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ENVIRONMENTAL, TECHNOLOGICAL, AND INSTITUTIONAL FACTORS IN THE GROWTH OF RICE PRODUCTION: PHILIPPINES, THAILAND, AND TAIWAN†

INTRODUCTION

A basic premise of the technical assistance and agricultural development programs of the late 1940's and early 1950's was that rapid growth in agricultural productivity and output could be achieved by the transfer of technology, institutions, and capital from high-income to low-income countries. It was thought that agricultural production could be expanded rapidly as a result of (a) the transfer of known agricultural technology from the high-productivity to the low-productivity countries, (b) the development of more effective rural marketing, credit, and land tenure institutions, and (c) capital investment in irrigation and flood control, mechanization and transportation. The diffusion of practices employed by the best farmers within the low-income countries was also regarded as an important source of productivity growth.

Such expectations have typically failed to materialize. The rate of growth of crop output in most developing countries has been disappointingly slow. Furthermore, a relatively large share of the recorded increases in production have been based on expansion of area planted rather than on increases in output per unit area (*6*).

Now, in the mid-1960's a new concensus appears to be emerging that intensive investment in research and development designed to produce improvements in the quality of agricultural inputs represents the missing link in the agricultural

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† This paper draws heavily on several earlier reports by Ruttan, Soothipan, and Venegas (*23, 24*); Hsieh and Lee (*9*); and Abarientos (*1*). The authors are indebted to M. K. Bennett and B. F. Johnston for helpful comments on an earlier draft of this paper.

development process in many countries (*8, 16, 25, 26*). There is increasing recognition that traditional practices employed by the more successful farmers in each area do not have a sufficiently high payoff to provide an incentive for rapid growth in aggregate output. And there is growing agreement that much agricultural research and development is highly location specific—it must be done in biological and economic environments approximating those where the innovation will be employed.

There is danger that these insights may be contributing to a new set of oversimplifications regarding the requisites for rapid agricultural development. The evidence presented in this paper emphasizes the essential complementarity between (a) increased investment in research and development leading to higher rates of return on purchased inputs, (b) increased investment in land and water development, and (c) improved institutional and organizational systems for providing technical inputs and services to farmers.

Most countries in Southeast Asia have been, and continue to be, more dependent on increased area than on increased yield as a source of growth in rice production (Table 1). This is in contrast to the countries of Northeast Asia where increases in yield have been more important than increases in area in recent years. Taiwan and Malaysia are the only countries, however, which seem to have achieved their total increase in output during the last decade from yield increases. The Philippines and Cambodia stand at the opposite extreme. Thailand occupies an intermediate position; changes in yield are somewhat more important than changes in area planted in accounting for increases in rice production in Thailand during the last decade.

Two hypotheses with respect to the factors affecting yield increases and yield differences are tested in this study.

The first is that the increases in yield of rice of the last decade and the differences in yield among major rice-producing areas within Southeast Asia at the present time primarily reflect variations in the environmental conditions under which rice is grown (soil, season, water, and weather differentials) rather than differences in variety or cultural practices.

The second hypothesis is that differences in rice yield between Southeast Asia and Northeast Asia reflect variations in the technological and institutional factors under which rice is grown in addition to environmental factors.

In this paper, we test these two hypotheses with data from the Philippines, Thailand, and Taiwan. Major emphasis will be placed on factors associated with changes or differences in yield.[1]

TRENDS IN RICE PRODUCTION, AREA, AND YIELD IN THREE COUNTRIES

The Philippines, Thailand, and Taiwan have all experienced relatively rapid growth in total rice production since the early 1900's. The pattern of growth over

[1] We do not attempt, in this paper, to analyze the factors associated with the expansion or decline of area devoted to rice. Work has recently been completed relating the response of area devoted to rice and other crops to product and factor price behavior (*2, 20*). In general the results indicate that the area planted to rice tends to be highly responsive to changes in produce prices relative to competing crops. These studies typically did not identify any significant response in yield to changes in relative prices.

TABLE 1.—PRODUCTION, AREA, AND YIELD OF RICE IN ASIA, 1961/62–1963/64 AVERAGE COMPARED WITH TEN YEARS EARLIER*

Regions and countries	Production, rough rice (*thousand metric tons*) 1951/52 to 1953/54	1961/62 to 1963/64	Per cent change	Area (*thousand hectares*) 1951/52 to 1953/54	1961/62 to 1963/64	Per cent change	Yield (*tons per hectare*) 1951/52 to 1953/54	1961/62 to 1963/64	Per cent change	Percentage contribution to change in production: Change in area	Change in yield
Northeast Asia											
Japan	12,043	16,880	40.2	3,013	3,286	9.1	4.00	5.14	28.5	26	74
Korea (Rep. of)	2,318	3,532	52.4	946	1,147	21.2	2.45	3.08	25.7	46	54
Taiwan[a]	1,947	2,586	32.8	784	775	− 1.1	2.48	3.34	34.7	− 4	104
Total	16,308	22,998	41.0	4,743	5,208	9.8	3.44	4.42	28.5	27	73
Southeast Asia[b]											
Burma	5,836	7,392	26.7	4,112[c]	4,637[c]	12.8	1.42	1.59	12.0	51	49
Cambodia	1,679	2,474	47.3	1,673	2,305	37.8	1.00	1.07	7.0	83	17
Indonesia	10,090	12,504	24.4	6,131	6,960	13.5	1.65	1.80	9.1	59	41
Malaysia	660	980	48.5	498[d]	474	− 4.8	1.32	2.07	56.8	−13	113
Philippines	3,052	3,907	28.0	2,589	3,142	21.4	1.18	1.24	5.1	78	22
Thailand	7,389	9,208	24.6	5,599	6,077	8.5	1.32	1.52	15.2	37	63
Total	28,706	36,465	27.0	20,602	23,595	14.5	1.39	1.55	11.5	57	43
South Asia[e]	49,874	69,756	39.9	40,441	45,741	13.1	1.23	1.53	24.4	37	63

* Data from FAO, *The World Rice Economy in Figures, 1909–1963* (Commodity Reference Series No. 3, Rome, 1965); FAO, *Production Yearbook 1965*; and FAO, *Monthly Bulletin of Agricultural Economics and Statistics*, June 1966. The author has computed the relative contribution of area and yield to the change in production on a logarithmic basis.

[a] Production and yield differ from figures used elsewhere in this paper, apparently due to conversion from brown to rough rice at 1.24 here rather than 1.312.

[b] Laos and Vietnam not included.

[c] Planted.

[d] Including approximation for Sarawak for comparability with production figures.

[e] Ceylon, India, Iran (unofficial), and Pakistan. Nepal not included.

TABLE 2.—CHANGES IN RICE PRODUCTION, AREA, AND YIELD IN THE PHILIPPINES, THAILAND, AND TAIWAN FOR SELECTED PERIODS (ROUGH RICE BASIS)*

Period	Production (*thousand metric tons*)	Area (*thousand hectares*)	Yield (*tons per hectare*)	Annual rate of change (*per cent*) Production	Area	Yield
			PHILIPPINES[a]			
1908/09–1909/10	798	1,174	.68	...	...	...
1925/26–1926/27	2,140	1,781	1.20	6.0	2.5	3.4
1952/53–1953/54	3,163	2,650	1.19	1.5	1.5	.0
1962/63–1963/64	3,905	3,124	1.25	2.1	1.7	.5
1908/10–1962/64	...	...	...	3.0	1.8	1.1
			THAILAND			
1907/08–1908/09	2,475	1,319	1.88	...	...	...
1920/21–1921/22	4,250	2,298	1.85	4.2	4.4	.1
1946/47–1947/48	4,974	3,907	1.27	.6	2.1	1.4
1962/63–1963/64	9,711	6,288	1.54	4.3	3.0	1.2
1907/09–1962/64	...	...	...	2.5	2.9	.4
			TAIWAN			
1903/04–1904/05	735	415	1.75	...	...	...
1919/20–1920/21	916	499	1.84	1.4	1.1	.3
1936/37–1937/38	1,761	670	2.63	3.9	1.7	2.1
1951/52–1952/53	2,004	787	2.55	.8	1.1	−.2
1962/63–1963/64	2,769	772	3.58	3.0	−.2	3.2
1903/05–1962/64	...	...	...	2.2	1.0	1.2
1919/21–1962/64	...	...	...	2.6	1.0	1.6

* See Appendix Note for sources of basic data. Area figures are harvested basis except as indicated for the Philippines in note *a*. Annual rates of change are the authors' computation.

[a] Area figures are area planted prior to 1953/54, area harvested thereafter. Yield figures reflect this change.

