadow price of fertilizer in terms of rice -- the real marginal value of fertilizer applied to rice.

Expressing this condition for the above response functions gives:

(6) $$a = 18 - 0.18F_1 = 15 - .22F_2 = 11 - .26F_3 = 9 - .32F_4$$

If the area in each type of rice (MVI, MVR, TVI, TVR) and the total amount of fertilizer (F) applied to rice is known, then one may solve for the rates of fertilizer applied to each type of rice, (F_i), and total production as follows. First, solve equation (6) for the F_i in terms of a, then substitute those values of F_i in the following equation which simply states that the total fertilizer used on rice equals the per hectare rates times the number of hectares planted.

(7) $$F = MVI \cdot F_1 + MVR \cdot F_2 + TVI \cdot F_3 + TVR \cdot F_4$$

Solve (7) for the value of a, the shadow price ratio of fertilizer, and substitute this back into equation (6), obtaining F_1 through F_4. Substituting these values in equations (2) through (5) gives the yields of each type of rice, which together with the acreages gives total rice production.

Investment in research and extension. Studies for a number of countries have shown such investment to have an extremely high payoff by all criteria. The study of Evenson, Flores and Hayami (1976) estimated the shift in the supply function of rice brought about by technological changes and their dissemination to farmers in the developing world. Costs were the total investments in rice research and extension in the developing rice producing countries adjusted by the proportion of the total research directed toward rice improvement, based on numbers of scientific publications on rice and other crops. The most conservative data from their study shows the following investments and increases in production for all developing rice producing countries excluding East Asia (China, Korea, Japan):

(Annual amounts)	1921-40	1950-60	1961-65	1966-70	1971-75
Investment (million $)	4.9	15.3	27.0	43.3	49.5
% shift in supply	-	0.157	0.319	1.528	1.437
Increased output (million t)	-	0.17	0.46	2.56	2.47
Value of increased output (million $)	-	20.97	57.60	320.43	308.78

These data indicate that $50 million annual investment in research and extension generated shifts of from 0.6 to 1.5% in the aggregate supply of rice in the developing countries during the last 15 years.

The Evenson, Flores and Hayami study provide convincing evidence of the payoff from new technology, but they do not indicate the mechanism of how new technology shifts the supply curve. The conventional economic explanation of technological change is that it arises from a change in the production function (Wilcox, Cochrane and Herdt). This could be

interpreted, in this case, as the difference between equations (2) and (4) or between (3) and (5). 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 such things as insect resistance, problem soils and drought, as well as fertilizer efficiency, so it is almost 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 response functions. If one agrees that the investment in rice research and extension between 1960 and 1970 caused the observed change in the fertilizer response function between (2) and (4), 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% 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 fraction of previous research. Even building the capacity for research by training additional researchers is a time

consuming process (Bateson, 1977) which can itself limit the amount of growth that can be obtained from this source.[7] Also, a certain amount of research investment is needed to maintain current levels of productivity. Hence, the 15% in marginal productivity will only be generated by $100 in addition to current (maintenance) research investments.

Model verification, 1963-67 to 1968-72

Inputs to production. To evaluate the validity of the projections model, it was used to estimate production with the actual levels of inputs used by the countries of the region for the five year average periods 1963-67 and 1968-72. The input data are shown in the "total" line of Table 8. It was assumed that in 1963-67 the modern varieties were planted only on irrigated land, that in 1968-72 95% of the modern varieties area was irrigated and by 1973-74, 90% of the MV area was irrigated. 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% as rapidly between 1968-72 and 1973-74 as it did in the previous five year period. Assuming the same proportional rate for all countries gave the 1.8% rate of irrigation growth used for the second validation period.

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[7] One of the functions of international institute like IRRI are to provide the capacity for research in a setting where it would otherwise not be available.

Estimated vs. actual output. Under these assumptions, the model estimates an average annual level of output of 112.1 million metric tons of rice (paddy) production compared to reported production of 111.1 for the included countries in 1963-67. For 1968-72, estimated production was 128.1 compared to reported production of 129.5. For 1973-74, estimated production was 141.3 million tons while reported output was 142.9. The estimated annual growth rates between the two periods were 2.7% and 2.5% while the growth rates of reported output were 3.1% and 2.8%.

These comparisons indicate that the model slightly underestimates the rate of growth of output. The unaccounted gains may be attributed to incremental output gains arising from other unmeasured inputs that have increased continuously, most notably, labor. It is assumed that these other inputs contributed the additional 0.3% annual growth in output. When this increase is added to that arising from fertilizer, technology and irrigation, estimated output for 1968-72 becomes 130.2 compared to reported output of 129.5, with a production growth rate of 3.0%. Including the labor contribution, estimated output for 1973-74 is 143.4 compared to reported output of 142.9, with an estimated production growth of 2.8% per year. Table 10 shows the inputs and results of the verification runs.

The implied price ratio of fertilizer exceeds 6.5 in both verification periods. Since the market price ratio was 4.0 or lower for most countries during the period, ample scope for using higher fertilizer rates still existed in 1973-74.

Investment costs. Given the known increases in fertilizer, irrigation, research and extension, the investment cost of the agricultural growth actually achieved between 1963-67 and 1968-72 was calculated as in Table 9. For convenience of comparison with future costs, all costs are shown in US$ at constant 1975 prices. Because of the range in costs that exists in the sources used, we show a low and high estimate for each alternative. Fertilizer may be either produced domestically or imported so both alternatives are shown. Using the fertilizer import alternative, the total estimated irrigation investment and expenditure on research, extension and imported fertilizer to generate the increased rice output from the sources identified in the model ranged between $4305 million and $5820 million for the five year period centered on 1965 to 1970. Using the domestic fertilizer plant construction alternative the cost ranged from $4334 to $5665 million. The same techniques of cost calculation were used to determine investment costs for increasing future rice output using various alternative combinations of inputs.

Projections from the model, 1985

Table 10 summarizes the results of six alternative sets of projections and comparable data from the two verification periods. In runs 1,2, and 3 irrigated area increases at 1.5, 2.0 and 3.0% annually. Fertilizer demand grows at 12% in 1974 then gradually declines to a rate of 8% annual growth in 1985, as projected by TVA. In run 4, irrigated area grows at 3% and fertilizer demand grows slightly more rapidly than projected by TVA. Runs 5 and 6 assume that farmers fertilizer productivity

is increased 30% through research and extension.

With a 1.5% annual rate of increase in irrigation, output grows at 1.6%. A 2.0% annual increase in irrigation pushes output growth to 1.8%/year, while a 3.0% growth rate of irrigated land increases output growth to 2.3%. All three are well below the observed rate of output growth during the recent historical periods, and all entail substantially higher rates of annual investment for irrigation and fertilizer. Faster increases in fertilizer will not help much, and the additional fertilizer will only be applied if its price is very low (run 4).

The most important finding of the analysis is that investment in irrigation and fertilizer at the levels considered (which are much larger than historical levels)will not be sufficient to increase production by more than 2.4% 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 getting that technology adopted).