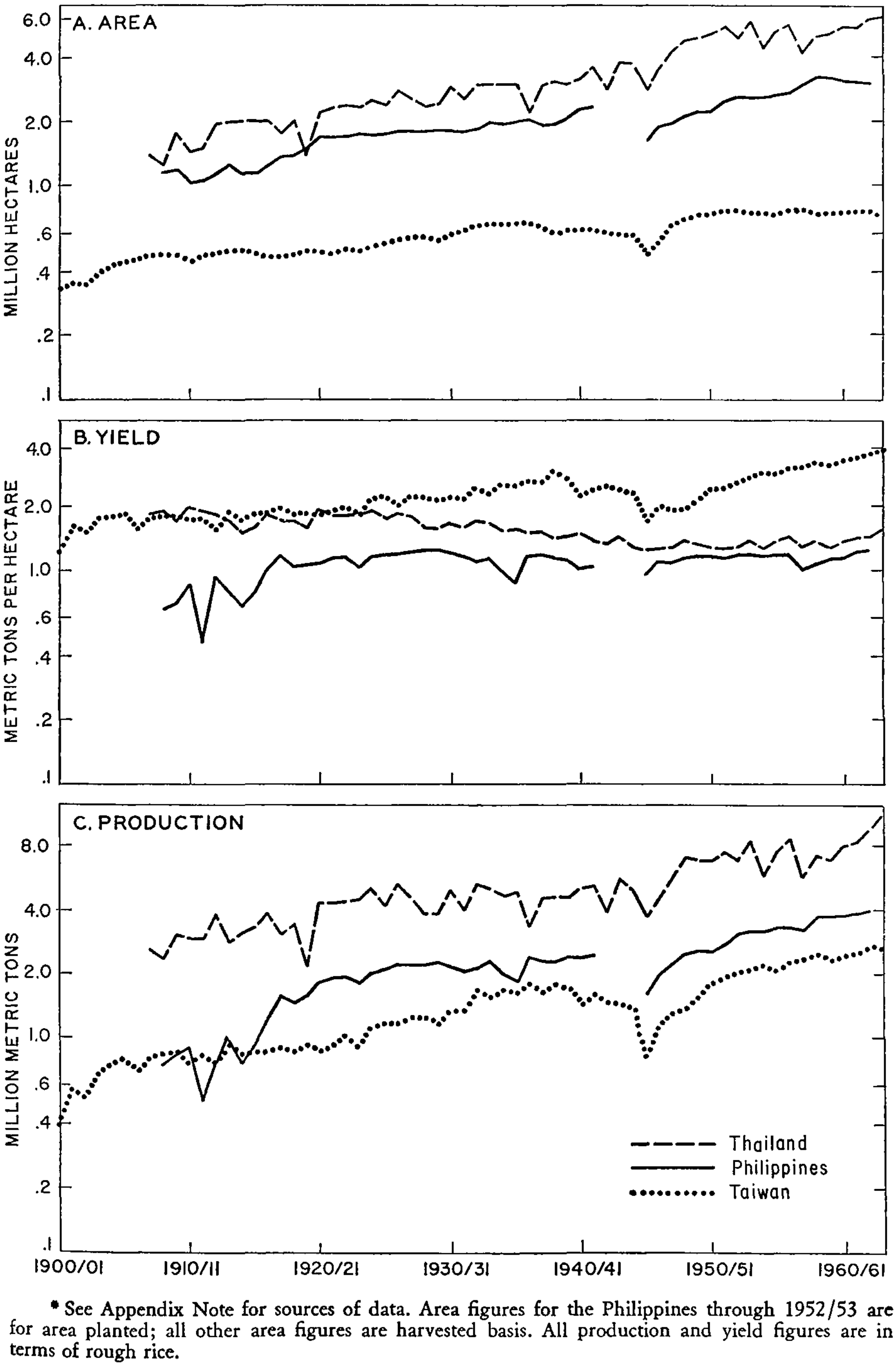
time and the relative contribution of area and yield are sharply different among the three countries (Chart 1, Table 2).

Throughout the entire period a substantial share of the total increase in output in both the Philippines and Thailand is accounted for by increases in the area devoted to rice production. Growth in area was particularly rapid in both countries prior to the early or mid-1920's. In Taiwan, however, the expansion of area planted was relatively slow throughout the entire period, although rather substantial increases were recorded during the 1920's and early 1930's.

There have also been sharp contrasts in yield. In the Philippines yield per hectare apparently rose rapidly from an extremely low level in the early years of the century to approximately 1.20 metric tons per hectare in the mid-1920's. In both Thailand and Taiwan yields were substantially higher than in the Philippines and in Taiwan remained slightly below 2.0 metric tons per hectare until the early 1920's.

Since the mid-1920's national average rice yields in the Philippines seem to have remained almost unchanged. In 1962/63–1963/64 the Philippine average yield was only 1.25 metric tons per hectare. The average yield in Thailand declined continuously from the early 1920's to the mid 1950's. During the late 1940's

CHART 1.—AREA, YIELD, AND PRODUCTION OF RICE IN THE PHILIPPINES, THAILAND, AND TAIWAN, FROM THE EARLY 1900'S TO 1963/64*



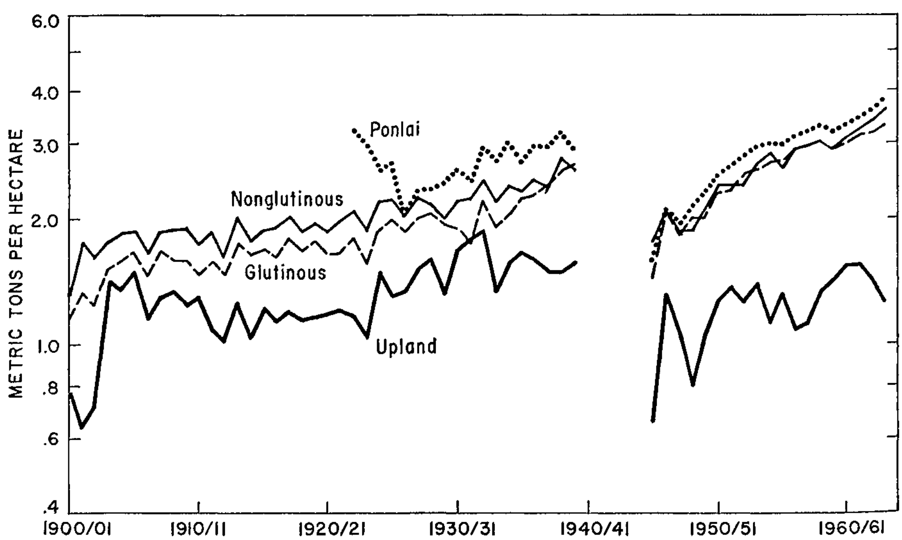
* See Appendix Note for sources of data. Area figures for the Philippines through 1952/53 are for area planted; all other area figures are harvested basis. All production and yield figures are in terms of rough rice.

and early 1950's it was only slightly higher than in the Philippines. Although the long term decline in yields was reversed by the late 1950's, the average yield in 1962/63–1963/64 was still only 1.54 metric tons per hectare—substantially below the levels achieved before the 1920's. During this same period Taiwan experienced a spectacular growth, with yield per hectare rising from 1.84 metric tons per hectare in 1919/20–1920/21 to 3.58 in 1962/63–1963/64.

Both the long-term stability in national average yield in the Philippines and the long-term decline in national average yield in Thailand are difficult to explain. The stability in national average yield in the Philippines may reflect the combined effect of expansion in area devoted to low-yielding upland and rainfed rice and a stable or declining area devoted to rice production in the higher-yielding irrigated areas. In Thailand, it is possible that increases in area devoted to rice in the low-yielding provinces of the northeast have more than offset the effect of stable or rising yields in the central and northern provinces.

In Taiwan, the higher yields seem to have been due primarily to favorable technological and institutional factors, which include the development and introduction of high-yielding *ponlai* rice varieties, increased use of chemical fertilizer, improved irrigation facilities and water management, improved cultural practices, reduced acreage of low-yielding upland and rainfed rice, and the organization of farmers' associations and irrigation associations for fertilizer distribution, rice collection, storage, processing and marketing, and water use, water distribution, and water management at the local level. Among all these factors it appears that innovations associated with the introduction of the *ponlai* varieties beginning in the early 1920's have been particularly important. Data on the long-term yield trends for the several classes of rice grown in Taiwan is presented in Chart 2.

CHART 2.—CHANGES IN AVERAGE YIELD OF DIFFERENT TYPES OF RICE, TAIWAN, 1900/01 TO 1963/64*



* See Appendix Note for source of data. Yields are in terms of rough rice. For ease of reading, the vertical scale on this chart is double that on Chart 1.

DIFFERENCES IN YIELD AMONG REGIONS IN THE PHILIPPINES, THAILAND, AND TAIWAN

National average yields can be regarded as a weighted average of the yield obtained in the several rice producing regions of each country. Differences in average yields among regions may reflect differences in the environmental conditions under which rice is grown—the proportion of rice grown under irrigated, rainfed, or upland conditions or during the wet and dry seasons, for example.[2] Differences in yield may also reflect differences in the level of technology employed in each region—cultural practices, varieties, use of technical inputs such as fertilizer, insecticides, and others. The level of technology itself may reflect differences in economic incentives such as factor and product prices; differences in institutional organization such as land tenure, credit, and marketing organization; and social and cultural differences that influence the adoption of new technology and use of technical inputs.

In this section, we examine the extent to which differences in yield among regions within each country reflect differences in the environmental conditions under which rice is grown. We include under environmental factors long-term infrastructure investment such as irrigation which modifies the natural environment and enables rice producers to achieve greater local environmental control.

In the Philippines, rice is produced under many situations. Each province grows some rice in the rainy (wet) season and some in the dry season, and in each some rice is grown under irrigated, rainfed, and upland conditions. Regional or national average yields differ depending on season (wet or dry) and water treatment (irrigated, rainfed, or upland).[3] Thus the average rice yield in each province or region (Map 1) and in the Philippines as a whole, is determined by (a) the yield obtained under different production conditions, and (b) the percentage of the total area on which different production practices are employed.