The means of increasing the productivity of resources applied by farmers is an area about which policy makers,economists and scientists know very little. We have assumed that an additional $200 million investment per year will raise productivity as indicated in runs 5 and 6. This assumption, while based on the best available data still leaves

us uncomfortable. For one thing, relatively little effort has so far been made to identify and close the gap between potential and actual yields of present technology. IRRI's recent efforts to develop a methodology for measuring the gap and identifying its sources may have some payoff in this regard. The limited experience with the "Training and Visits" extension system being advocated by the World Bank seems to have been very favorable (Benor and Harrison). 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 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 8-10 years. An additional 5 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 10). It also requires a supply of individuals suitable for training. Thus, the main constraints to increasing investment in research and extension may not be quickly removed.[8]

The above results are only tentative because of the many data assumptions made. They are presented in order to stimulate further research of this type. 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 may indicate the general magnitude of agricultural investments and productivity increases needed in order to produce enough rice for Asia in 1985.

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[8]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 MS and Ph.D. training in order to produce the new knowledge and technology required to meet Nepal's food requirements for the year 2000. This is especially difficult for Nepal which even sends its BS agricultural students abroad.

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Table 1. Growth in per capita calorie consumption and in gross domestic product per capita at 1975 constant prices, selected Asian countries, 1965-73.

Countries	Calories/capita/day 1965 (US$)	1973	Annual growth 1965 to 1973 (%)	Gross domestic product/capita 1965 (calories)	1973	Annual growth 1965 to 1973 (%)
	(Calorie consumption 2200 and above)					
South Korea	219	417	8.5	2289	2706	2.1
Taiwan	482	824	6.9	2629	2804	0.8
Thailand	242	330	4.0	2208	2312	0.6
Malaysia	593	779	3.5	2435	2531	0.5
	(Calorie consumption less than 2200)					
Indonesia	121	164	3.9	1846	2032	1.2
Pakistan	153	184	2.4	1882	2152	1.8
Philippines	246	297	2.4	1938	1962	0.2
Sri Lanka	113	129	1.7	2219	2044	-1.4
India	134	140	0.5	1955	1977	0.1
Burma	92	95	0.4	1997	2160	1.0
Nepal	137	134	-0.3	2094	1994	-0.3
Bangladesh	119	104	-1.7	2012	1957	-0.3

Table 2. Percent annual growth[a] in food production, population, and domestic demand in selected Asian countries, 1952/72.

Countries	Food production[b]	Population	Domestic demand[c]
	Production failed to equal population growth		
Nepal	0.1	1.8	2.1
Bangladesh	1.6[d]	3.5[d]	n.a.
Indonesia	2.0	2.5	2.6
	Production failed to equal growth in domestic demand		
Burma, Union of	2.4	2.2	3.3
India	2.4	2.1	3.0
Pakistan	3.0	3.0	4.2
Philippines	3.2	3.2	4.2
	Production exceeded growth in domestic demand		
Sri Lanka	3.6	2.5	3.1
Korea, Republic of	4.8	2.7	4.7
Malaysia (West)	5.2	3.0	4.3
Thailand	5.3	3.1	4.6

[a]Exponential trend, 1952/72.

[b]Food component of crop and livestock production only (i.e., excl. fish production).

[c]Calculated on basis of growth of population and per capita income and estimates of income elasticity of farm value of demand in FAO Commodity Projections, 1970-1980, Tome, Italy, 1971. Total food, including fish.

[d]1962/72.

n.a. = data not available.

Source: United Nations World Food Conference, Rome, Nov. 5-16, 1974, Assessment of the World Food Situation Present and Future, pp. 53-54.

Table 3. Growth rates of production, area and yield of rice and their components, Philippines, 1955/1973.

	1955/73	1955/65	1965/73
		Annual growth rates (%)	
Production	2.78	2.41	3.24
Area	1.11	1.15	1.05
Yield	1.62	1.20	2.15
		Percentage points attributed	
Area			
Physical area	-0.18	0.28	-1.01
Double cropping	1.29	0.87	2.06
Yield			
Type of rice land[a]	0.79	0.96	0.44
Fertilizer[b]	0.85	0.32	1.47
Residual	-0.02	-0.08	0.24

[a]Changes in the proportion of upland, rainfed, wet season and dry season irrigated.

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

Table 4. Growth rates of food grain production and the contribution from specified inputs, India, 1955-1973.

	1955-73	1955-65	1965-73
	Annual growth rate		
Production	2.71	2.21	3.33
	Percentage points attributed to		
Area			
Unirrigated land	0.09	0.06	0.11
Irrigated land	0.61	0.36	0.89
Yield			
Fertilizer	1.19	0.54	1.88
Irrigated land	0.82	1.25	0.45

Source: Calculated as in the Appendix from data presented by J.W. Mellor in The New Economics of Growth, Appendix Table 9.

Table 5. Estimated proportion of growth in rice output attributed to components of area and yield for selected Asian countries, mid-1960s to early 1970s.

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

[a]Calculated on the basis of 10 kg of 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.

Table 6. Annual growth in production, irrigated area, fertilizer per hectare, and area in MVs, 1965-70 and 1970-74.

Country	Annual compound growth rates						Average annual increment			
	Production		Irrigated land		Other land		Fertilizer (Kg NPK/ha)		Area in MV (% of rice area)	
	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.	2.72[b]	n.a.	5.50	20.40	1.6[illegible]	12.55
India	3.20	0.83	1.56	n.a.	0.33	n.a.	2.28	1.05	2.42[e]	3.75
Thailand	2.61	0.93	0.35	0.62	3.02	0.04	0.78	-0.23	0.20[f]	1.52
Indonesia	4.92	4.71	2.89[c]	2.53[c]	-0.64	-4.36	2.37	4.41	3.70[g]	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	0.20	0.92	2.50
Burma	0.49	2.28	2.02	3.87	-0.61	0.40	0.61	0.40	1.0[h]	0.65

n.a. = data not available.

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

[b]This refers to time period 1965-69.

[c]This includes rainfed area.

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

[e]1964-70

[f]1968-70

[g]1967-70

[h]1966-70

Source of basic data: Production data is from USDA except for Indonesia and Thailand which use national source. Irrigation data is from national source. Fertilizer data is estimated from FAO Annual Fertilizer Review, national source and special studies. Modern varieties data is from D. Dalrymple, Development and Spread of High Yielding Varieties of Wheat and Rice in the Less Developed Nations, USDA, August 1976. For more detailed explanation on sources of irrigation and fertilizer data, see Palacpac, World Rice Statistics, Dept. of Agricultural Economics, IRRI, Revised April 1977.

Table 7. Alternative sets of cereal grain production projections and rates of growth for selected Asian countries.

	IFPRI[a]			ADB			World Bank		
	1969-71	1985-86	Rate	1970-74	1985	Rate	1974	1985	Rate
India	101.7	133.5[b]	1.8	111.5	176.9	3.6	80.7	106.1	2.5
Bangladesh	11.1	13.1	1.1	16.8	26.7	3.6	11.7	13.9	1.6
Pakistan	10.5	22.3	5.0	11.5	19.2	4.0	11.2	17.2	3.9
Indonesia	15.6	23.3	2.7	24.5	34.5	2.7	18.3	27.5	3.7
Philippines	5.4	8.7	3.2	7.3	12.8	4.4	6.2	9.5	3.9
Thailand	11.0	18.4	3.4	15.4	23.4	3.3	11.5	16.5	3.3
Sri Lanka	-	-	-	1.5	2.3	3.3	1.2	1.7	3.2
Burma	-	-	-	8.3	12.1	2.9	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	307.9	3.5	149.0	201.6	2.8

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

[b]Hendrix projects 1984/85 production for India at 141.6 million metric tons from a base year 1974/75 production of 102.6

Source: IFPRI, 1976; Asian Development Bank, 1977; Hadler, 1976.