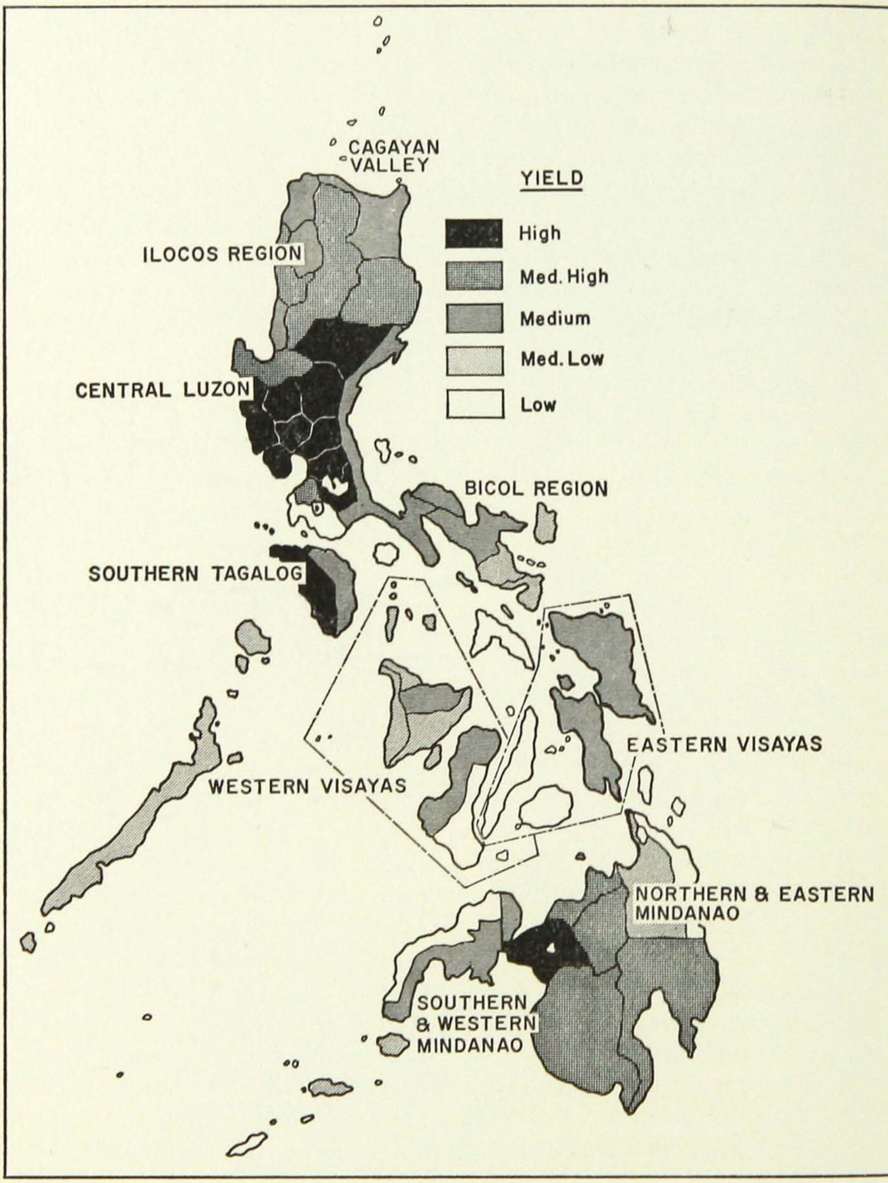
The nonirrigated or rainfed first crop (wet season) accounts for the largest share of rice area in almost all regions (Chart 3). Irrigated first crop areas are substantial only in a few regions, such as central Luzon, Bicol, and southern and western Mindanao. The area devoted to the irrigated and rainfed second crop (dry season) rice is relatively small in all regions. The area devoted to upland rice relative to lowland rice is relatively large in a few regions, such as southern Tagalog and southern and western Mindanao.

The data in Table 3 represent an attempt to estimate the effects of season (wet or dry) and water use (irrigated, rainfed, or upland) on regional average yields. The data in column 1 are the actual average yields obtained in 1960/61 in each region. The data in column 3 are the average yields that would have been reported for the region if the distribution of rice area by season and water supply

[2] *Irrigated rice* is typically grown in fields where water can be impounded by bunds or dikes and where water can be delivered to the field from surface storage, stream diversion, or wells. *Rainfed rice* is grown in similar fields but without access to water from surface storage, stream diversion, or wells. *Upland rice* is grown in fields where water is not impounded. Production of rainfed and upland rice is typically confined to the wet season in Southeast Asia. In areas where seasonal differences are not too pronounced two crops of rainfed or upland rice per year are sometimes obtained. Typically, however, two or more crops per year are obtained only where irrigation is available from surface storage or wells.

[3] Yield is measured in terms of kilograms of palay or paddy (i.e., rough rice) per hectare per season. Thus if both a wet and dry season crop is grown on the same hectare it is counted as two hectares and the average yield is the total production for both seasons divided by two.

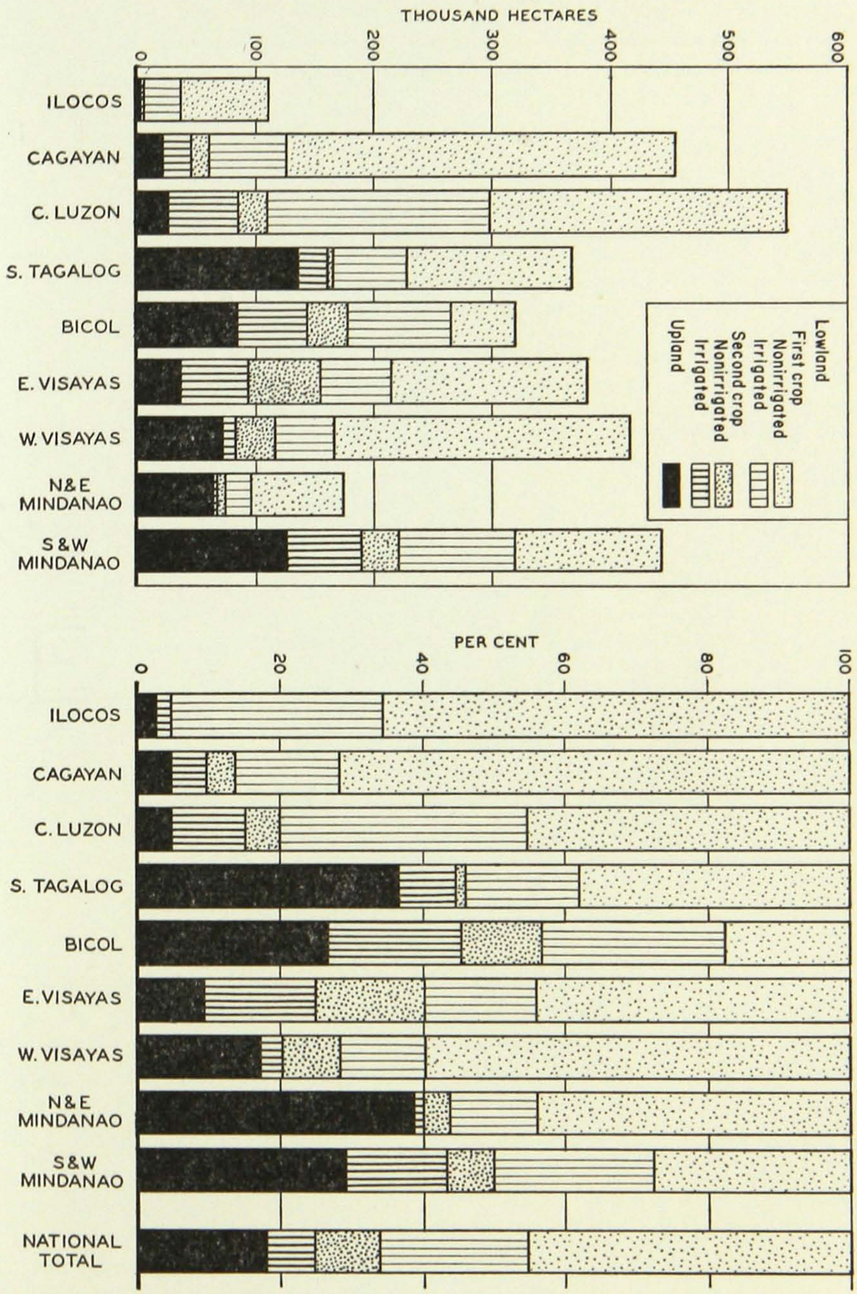
Map 1.—Distribution of Rice Yields Among Philippine Provinces, 1956/57–1958/59 Average*



* See Appendix Note for sources of data; 10 provinces are included in each category except medium which includes 13. The categories represent yields in metric tons of rough rice per hectare harvested, and indexes with the Philippine national average of 1.10 tons = 100, as follows:

	Yield	Index
High	1.28–2.13	116.4–193.6
Medium high	1.10–1.27	100.0–115.5
Medium	.92–1.09	83.6– 99.1
Medium low	.77– .91	70.0– 82.7
Low	below .77	below 70.0

CHART 3.—REGIONAL DISTRIBUTION OF RICE AREA HARVESTED IN THE PHILIPPINES, 1960/61*



* See Appendix Note for source of data.

TABLE 3.—EFFECT OF DIFFERENCES IN REGIONAL PRODUCTION PATTERNS ON REGIONAL AVERAGE YIELDS OF ROUGH RICE PER HECTARE HARVESTED IN THE PHILIPPINES AND THAILAND*

Country and region	Actual yield: Tons per hectare (1)	Actual yield: Index (2)	Standardized yield[a]: Tons per hectare (3)	Standardized yield[a]: Index (4)
Philippines, 1960/61	1.159	100.0	1.159	100.0
Ilocos	1.278	110.3	1.201	103.6
Cagayan Valley	1.087	93.8	1.174	101.3
Central Luzon	1.574	135.8	1.382	119.2
Southern Tagalog	1.049	90.5	1.143	98.6
Bicol	1.025	88.4	1.013	87.4
Eastern Visayas	.891	76.9	.891	76.9
Western Visayas	1.263	109.0	1.289	111.2
Northern and Eastern Mindanao	.847	73.1	.851	73.4
Southern and Western Mindanao	1.127	97.2	1.176	101.5
Thailand, 1961/62–1963/64	1.514	100.0	1.514	100.0
Central Plain	1.766	116.6	1.394	92.1
Northeast	1.123	74.2	1.409	93.1
North	2.144	141.6	2.125	140.4
South	1.602	105.8	1.770	116.9

* See Appendix Note for sources of actual yield figures; for Thailand see text description of estimates for irrigated and nonirrigated areas. Tons are metric.

[a] In the Philippines, to obtain the standardized yields, regional yields of rough rice from first crop (1) irrigated, (2) nonirrigated; second crop (3) irrigated, (4) nonirrigated; and (5) upland areas are weighted by the national average distribution for the five categories. In Thailand the regional yields of rough rice, on a harvested area basis, for the irrigated and nonirrigated areas, were weighted by the national distribution of irrigated and nonirrigated area harvested to obtain the standardized yields.

Standardization for the differences among regions identified above reduces the coefficient of variation for yields among regions in both the Philippines and Thailand by about 20 per cent (from .20 to .16 in the Philippines and from .26 to .21 in Thailand). It seems reasonable to expect that if data were available to permit standardization for differences in water control and season among provinces within regions and among villages within provinces, the coefficient of variation for the standardized yields would be even lower.

in the region had been the same as the national average. The only year for which sufficient data are available to make this calculation is 1960/61.

In central Luzon, for example, the actual average yield in 1960/61 was 1.574 metric tons of rough rice per hectare, or almost 36 per cent above the national average. If the distribution of area (a) between the wet and the dry season, and (b) among irrigated, rainfed and upland areas had been the same as the national average, the 1960/61 average yields in central Luzon would have been 1.382 metric tons or only 19 per cent above the national average. This means that almost half of the difference between the actual average yield in central Luzon and the average national yield is accounted for by the relatively favorable area distribution with respect to season and water treatment rather than by actual yield differences under similar environmental conditions. In the Ilocos region, about three-fifths of the margin of actual yield over the national average yield results primarily from the favorable area distribution.