Table 8. Area, irrigation, modern varieties and fertilizer used in rice production in South and Southeast Asia, 1963 to 1

Country	Total rice area ('000 ha)			Irrigated rice area ('000 ha)			Modern varieties area (000 ha)			Fertilizer applied to rice '000 nutrient t		
	1963-67	1968-72	1973-74	1963-67	1968-72	1973-74	1963-67	1968-72	1973-74	1963-67	1968-72	1973
India	35886	37333	38302	13413	14498		894	5539	10249	279	715	869
Bangladesh	9311	9745	9900	500[a]	910[a]	1106[a]	34	513	1515	20[e]	43[e]	50
Indonesia	7249	8078	8625	5739	6616	7220	0	1039	3270	64	167	285
Thailand	6153	6941	7398	1706	1780	1819	0	108	425	22	52	49
Burma	5019	4958	5143	667	737	858[b]	3	177	292	6	21	29
Philippines	3159	3183	3544	1102	1374	1447	392	1556	2217	24	61	83
Pakistan	1373	1523	1624	1373[b]	1523[b]	1624[b]	2	547	634	11	33	41
Malaysia	399	515	587	167	375	442[d]	65	161	219	19	32	49
Sri Lanka	597	627	574	359	403		0	73	360	15	33	65
Total	69146	72903	75697	25026	28216	30035[f]	1390	9713	19181	460	1157	1520
Growth rate	-	1.1%	1.1%	-	2.4%	1.8%[f]	-	38.9%	19.4%	-	18.5%	7.8
7 country total[g]	32.663	34943	36821	11254	13315	14516	496	4101	8572	166	409	586
Growth rate		1.3%	1.5%	-	3.4%	2.5%		42.2%	21.1%	-	18.0	10.

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

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

[c]Projected at 20% of total fertilizer for the country, projected from two previous periods when it was 30% and 23%.

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

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

[f]Projected based on Bangladesh to Malaysia growth of 9% compared to 18% in previous 5 years period.

[g]Bangladesh through Malaysia.

Table 9. Estimation of costs associated with increased input use for increased rice production achieved, nine Asian countries, 1963-67 to 1968-72.

Input	Cost range	Av. annual increase	Unit cost ($) for Capital investment	Unit cost ($) for Current costs	Annual capital investment Domestic	Annual capital investment Foreign	Annual additional current costs[a] Domestic	Annual additional current costs[a] Foreign	Total five year Total	Total five year Domestic	Total five year Fore
Irrigated land	Low	638,000 ha	1000	10	319	319	6	0	3280	1685	159
Irrigated land	High	638,000 ha	1300	20	415	415	12	0	4330	2255	207
Fertilizer, urea	Low	232,000 t[b]	0	150[c]	0	0	0	35	525	0	52
Fertilizer, TSP	Low	77,000 t	0	250[c]	0	0	0	19	285	0	28
Fertilizer, urea	High	232,000 t	0	250[c]	0	0	0	58	870	0	87
Fertilizer, TSP	High	77,000 t	0	350[c]	0	0	0	27	405	0	40
Fertilizer, urea	Low	0.47 units[d]	187(m)	60[e]	0	87	7	7	649	105	54
Fertilizer, TSP	Low	0.23 units[f]	78(m)	132[e]	0	18	5	5	190	75	16
Fertilizer, urea	High	0.47 units	190(m)	70[e]	0	89	8	8	685	120	56
Fertilizer, TSP	High	0.23 units	133(m)	243[e]	0	30	9	9	435	150	28
Research extn.	-	-	43(m)	0[h]	33[g]	10	0	0	215	165	5

[a]The additional amount must be cumulated so that the 5-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, etc

[b]Annual increase of 139,000 nutrient tons converted to Urea and TSP assuming 3/4 of fertilizer is Urea, 1/4 is TSP.

[c]All fertilizer is imported in these cases.

[d]One ammonia-urea production unit will produce 495,000 tons urea/year. About one every 2 years would meet the needs

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

[f]One TSP production complex with phosphate rock grinding and sulphuric acid plant will produce 340,000 tons TSP/year with investment cost ranging from 78 to 133 million (TVA, p.99).

[g]Arbitrary breakdown between domestic and foreign.

[h]Assumed to be entirely an investment.

Table 10. Projected rates of increase of irrigation, fertilizer and technology[a] and associated output growth, and investment required, South and Southeast Asia, 1974-1985.

Run no.	Inputs to the model: Irrigated area (%/yr)	Inputs to the model: Fertilizer (%/yr)	Outputs of the model: Production (%/yr)	Outputs of the model: Implied N:rice price	Annual investment ($ million): Low fertilizer, Imported	Annual investment ($ million): Low fertilizer, Domestic	Annual investment ($ million): High fertilizer, Imported	Annual investment ($ million): High fertilizer, Domestic
			Verification					
V1[b]	2.4	18.5	3.0	6.6	861	866	164	1133
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	1072	960	1530	1237
2	2.0	12-8	1.8	1.8	1252	1140	1768	1475
3	3.0	12-8	2.3	2.6	1641	1529	2256	1963
4	3.0	12-9.5	2.4	0.8	1754	1619	2435	2080
			Projections with improved technology and inputs					
5 T[c]	1.5	12-8	2.5	5.5	1272	1160	1730	1437
6 T[c]	3.0	12-8	3.0	6.8	1841	1729	2456	1963

[a]MVs covered 6% of irrigated rice land in 1963-67, 33% in 1968-72 and 57% in 1973-74. They are assumed to cover 90% of irrigated and 30% 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%/year in 1974, that rate declines gradually to 8%/year by 1985.

Appendix

The following formulae were used in calculating the annual compound growth rate and estimated shares of increased output attributed to area and yield (Appendix Table 1).

1. Annual compound growth rate (%) of area (G_A) or yield (G_Y).

Compute

$$\left[\sqrt[t]{\frac{V_2}{V_1}} - 1 \right] \times 100$$

where V_1 is the value for period 1 which is a 5-year average centered at year shown.

V_2 is the value for period 2 which is a t-year average centered at year shown.

t is the number of years interval between period 1 and 2.

2. Breakdown of output growth into percentage points attributed to components of <u>area</u>.

a) percentage points attributed to <u>irrigated land</u>.

Compute

$$\frac{I_2 - I_1}{A_2 - A_1} \times G_A$$

where:

I is irrigated rice area for the period indicated in the subscript which is a 5-year average centered at year shown.

A is total rice area, also 5-year average centered at year shown.

G_A is the annual compound growth rate (%) of total rice area.

b) percentage points attributed to <u>unirrigated land</u>.
- compute as in 2a above but unirrigated area is used in place of irrigated area.

c) percentage points attributed to upland area
- compute as in 2a above but upland area is used in place of irrigated area.

3. Breakdown of output growth into percentage points attributed to components of yield.

a) Fertilizer - calculated on the basis of 10 kg of yield for every 1 kg of fertilizer.

Compute

$$\frac{(F_2 - F_1) \times 10}{Y_2 - Y_1} \times G_y$$

Where:

F is kilogram of NPK used on rice per hectare for the period indicated in the subscript which is a 5-year average centered at year shown.

Y is yield in kilogram per hectare for the period indicated in the subscript which is also a 5-year average centered at year shown.