In the Cagayan Valley, southern and western Mindanao, and southern Tagalog regions, the relatively high proportion of upland area accounts for the below-average yield obtained in each. If the distribution of area among different types of production had been the same as the national average, yields in these three regions would have approximated the national average.

The close agreement between the actual and standardized yield in western Visayas is particularly striking. This implies that the higher than average yields are primarily the result of higher real yields rather than area distribution. Similarly in Bicol, eastern Visayas, and northern and eastern Mindanao yields are low although the distribution of production is close to the national average.

The limited fraction of the total area devoted to rice that is irrigated in both the wet and the dry seasons represents a major barrier to increased production and higher average yields in most regions. Even in central Luzon, a region where yields are relatively high, a shift of one hectare from production of one crop of rainfed rice to production of irrigated rice during both the wet and dry seasons would add almost 2.37 tons to the total production, assuming the cultural practices of 1961. This would represent a 168 per cent increase in rice production per hectare per year.[4]

In Thailand the range in yield variation among provinces is similar to that in the Philippines (Map 2). However, most of the rice is grown under irrigated or rainfed conditions. The percentage of upland rice is low—probably not more than 1 per cent in recent years. The second crop (dry season) production is also low. It accounts for less than 1 per cent of the total area planted (or harvested). Most of the dry season crop is grown in the north and in the Central Plain. But the relative importance of irrigated and rainfed areas varies sharply among provinces (Chart 4). In central Thailand almost half of the area planted, and in the north more than one-fourth of the area planted is irrigated.[5]

The yields reported by the Royal Irrigation Department for irrigated areas are substantially higher than the yields estimated for nonirrigated areas by the

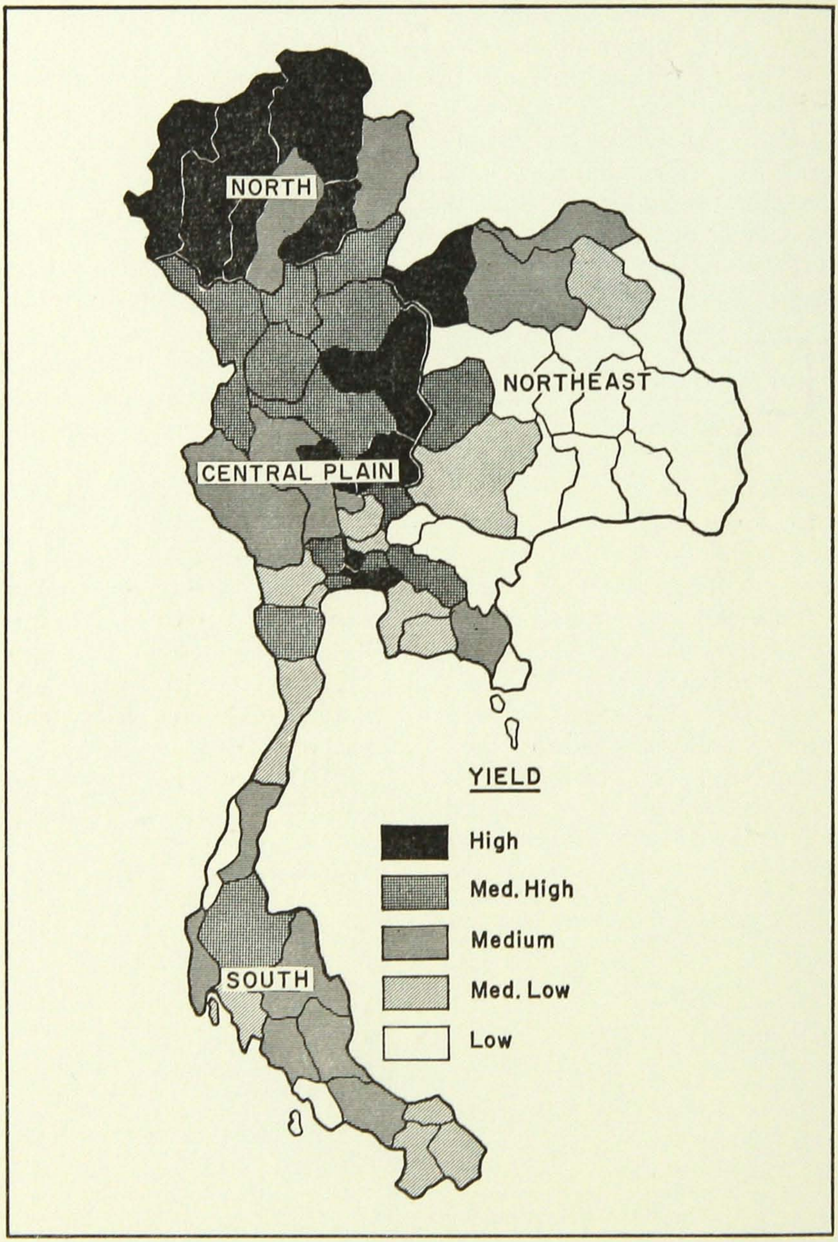
[4]

	Tons per hectare
Wet season irrigated	1.97
Dry season irrigated	1.81
Total irrigated	3.78
Wet season rainfed	1.41
Increase from irrigation	2.37

This is clearly a conservative estimate of the increase in output that would accompany irrigation. The dry season yield reflects a situation where there is inadequate water throughout the dry season. Experimental evidence from the IRRI and elsewhere indicates that with adequate irrigation water the dry season yield should exceed the wet season yield by 25 to 50 per cent.

[5] There are some difficulties in comparing the production, area, and yield of irrigated and nonirrigated land in Thailand. The Rice Department (Ministry of Agriculture) reports only total production, total area planted and harvested, and provincial, regional, and national average yields. It does not report separately production, area, and yield for irrigated, nonirrigated, and upland rice. Since 1958/59 data on production, area planted and harvested, and yield for irrigated land have been reported by the Royal Irrigation Department (Ministry of National Development). The data on production, area, and yield for nonirrigated land utilized in this report were obtained by subtracting the production and area estimates of the Royal Irrigation Department from the total production and area estimates of the Rice Department. Any bias in the Royal Irrigation Department data would, therefore, result in an opposite bias in the residual estimates of production, area, and yield in nonirrigated areas. In both Thailand and the Philippines the definition of irrigated land is rather imprecise. Irrigation water is usually supplied by diversion dams in streams and is available only during the wet season. Thus in the Philippines and Thailand the area of the second (dry season) crop that is irrigated may represent a better estimate of the area that is adequately irrigated than the area of the first (wet) season crop that is irrigated. In Thailand, substantial areas classified as irrigated are subject to serious flooding and have inadequate drainage.

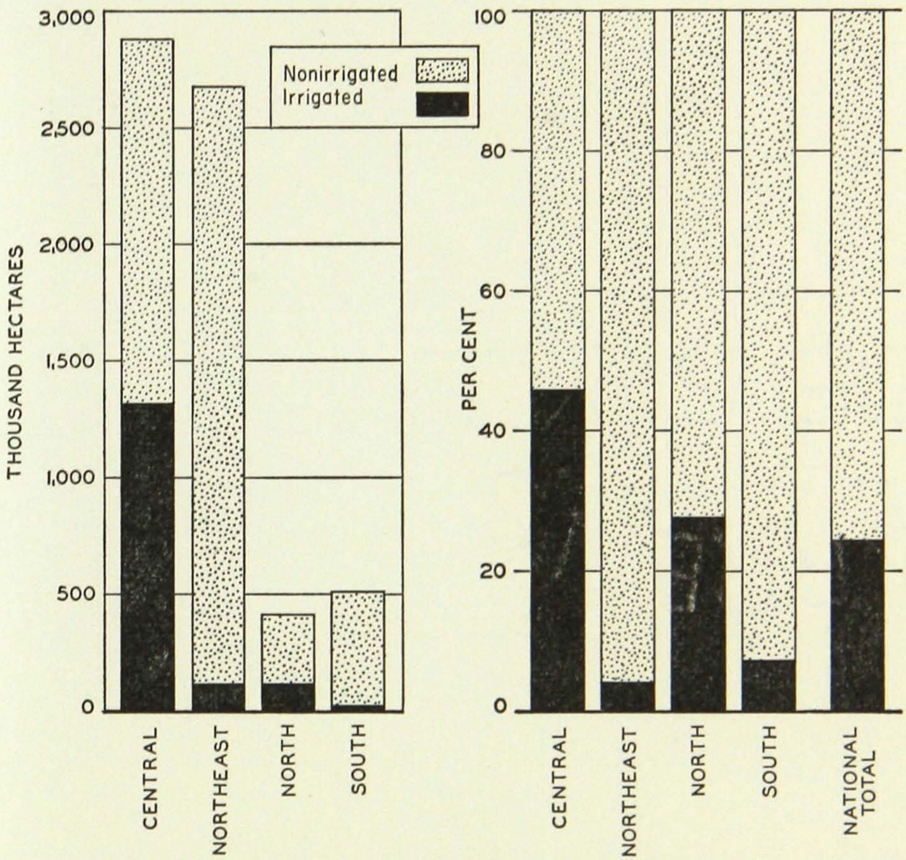
MAP 2.—DISTRIBUTION OF RICE YIELDS AMONG THAI PROVINCES, 1961/62–1963/64 AVERAGE*



* See Appendix Note for sources of data; 14 provinces are included in each category except medium which includes 15. The categories represent yields in metric tons of rough rice per hectare harvested, and indexes with the Thai national average of 1.51 tons = 100, as follows:

	Yield	Index
High	1.93–3.24	129.80–214.57
Medium high	1.68–1.95	111.26–129.14
Medium	1.52–1.67	100.66–110.60
Medium low	1.29–1.51	85.43–100.00
Low	.74–1.28	49.01– 84.77