G_Y is the annual compound growth rate (%) of yield.

b) Residual

Compute

$$G_Y - \left[\frac{(F_2 - F_1) \times 10}{Y_2 - Y_1} \times G_Y \right]$$

Appendix Table 1. Estimated shares in paddy output attributed to area and yield.[a]

	Production (000 m.t.)	Attributed to area: Irrigated	Unirrigated	Upland	Total	Attributed to yield: Fertilizer (kg of NPK/ha)	Residual	Yield (ton/ha)
		(thousand hectares)						
India								
Average 1963-67	52,525	13,413	22,473	-	35,886	7.77	-	1.462
Average 1968-72	61,480	14,490	22,843	-	37,333	19.15	-	1.647
Annual compound growth rate 1965-70	3.2	1.6	0.3	-	0.8	19.8	-	2.4
		(0.6)	(0.2)			(1.5)	(0.9)	
Indonesia								
Average 1963-67	15,478	5,739[b]	-	1,510	7,249	8.83	-	2.134
Average 1970-74	21,571	6,923[b]	-	1,337	8,260	26.30	-	2.610
Annual compound growth rate 1965-72	4.8	2.7	-	-1.7	1.9	16.9	-	2.9
		(2.2)		(-0.3)		(1.1)	(1.8)	
Philippines								
Average 1963-67	4,113	1,102	1,508	549	3,159	7.61	-	1.301
Average 1971-75	5,386	1,394	1,578	411	3,383	24.90	-	1.588
Annual compound growth rate 1965-73	3.4	3.0	0.6	-3.6	0.9	16.0	-	2.5
		(1.2)	(0.3)	(-0.6)		(1.5)	(1.0)	
Thailand								
Average 1963-67	11,456	1,706	4,447	-	6,153	3.58	-	1.862
Average 1970-74	13,237	1,808	5,227	-	7,035	6.79	-	1.880
Annual compound growth rate 1965-72	2.08	0.83	2.34	-	1.93	9.58	-	0.14
		(0.2)	(1.7)			(0.3)	(-0.1)	
Pakistan								
Average 1963-67	2,019	1,373[c]	-	-	1,373	8.01	-	1.469
Average 1970-74	3,437	1,511[c]	-	-	1,511	25.54	-	2.276
Annual compound growth rate 1965-72	7.9	1.4	-	-	1.4	18.0	-	6.5
		(1.4)				(1.7)	(4.8)	
Malaysia (West)[d]								
Average 1963-67	1,083	53	359	21	433	45.0	-	2.500
Average 1971-75	1,695	200	370	13	583	75.0	-	2.900
Annual compound growth rate 1965-73	5.7	18.1	0.4	-5.8	3.8	6.8	-	1.85
		(3.7)	(0.3)	(-0.2)		(1.4)	(0.5)	
Sri Lanka								
Average 1963-67	987	359	238	-	597	25.13		1.653
Average 1970-74	1,448	380	241	-	621	72.22		2.331
Annual compound growth rate 1965-72	5.6	0.8	0.2	-	0.6	16.3		5.0
		(0.5)	(0.1)			(3.5)	(1.5)	

[a]Figures in parentheses indicate the percentage points of annual production growth over the period which is attributable to each input.

[b]This includes rainfed area.

[c]Assume 100% of rice area is irrigated.

[d]Figures for West Malaysia are adopted from Yim Kong Ming, "A Study into the Sources of Agricultural Growth in West Malaysia," a term paper submitted to the University of the Philippines at Los Baños in partial fulfillment for the subject in Agricultural Economics 236, Second Semester, 1976/77.

Sources of basic data: Production, total area, and yield data are from USDA except for Indonesia and Thailand which use national source.
Data on irrigated area is from national source.
Fertilizer data is estimated from FAO Annual Fertilizer Review, national source, and special studies.
For more detailed explanation on the sources and estimation of irrigation and fertilizer data, see Palacpac, World Rice Statistics, Dept. of Agricultural Economics, IRRI, Revised April 1977.

Appendix Table 2. World rice, wheat and coarse grains production and rice production in selected countries (million metric t), 1974-1977.

	1963-67	1968-72	1973-74	1974-75	1975-76	1976-77[a]
			World Total			
Wheat	276.7	329.2	371.6	356.4	350.0	412.4
Coarse grains	505.0	601.6	659.6	620.4	634.4	692.1
Rice[b]	265.8	302.8	324.3	330.0	352.3	343.8
			Country Rice Production			
China	95.2	107.6	112.9	120.0	119.0	118.0
India	52.5	61.4	66.1	59.4	74.3	67.1
Indonesia	15.5	19.7	21.5	22.5	22.6	22.6
Bangladesh	15.7	16.3	17.6	17.1	18.8	19.1
Japan	16.2	16.0	15.2	15.4	16.5	14.7
Thailand	11.4	13.0	14.3	14.5	15.2	15.0
Burma	7.8	7.9	8.6	8.6	9.2	9.3
Brazil	6.4	6.2	6.5	7.0	8.5	7.8
Korea (S)	5.1	5.3	5.8	6.2	6.5	7.2
USA	3.6	4.1	4.2	5.1	5.8	5.3
Pakistan	2.0	3.3	3.7	3.5	3.9	3.7
All others	34.4	42.0	47.9	50.9	52.1	53.9

Source: USDA "Foreign Agriculture Circular," March 23, 1977 and IRRI Agricultural Economics Department, "World Rice Statistics," 1977.

[a]As of March 23, 1977 USDA estimate.

[b]Rice data are for rough rice (paddy).