CHART 4.—REGIONAL DISTRIBUTION OF RICE AREA PLANTED IN THAILAND, 1961/62–1963/64 AVERAGE*



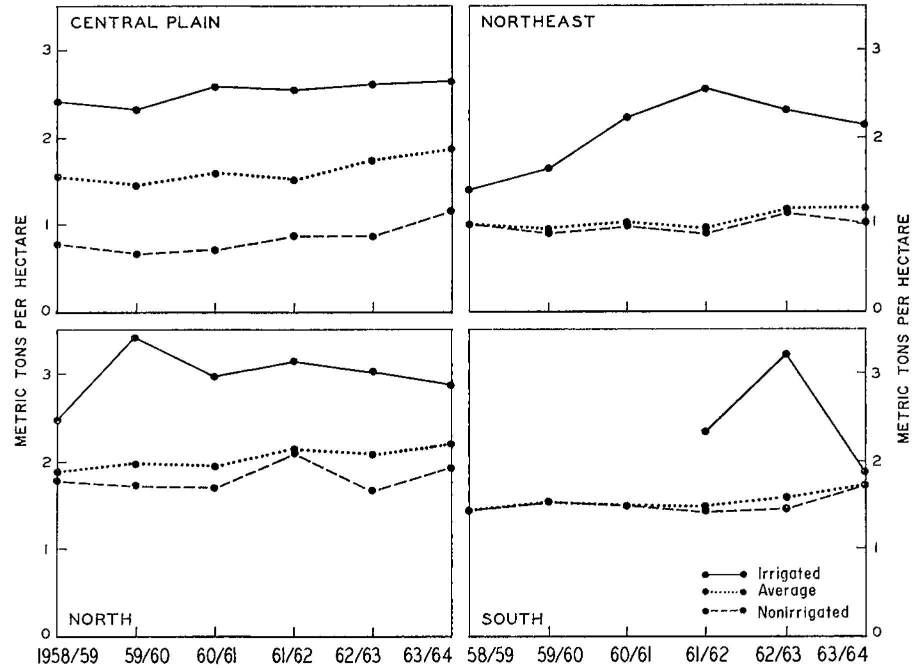
* Total planted area from Ministry of Agriculture, Department of Rice, *Annual Report on Rice Production in Thailand* [in Thai] (Bangkok, 1965), and earlier issues. Irrigated area planted from Ministry of National Development, Royal Irrigation Department, *Rice Production Under Irrigated Area, 1958/59 to 1963/64* [in Thai] (Bangkok, 1965), mimeo worksheets. Nonirrigated area approximated as the difference.

residual method (Chart 5). Both the irrigated and nonirrigated areas have experienced increases in yield since 1958/59. The most dramatic increase occurred on irrigated land in the northeast. Irrigated land represents such a small proportion of the total increases in the northeast that the rise in yield on irrigated land had a relatively minor impact in the average yield for the entire region. In the central plain, the estimated yield on nonirrigated land has risen more rapidly than on irrigated land.

Differences in the proportion of area irrigated in each region have a substantial impact on the regional average yield. In those regions where only a small share of the land is irrigated, the average yield is close to the yield on nonirrigated land.

The data for Thailand in Table 3 attempt to measure the effect of different

CHART 5.—REGIONAL AVERAGE YIELD PER HECTARE HARVESTED IN IRRIGATED AND NONIRRIGATED AREAS, THAILAND, 1958/59–1963/64*



* Based on data from sources cited for Chart 4, but using harvested-basis area figures. See text for further description.

regional production patterns on regional yields. The data presented in column 3 are estimates of the average yields that would have been reported for the region if the distribution of area between irrigated and nonirrigated areas in the region had been the same as the national average. In the Central Plain, for example, the actual average yield in 1961/62–1963/64 was 1.766 metric tons of rough rice per hectare, or almost 17 per cent above the national average. If the distribution of area between irrigated and rainfed culture had been the same as the national average, the 1961/63 average yield in the Central Plain would have been 1.394 metric tons, or 8 per cent below the national average.

The northern region is particularly striking because of the close agreement between the actual and standardized yield. This implies that the higher than average yields are primarily the result of higher rice yields under comparable conditions of water use rather than to a favorable distribution of irrigated area.

In Taiwan two crops of rice per year are grown in most areas. The rice crop harvested before August 15 is considered the first or dry season crop. The crop harvested after August 15 is considered the second or wet season crop. In each area and each season rice is grown under irrigated, rainfed, and upland conditions. Taiwan differs from the Philippines and Thailand, however, in that a very high percentage of the rice area is served by irrigation systems designed to provide sufficient water for rice production during both the dry and wet seasons. Even in the mid-1920's, before the *ponlai* varieties were introduced, most rice land was fully irrigated. With further extension of irrigation during the last 40 years the area devoted to rainfed and upland rice has been further reduced. At present, upland rice accounts for less than 3 per cent of the total rice area. It seems unlikely then that rainfed rice accounts for more than 10 per cent of the total area devoted to rice.[6]

It seems reasonable to hypothesize that the very high proportion of total rice area that is irrigated accounts for the small variation in yield among districts in Taiwan (Map 3) as compared with the wide provincial yield variations in the Philippines (Map 1) and Thailand (Map 2). Measurement of the effect of differences in season and water treatment on differences in rice yields among geographic subdivisions (*Hsiens*) in Taiwan is more difficult than in the Philippines and Thailand. The differences in rainfall between the dry and wet seasons is not as pronounced. And the Provincial Food Bureau does not report yields separately for irrigated and rainfed rice.

Certain data, however, permit alternative tests of the relationship between irrigation and yield differences. Regression analysis of the relationship between yield and area irrigated for the period 1922–38 and 1950–60 indicates a very high association between area irrigated and yield per hectare.[7] And the highest average yields are obtained in those *Hsiens* in western and southwestern Taiwan where irrigation is most highly developed.

Although the data from Taiwan do not permit the same degree of precision in identifying yield differences among areas associated with environmental factors such as irrigation as in the Philippines and Thailand, it is organized to permit identification of the effect of differences in type of rice on yield differences among *Hsiens*. The highest yielding rice varieties grown in Taiwan are of the *ponlai* type (Chart 2, Table 4). The *ponlai* varieties account for well over half of the rice area in each food district (Chart 6). The average yield in each region is a weighted average of the yield obtained from each type and the proportion of the area devoted to each type.

The effect of differences in area devoted to each type on regional average yields can be measured by comparing the actual average yield in each region with the standardized average yield that would have been obtained if the distribution of

[6] The Provincial Food Bureau (PFB) reports rice production statistics in terms of paddy rice and upland rice. While all upland rice is rainfed, part of the paddy rice is also grown on rainfed (without irrigation) or so-called "weather-depending paddy land." However, the PFB data do not differentiate between irrigated rice and rainfed rice on paddy land. The available data do indicate that even in the mid-1920's, the irrigation ratio (percentage of irrigated land to total cultivated land) was 42 per cent in 1922 and 48 per cent in 1928. Since irrigation was developed primarily in the lowland rice producing areas, the area of irrigated land is even higher relative to the total rice area. Since most of the irrigated land is devoted to rice, and two crops of rice per year are typically grown in irrigation areas, the percentage of rice land that is irrigated is much higher than the percentage of total cultivated land that is irrigated. It seems likely that more than 75 per cent of the area devoted to rice was irrigated by the mid-1920's.

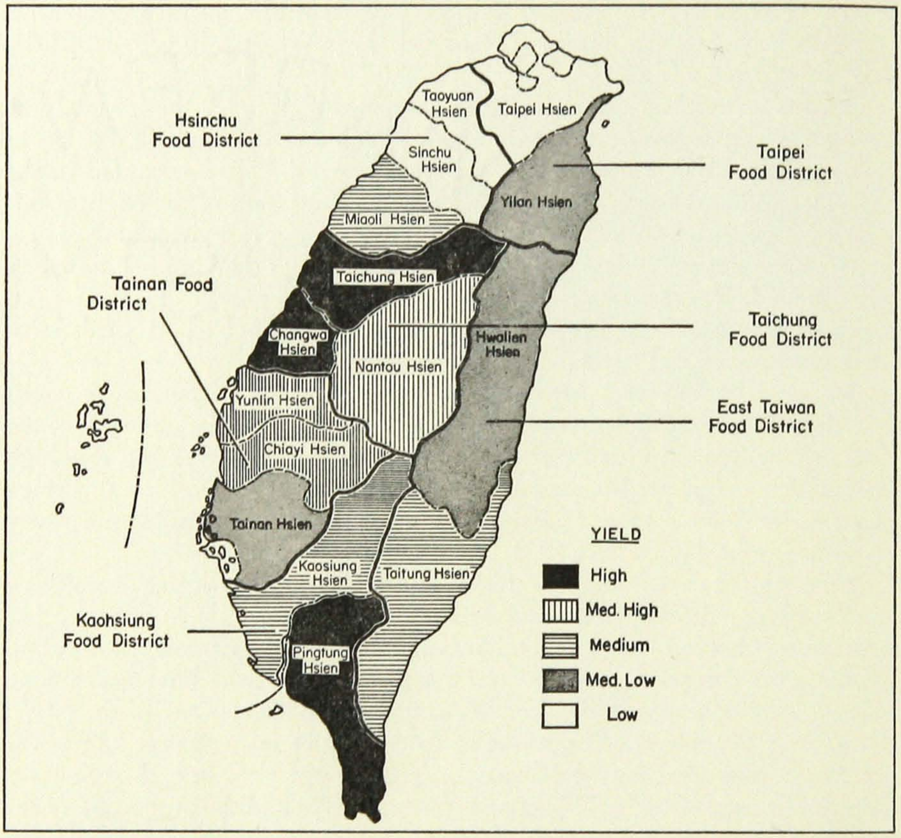
[7] The regression analysis by Rada and Lee (*22*) can be summarized as follows:

$$\text{1922–38:}\quad \underset{}{Y = 9.6196} + \underset{(0.1240)}{0.2595\,F} + \underset{(0.2774)}{0.6232\,I} + \underset{(0.1109)}{0.0375\,P}\qquad R^2 = 0.91,\; S = 5.3643$$

$$\text{1950–60:}\quad Y = 186.5523 + \underset{(0.7273)}{0.4971\,F} + \underset{(0.6880)}{2.4786\,I} - \underset{(0.0036)}{0.0047\,P}\qquad R^2 = 0.97,\; S = 2.4918$$

Where: Y = rice yield per hectare
F = total fertilizer application
I = total area irrigated
P = rice price

MAP 3.—DISTRIBUTION OF RICE YIELDS AMONG HSIENS IN TAIWAN, 1961/62–1963/64 AVERAGE*



* See Appendix Note for sources of data; 3 *Hsiens* are included in each category. The categories represent yields in metric tons of rough rice per hectare harvested, and indexes with the Taiwan national average of 3.52 tons = 100, as follows:

	Yield	Index
High	3.91–3.98	111.13–111.92
Medium high	3.63–3.82	102.98–108.49
Medium	3.29–3.56	93.52–101.16
Medium low	3.09–3.24	87.62– 92.08
Low	2.90–3.06	82.33– 86.76

area in the region had been the same as for Taiwan as a whole. If standardization results in convergence (i.e., less variation in the standardized than actual yields) this would be consistent with the hypothesis that differences in the type of rice grown represent an important source of variations in yield among regions.