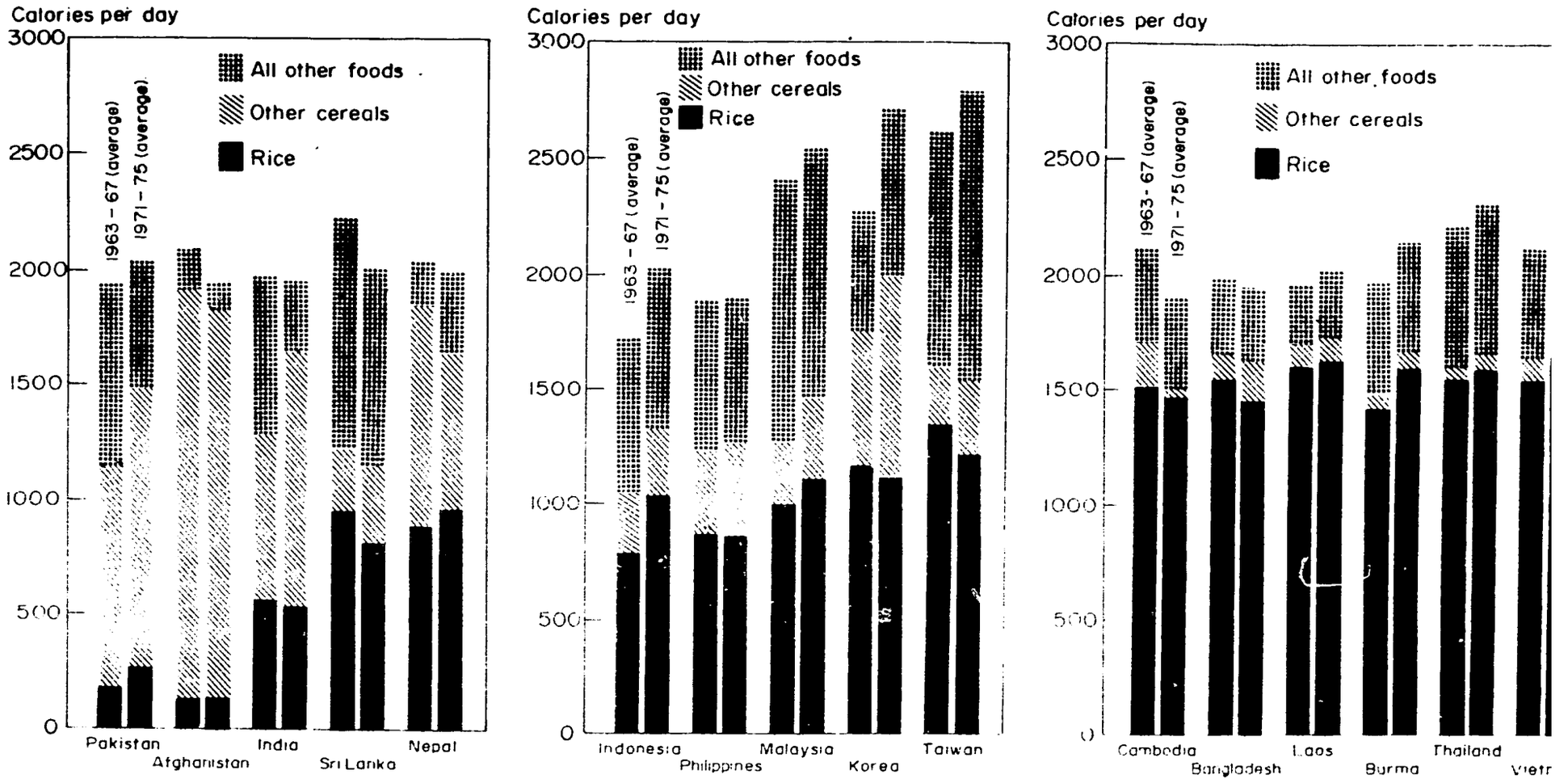


Fig 1 Apparent per capita daily calorie consumption, 1963 - 67 and 1971 - 75

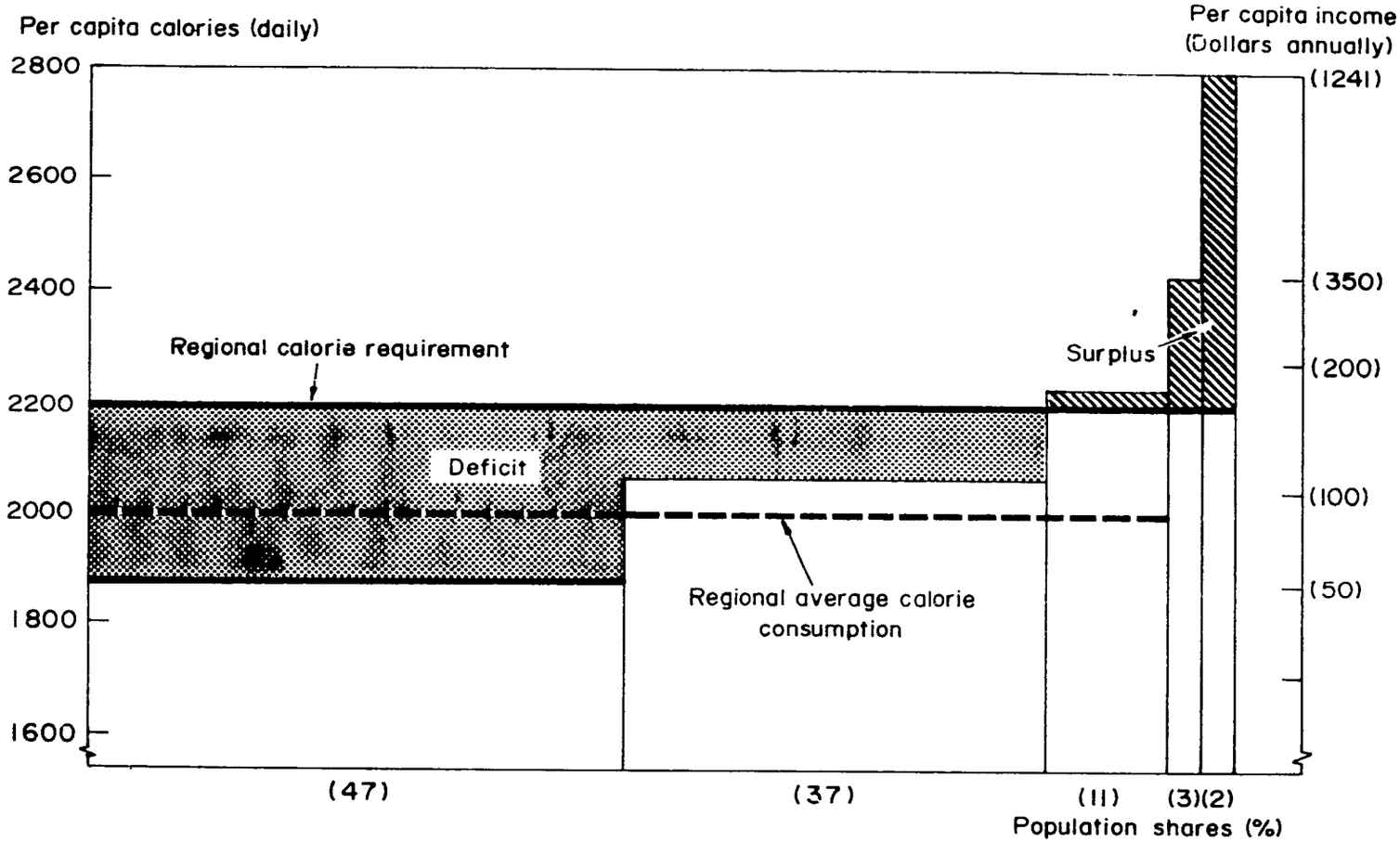
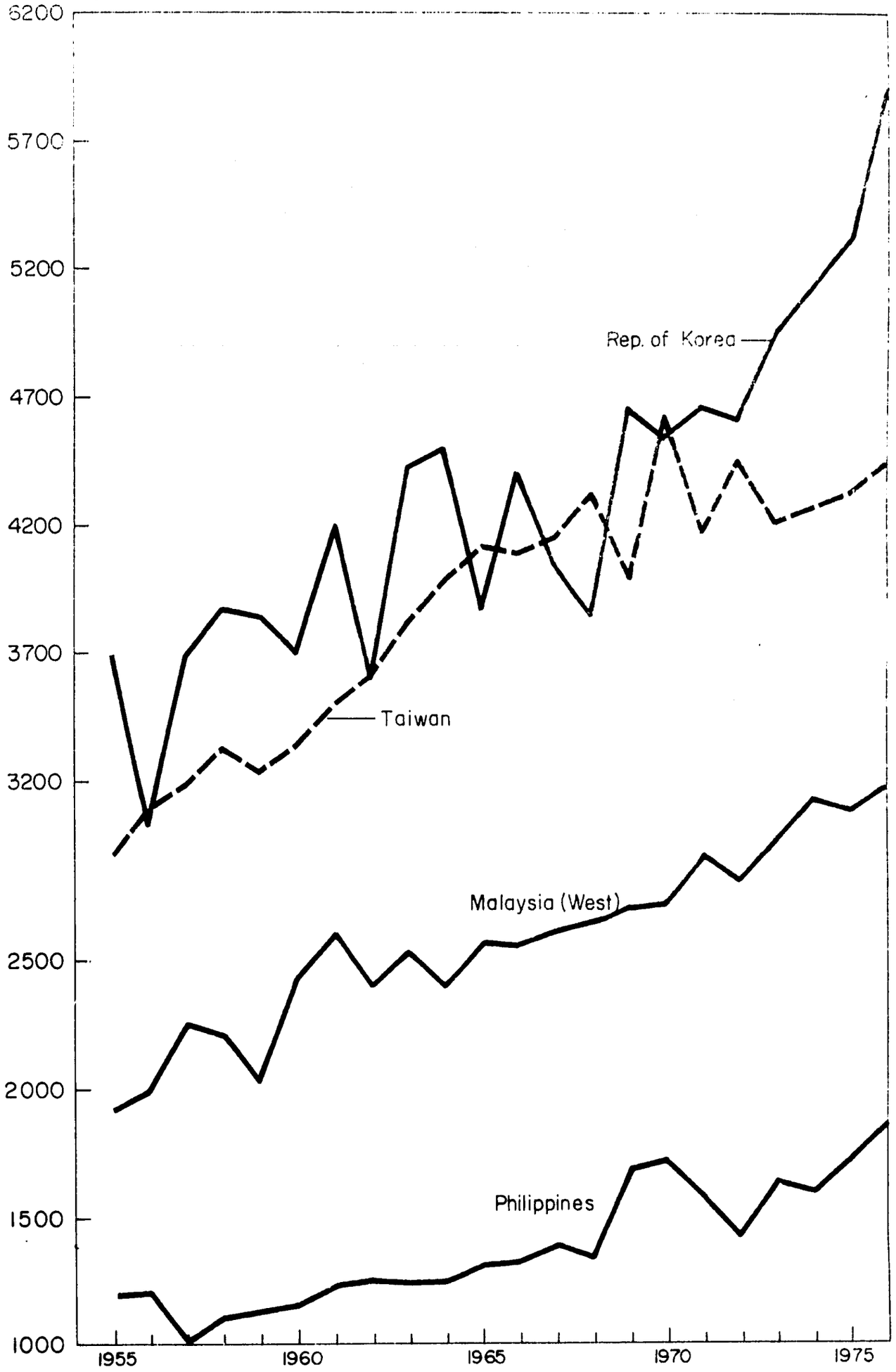


Fig. 2. Calorie consumption by Income Groups, Asia, 1965.


6200
5700
5200
4700
4200
3700
3200
2500
2000
1500
1000
1955
1960
1965
1970
1975
Rep. of Korea
Taiwan
Malaysia (West)
Philippines

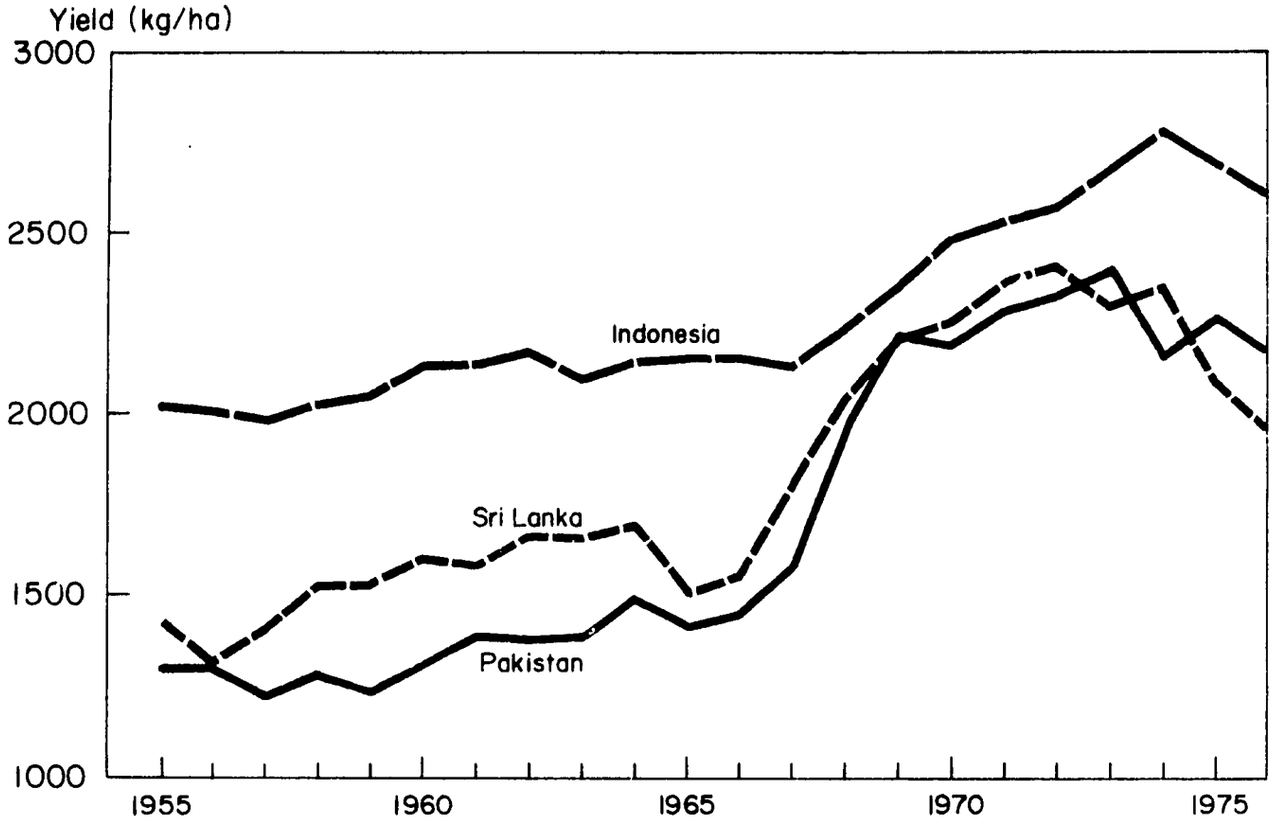


Fig. 3b. Yields of Rice (Paddy), 1955 – 1976.