The results (Table 5) indicate that standardization of average yields among food districts in Taiwan, to reflect the effects of differences in area devoted to the several classes of rice during the wet and dry seasons, tends to widen rather than narrow the yield dispersion among regions. That is, if each food region allocated exactly the same proportion of its rice area among types as the national average the yield variation among regions would be wider than at present—yields would

TABLE 4.—ACTUAL YIELDS OF VARIOUS TYPES OF RICE IN TAIWAN, SELECTED AVERAGES, 1926/27–1928/29 TO 1961/62–1963/64*
(*Metric tons rough rice per hectare*)

	1926/27–1928/29		1937/38–1939/40		1954/55–1956/57		1961/62–1963/64	
Type of rice	Yield	Index	Yield	Index	Yield	Index	Yield	Index
National Average	2.15	100.0	2.77	100.0	2.90	100.0	3.52	100.0
Ponlai	2.24	104.2	3.06	110.5	3.11	107.2	3.64	103.4
Nonglutinous	2.23	103.7	2.60	93.9	2.85	98.3	3.45	98.0
Glutinous	2.01	93.5	2.62	94.6	2.81	96.9	3.27	92.9
Upland	1.50	69.8	1.52	54.9	1.18	40.7	1.47	41.8

* Yields from Taiwan Provincial Food Bureau, *Taiwan Food Statistics 1964* (Taipei).

decline in Taipei and rise in Kaohsiung, for example. Apparently there are substantial differences in yield for the same types in different food districts. It seems reasonable, therefore, to conclude that environmental differences continue to account for a substantial share of the variations in yield among districts in Taiwan.

The analysis of regional yield data for the Philippines, Thailand, and Taiwan reveals several significant differences. First, actual yield differences are less among regions in Taiwan than in the Philippines and Thailand. Second, standardization for differences in the type of rice grown among regions in Taiwan does not result in a convergence of yield differentials in the same way that standardization for differences in season and/or water treatment resulted in convergence of yield differentials in the Philippines and Thailand.

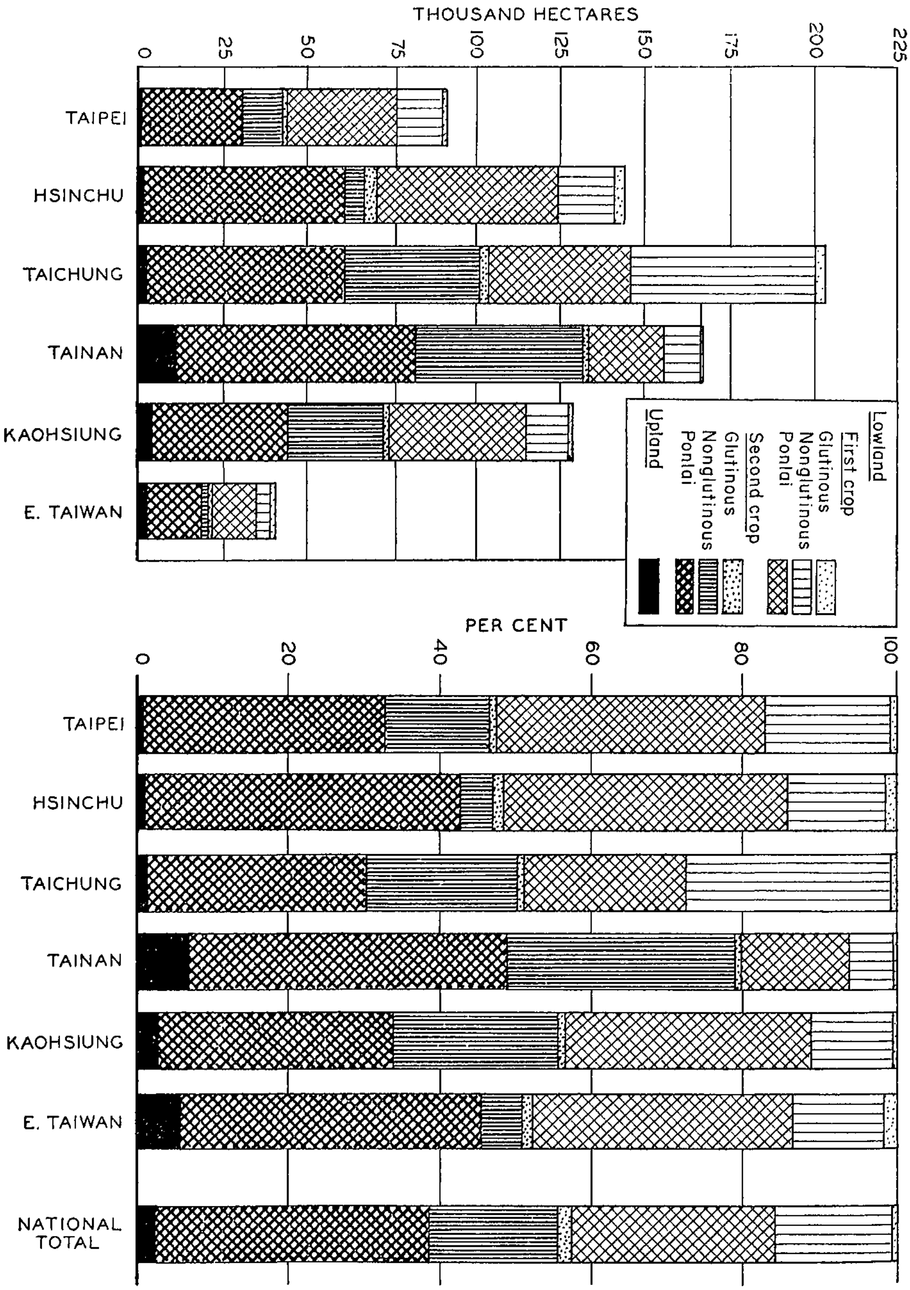
Apparently the fact that most rice is grown under fully irrigated conditions in Taiwan imposes, by itself, a high degree of yield uniformity. In addition a very high proportion of the total rice area is planted to the *ponlai* varieties. The yield uniformity also reflects genetic improvements in the glutinous and nonglutinous *indica* (*Chailai*) varieties grown in Taiwan which has permitted some convergence of yield differential among the *ponlai*, nonglutinous, and glutinous types (Table 5). Apparently only the upland varieties have failed to share in the yield improvements since the late 1930's.

TABLE 5.—EFFECT OF DIFFERENCES IN REGIONAL PRODUCTION PATTERNS ON REGIONAL AVERAGE YIELDS OF ROUGH RICE IN TAIWAN, 1961/62–1963/64*

	Actual yield		Standardized yield	
Food district	Tons per hectare	Index	Tons per hectare	Index
Taiwan	3.520	100.00	3.520	100.00
Taipei	2.965	84.23	2.864	81.36
Hsinchu	3.158	89.71	3.021	85.83
Taichung	3.904	110.92	3.785	107.53
Tainan	3.530	100.28	3.762	106.88
Kaohsiung	3.793	107.76	4.378	124.38
East Taiwan	3.224	91.59	3.224	91.59

* Actual yields are from 1962, 1963, and 1964 issues of source cited for Table 4. Tons are metric.

CHART 6.—DISTRIBUTION OF RICE AREA BY FOOD DISTRICTS IN TAIWAN, 1961/62–1963/64 AVERAGE*



* See Appendix Note for source of data.

REGIONAL YIELD COMPARISONS BETWEEN THE PHILIPPINES, THAILAND, AND TAIWAN

In the previous section an attempt was made to determine the extent to which differences in the yield of rice among regions within each country are accounted for by environmental or technological factors. In this section an attempt is made to assess the relative importance of environmental and technological factors in determining yield trends in the major rice-producing regions of the Philippines, Thailand, and Taiwan. Taiwan is treated as a single region because of the relative uniformity of yields among regions and its small size relative to the other countries.

Clearly, national average yields per hectare are lower in the Philippines than in Thailand and are relatively lower today than a decade ago. Taiwan's average yields are higher than in either the Philippines or Thailand and are much higher relative to the other two countries today than in the early 1950's (Table 6).

Disaggregation to the regional level, in an attempt to achieve greater uniformity of environmental factors, reveals a somewhat different picture. Yields in central Thailand and the central Luzon areas of the Philippines—the two regions in each country in which irrigation is most highly developed and which account for a relatively high percentage of the rice which enters the commercial market—are almost identical in most years and have risen at approximately the same rate over the last decade (Table 7). Moreover, the rate of yield increase in both central Luzon and central Thailand has been approximately the same as in Taiwan. Thus the average yield in the two regions has remained at just slightly less than 50 per cent of the Taiwan yield since the early 1950's (Table 7).

It is also of interest to compare yields in regions in which irrigation is least developed and where the area grown under rainfed and upland conditions has been expanding rapidly. Northeastern Thailand has experienced a rapid expansion in rainfed rice area. The Philippines has seen rapid expansion of both upland and rainfed area in southern and western Mindanao and in the Cagayan

TABLE 6.—COMPARISON OF NATIONAL AVERAGE YIELDS OF ROUGH RICE IN THE PHILIPPINES, THAILAND, AND TAIWAN, 1953/54–1963/64*
(Yields in metric tons per hectare harvested)

Year	Philippines (1)	Thailand (2)	Taiwan (3)	Yield ratios (1)/(3)	(2)/(3)	(1)/(2)
1953/54	1.20	1.39	2.77	.43	.50	.86
1954/55	1.21	1.26	2.86	.42	.44	.96
1955/56	1.19	1.36	2.82	.42	.48	.88
1956/57	1.21	1.44	3.00	.40	.48	.84
1957/58	1.02	1.30	3.08	.33	.42	.78
1958/59	1.11	1.36	3.19	.35	.43	.82
1959/60	1.13	1.29	3.14	.36	.41	.88
1960/61	1.16	1.39	3.27	.35	.43	.83
1961/62	1.23	1.44	3.38	.36	.43	.85
1962/63	1.25	1.49	3.49	.36	.43	.84
1963/64	1.24	1.59	3.69	.34	.43	.78

* See Appendix Note for sources of yield figures.