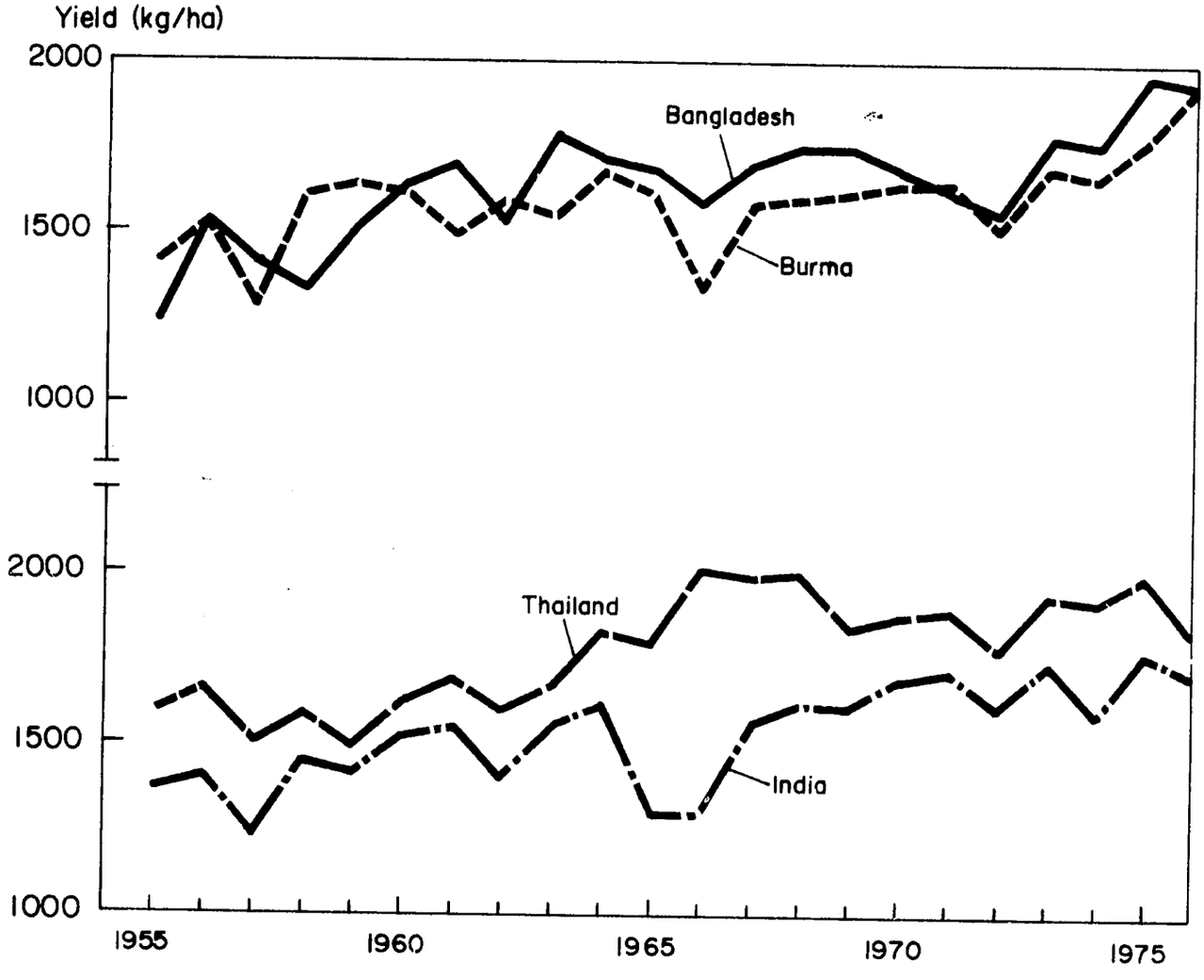


Fig. 3c. Yields of Rice (Paddy), 1955 – 1976.

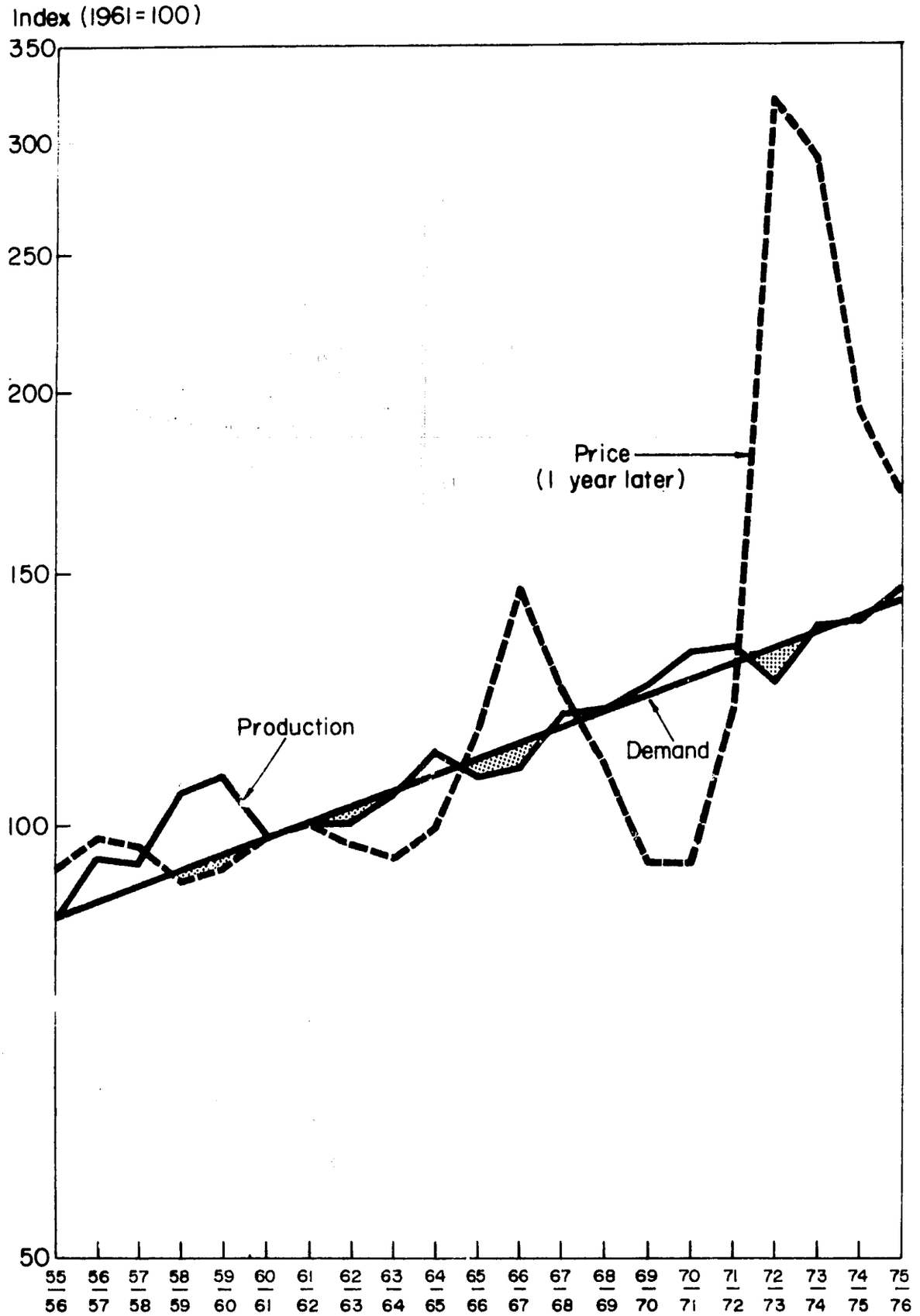


Fig. 4. World demand, production and export price of rice.

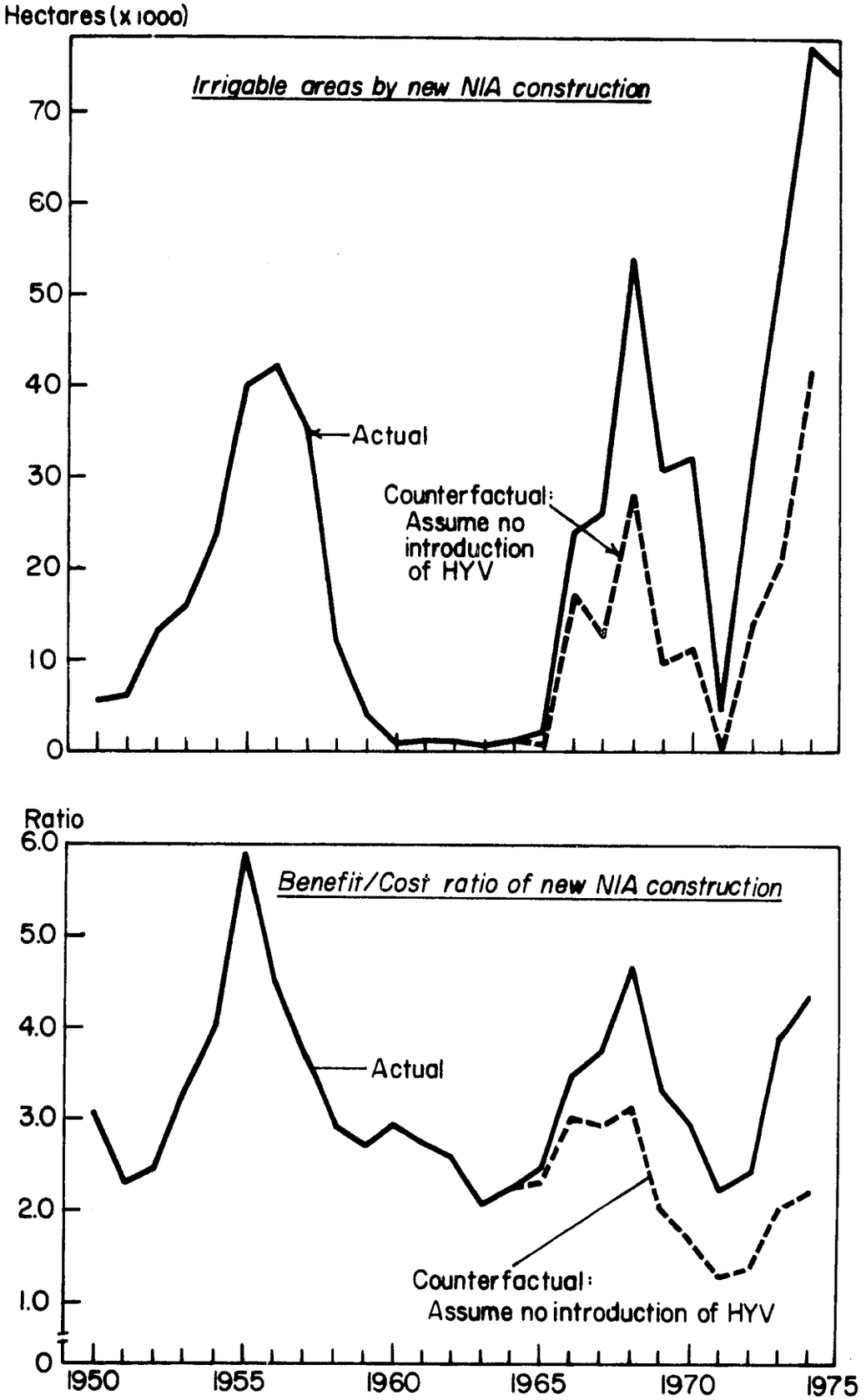


Figure 5. Comparisons between the areas for which the new construction of the NIA system was initiated and the benefit/cost ratios of the construction evaluated at current prices, 3-year moving averages.

Source: M. Kikuchi.

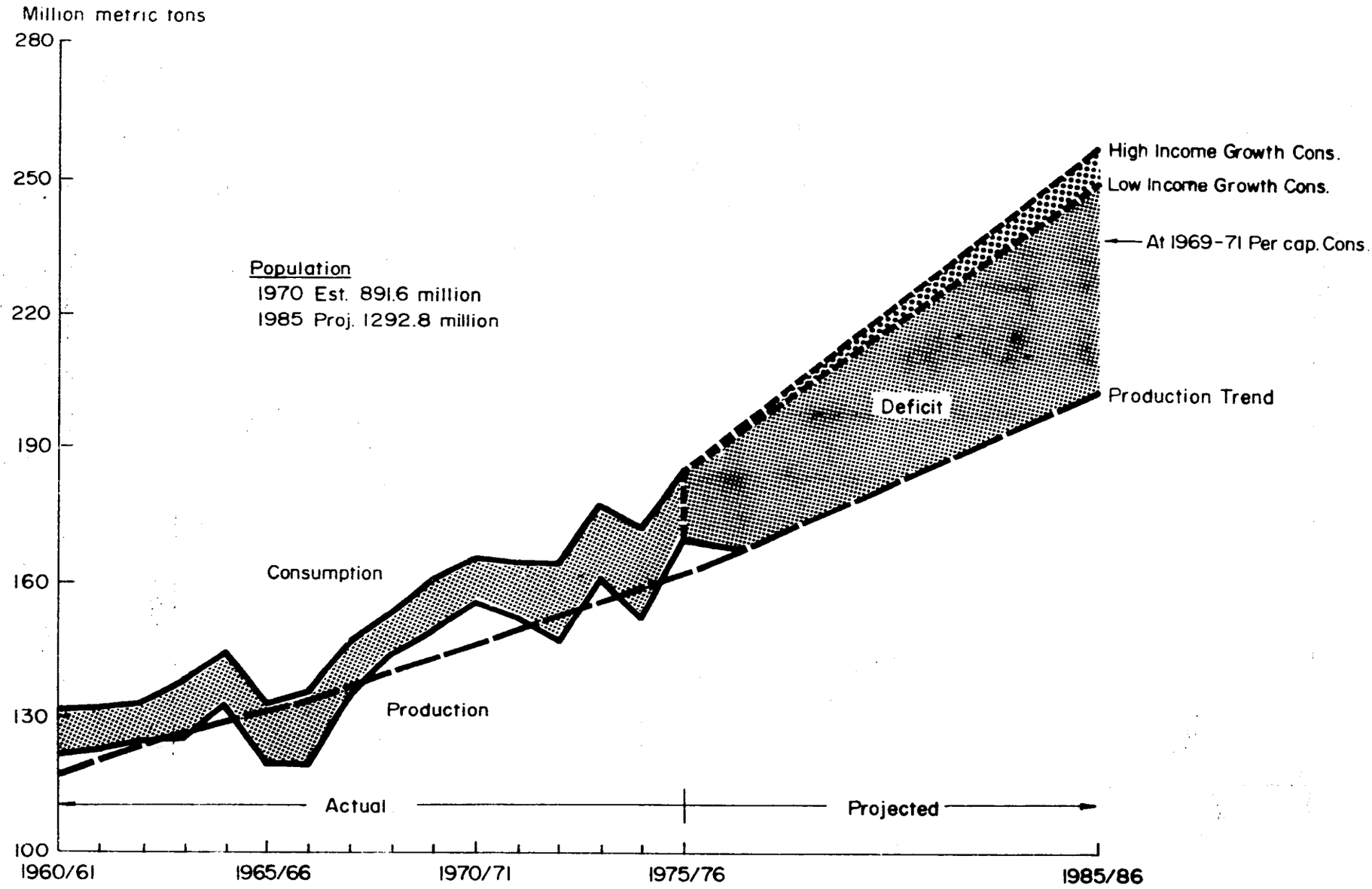


Fig 6. ASIA CEREALS: Production and consumption 1960-1975, and projected 1985 (IFPRI)