TABLE 7.—COMPARISON OF YIELDS OF ROUGH RICE IN CENTRAL LUZON, CENTRAL THAILAND, AND TAIWAN, 1953/54–1963/64*

(Yields in metric tons per hectare harvested)

Year	Central Luzon (1)	Central Thailand (2)	Taiwan (3)	Yield ratios (1)/(3)	(2)/(3)	(1)/(2)
1953/54	1.33	1.61	2.77	.48	.58	.83
1954/55	1.50	1.38	2.86	.52	.48	1.09
1955/56	1.61	1.53	2.82	.57	.54	1.05
1956/57	1.61	1.60	3.00	.54	.53	1.01
1957/58	1.41	1.30	3.08	.46	.42	1.08
1958/59	1.51	1.56	3.19	.47	.49	.97
1959/60	1.39	1.46	3.14	.44	.46	.95
1960/61	1.57	1.59	3.27	.48	.49	.99
1961/62	1.80	1.51	3.38	.53	.45	1.19
1962/63	1.82	1.73	3.49	.52	.50	1.05
1963/64	1.86	1.86	3.69	.50	.50	1.00

* See Appendix Note for sources of yield figures.

Valley. In the early 1950's rice yields in southern and western Mindanao and in the Cagayan Valley were substantially higher than in northeastern Thailand. With the rapid expansion in area in southern and western Mindanao, yields have declined and are now only slightly higher than in northeastern Thailand. Area expanded primarily through the addition of area in upland and rainfed rice. Under this type of cultivation rice yields are low, and apparently differ little in northeastern Thailand, southern and western Mindanao, and the Cagayan Valley in spite of rather substantial differences in soil and climate (Table 8).

TABLE 8.—COMPARISON OF YIELDS OF ROUGH RICE IN THE PHILIPPINES AND THAILAND, REGIONS WITH RAPID EXPANSION, 1953/54–1963/64*

(Yields in metric tons per hectare harvested)

Year	Southern and Western Mindinao (1)	Cagayan Valley (2)	Northeast Thailand (3)	Yield ratios (1)/(3)	(2)/(3)
1953/54	2.04	1.59	1.08	1.89	1.47
1954/55	1.47	1.31	.93	1.58	1.41
1955/56	1.35	1.25	1.01	1.34	1.24
1956/57	1.36	1.25	1.13	1.20	1.11
1957/58	1.04	1.08	1.03	1.01	1.05
1958/59	1.04	1.28	1.01	1.03	1.27
1959/60	1.03	1.38	.93	1.11	1.48
1960/61	1.13	1.09	1.03	1.10	1.06
1961/62	1.14	1.21	.94	1.21	1.29
1962/63	1.26	1.28	1.16	1.09	1.10
1963/64	1.26	1.13	1.17	1.08	.97

* See Appendix Note for sources of yield figures.

TABLE 9.—COMPARISON OF YIELDS OF ROUGH RICE IN CENTRAL LUZON AND CENTRAL THAILAND, 1953/54–1963/64, WITH TAIWAN YIELDS 1924/25–1934/35*

(Yields in metric tons per hectare harvested)

Year	Central Luzon (1)	Central Thailand (2)	Year	Taiwan (3)	Yield ratios (1)/(3)	Yield ratios (2)/(3)
1953/54	1.33	1.61	1924/25	2.14	.62	.75
1954/55	1.50	1.38	1925/26	2.19	.68	.63
1955/56	1.61	1.53	1926/27	2.05	.79	.75
1956/57	1.61	1.60	1927/28	2.21	.73	.72
1957/58	1.41	1.30	1928/29	2.18	.65	.60
1958/59	1.51	1.56	1929/30	2.14	.71	.73
1959/60	1.39	1.46	1930/31	2.25	.62	.65
1960/61	1.57	1.59	1931/32	2.21	.71	.72
1961/62	1.80	1.51	1932/33	2.52	.71	.60
1962/63	1.82	1.73	1933/34	2.32	.78	.75
1963/64	1.86	1.86	1934/35	2.55	.73	.73

* See Appendix Note for sources of yield figures.

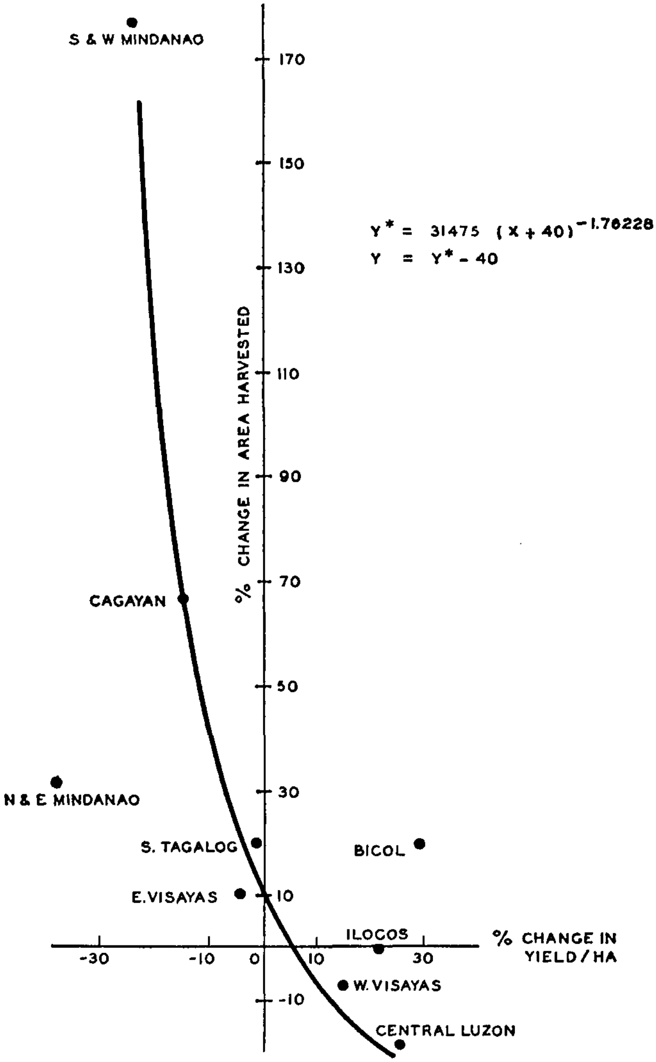
It would also be instructive to see whether the pattern of yield increases now occurring in central Luzon and central Thailand are similar to those that occurred in Taiwan after the early or mid-1920's when the rice yield "take off" began. In Table 9 the decade 1924/25 to 1934/35 for Taiwan is selected for comparison with the decade 1953/54 to 1963/64 for central Thailand and central Luzon. The absolute yields of rough rice in Taiwan during the 1924/25–1934/35 period were typically about 25 per cent higher than in central Thailand and central Luzon during 1953/54–1963/64. The relative yield remained roughly unchanged, indicating that the rate of yield increases in central Luzon and in central Thailand from 1953/54 to 1963/64 was about the same as in Taiwan from 1924/25 to 1934/35 (Table 8). Inspection of the data would seem to indicate that rice yields in central Thailand and central Luzon may have entered a take-off stage after the mid-1950's resembling that in Taiwan after the mid-1920's.

A closer examination of the yield increases in central Luzon and central Thailand indicates, however, that one should be cautious in accepting this conclusion. In central Luzon the recent increases in yield are associated with a substantial decline in the area devoted to rice (Chart 7). Competition between rice and sugarcane for land has resulted in a shift of marginal rice land to other uses (*20*). At least part of the yield increases in central Luzon over the last decade must be attributed to a transfer of lower yielding upland and rainfed rice hectarage to other uses.

In Thailand, natural disasters, typically excess flooding in the Central Plain and both excess flooding and extreme dry weather in the northeast, frequently reduce sharply the percentage of the area planted that can be harvested. In some years, severe flooding or drought also reduces the yield on land that is harvested in areas that are not completely damaged.

The relationship between yield per hectare harvested and percentage of

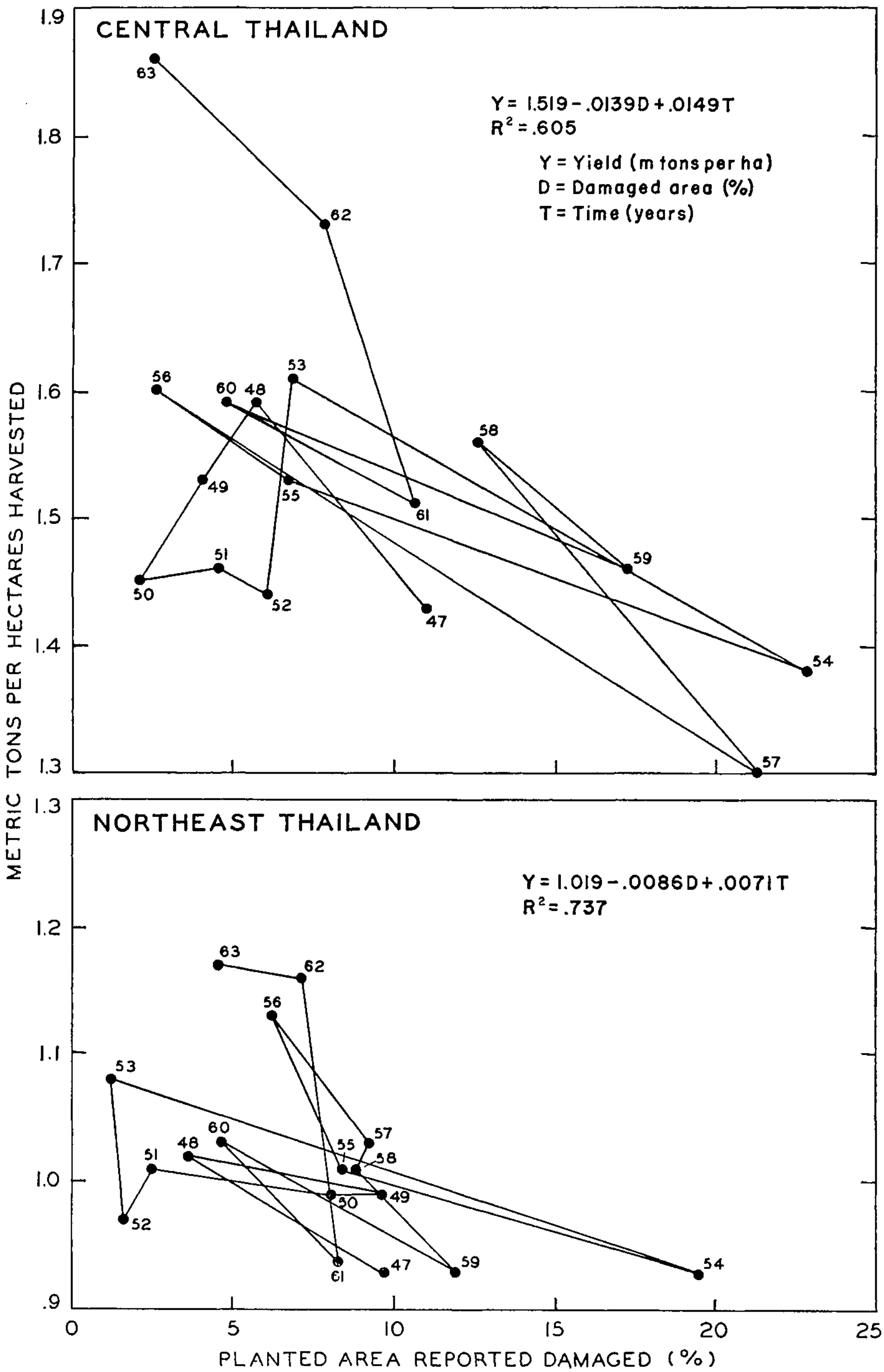
CHART 7.—INTERACTION OF AREA AND YIELD CHANGES IN PHILIPPINE REGIONS BETWEEN 1952/53–1954/55 AND 1960/61–1962/63*



* Data from E. C. Venegas and V. W. Ruttan, "An Analysis of Rice Production in the Philippines," *Economic Research Journal,* December 1964, pp. 160, 176. See Appendix Note for source of basic data.

planted area reported damaged between 1947/48 and 1963/64 are presented in Chart 8. A relatively high percentage of the variation in yield from year to year can be explained by variations in the percentage of damaged areas in the northeast and the Central Plain. In addition, most of the upward trend in yield in these two regions in recent years appears to result from a sequence of years in which the damaged area has declined continuously. If damage again rises to the range of 12 to 17 per cent, as in 1958/59 and 1959/60, the average yield in the Central Plain could drop to around 1.5 metric tons per hectare. In the northeast, damage

CHART 8.—RELATIONSHIP BETWEEN YIELD PER HECTARE HARVESTED AND PERCENTAGE OF PLANTED AREA REPORTED DAMAGED, THAILAND, 1947/48–1963/64*



* See Appendix Note for source of data.

in the range of 9 to 12 per cent, as in 1957/58–1959/60 could again result in yields of around 1.0 metric ton per hectare.[8]

TECHNOLOGICAL AND INSTITUTIONAL FACTORS IN TAIWAN

Despite numerous deficiencies, the data examined above are consistent with the first hypothesis—that both the yield increases of the last decade and the yield differences among major rice-producing regions in the Philippines and Thailand primarily reflect variations in the environmental factors under which rice is grown rather than differences in variety planted or cultural practices. After the effects of the environmental factors are taken into account, there is little yield increase or yield differential left to be explained by such factors as new varieties, better cultural practices, or more intensive use of technical inputs such as fertilizer and insecticides or by economic and social differences among regions and between Thailand and the Philippines.

This conclusion would not have much significance if there had been no changes in varieties, cultural practices, or the use of technical inputs. Fertilizer is not widely used on rice in Southeast Asia. A major obstacle to higher levels of fertilizer use is the limited response to increased applications of nitrogen, particularly during the wet season when most rice is grown (*7, 29*). There have been other significant changes in technology over the last decade and a half in both the Philippines and Thailand. Higher-yielding local varieties have been widely diffused; new varieties have been introduced from other Southeast Asian countries (principally Indonesia); and a number of new varieties based on local crosses have been developed and distributed. In the Philippines, straight row planting and use of the mechanical weeder has resulted in better weed control in substantial areas. Increasingly effective insecticides have been introduced in both countries. It seems apparent, however, that the innovations of the last several decades have not yet had any measurable impact on national average yields.

It is possible, however, that both the Philippines and Thailand may be entering the preliminary phase of a "yield take off" similar to the situation in Taiwan in the mid-1920's. Some new technology has been introduced. New rice varieties are now being developed which resemble, in their fertilizer response and yield potential, the *ponlai* varieties that were introduced in Taiwan in the mid-1920's. Although the yield increases in central Luzon and central Thailand since the mid-1950's appear to be based primarily on environmental factors it is possible that some "real" yield increases have occurred. It is useful, therefore, to examine in greater detail the conditions under which the "yield take off" in Taiwan actually occurred.

The simplest answer may lie in the fact that (a) the development and introduction of high-yielding *ponlai* varieties in Taiwan in the early 1920's provided an important breakthrough in rice yield potentials in Taiwan, and (b) the substan-

[8] As long as the parameters for damaged area (d) in the equations presented in Chart 8 hold a decline in the area damaged by 10 percentage points, say from 15 to 5 per cent, would result in a rise in yield of 139 kilograms (0.139 metric ton) per hectare in the Central Plain and 86 kilograms (0.086 metric ton) in the northeast. In contrast, the parameter for time or trend (*T*) indicates an average rise in yield of only 14.9 kilograms (.0149 ton) per hectare per year in the Central Plain and 7.1 kilograms (.0071 ton) per year in the northeast. The effect is to produce a rather substantial increase in average yield during a period when the damage is declining which could be sharply reversed by one or two bad years.

tial irrigation development that had already been completed or was completed within the next several years provided the essential infrastructure investment for rapid diffusion of the new technology. However, the answer is not really so simple. One can also ask, given the technology and infrastructure prerequisites, why it took roughly forty years—from the early 1920's to the early 1960's—to realize the yield potentials of the new varieties. An average yield of 3.78 metric tons of rough rice per hectare was achieved on the first 414 hectares of commercial *ponlai* production in 1922. The national average yield for *ponlai* varieties in 1961/63 was 3.64 metric tons of rough rice per hectare.

THE TECHNOLOGICAL CONDITIONS FOR GROWTH

By the mid-1920's Taiwan had acquired a number of essential elements for rapid development of its rice economy.[9] New and improved rice varieties had been introduced and research and development institutions capable of making continuous improvements in varietal characteristics had been established. Much of the potential rice land was served by irrigation systems capable of delivering water to the land throughout the year. Technical inputs such as fertilizer were made available through economic integration with the Japanese economy. Economic integration also resulted in rapid development of the local transportation and marketing systems, opened up the Japanese markets, and created incentives to increase the marketable surplus of rice in Taiwan (*4*).

Higher yielding varieties.—Early efforts by the Japanese to improve rice varieties in Taiwan emphasized selection and diffusion of native *indica* varieties characterized by high yields (*4, 14, 17*). In spite of a large reduction in the number of inferior varieties grown and substantial diffusion of superior varieties the national average yield showed only modest gains. Early efforts to introduce *Japonica* varieties from Japan were not successful. Even after substantial modifications in cultural practices the high yield potentials of the *japonica* varieties were only partially realized under Taiwan conditions. Efforts were then directed to breeding varieties of the *japonica* type which combined the desirable characteristics of the introduced *japonica* varieties (high fertilizer response, short growing period, nonsensitivity to photoperiod, and better quality) with the resistance to disease and the superior adaptation to the local ecology of the native *indica* varieties. The new *japonica-indica* crosses developed in Taiwan are referred to as *ponlai* varieties.

The first *ponlai* variety, Nakamaru, was introduced commercially in 1922 when it was planted on 414 hectares in the Hsinchu region. An exceptionally high yield of 3.78 metric tons per hectare was achieved. Later the planted areas were increased and extended to the Taipei and Taichung regions. With the diffusion average yield declined. After 1925 an outbreak of rice blast disease, to which the new varieties were highly susceptible, sharply reduced the *ponlai*

[9] Mosher (*21*) identifies (1) five agricultural development essentials—(a) markets for farm products, (b) constantly changing technology, (c) local availability of supplies and equipment, (d) production incentives for farmers, and (e) transportation—and (2) five accelerators—(a) education for development, (b) production credit, (c) group action by farmers, (d) improving and expanding agricultural land, and (e) national planning for agricultural development. Our analysis leads us to classify irrigation development as an essential element for agricultural development in the rice producing areas of the tropics.

yields. Beginning in 1930, other *ponlai* varieties with greater resistance to the rice blast disease were introduced, and by 1940 half the total rice area was planted to *ponlai* varieties. Approximately 20 years had elapsed between the introduction of the first *japonica* varieties and the development of *ponlai* varieties which possessed sufficient advantages relative to local varieties to justify rapid diffusion.

Two characteristics of the new varieties were particularly important in establishing a high complementarity with other inputs. First, the higher yield potentials of the *ponlai* varieties could only be realized with high levels of fertilization and careful management of water. At low levels of fertilization and with inadequate or undependable control over irrigation water the local *indica* varieties had higher yields than the *ponlai* varieties. Second, elimination of photoperiod sensitivity (flowering dependent on day length) and shortening of the number of days from transplanting to harvest made it possible to obtain two crops of rice per year, given a high level of crop husbandry and effective water control.

After World War II, strenuous efforts were made to develop new *ponlai* rice varieties to replace the old ones. Sixty-two improved varieties of *ponlai* rice were officially registered from 1946 to 1964. As a result the *ponlai* rice varieties released in the early period have been largely replaced by varieties developed in the postwar period. The new varieties developed are of early maturity, high yielding capacity, short and sturdy straw (i.e., resistance to lodging), responsive to heavy fertilization, and resistant to most prevalent diseases.

Breeding efforts to increase yields of the native *indica* varieties were also emphasized after World War II. Efforts to develop *indica* varieties with such desirable characters as nonsensitiveness to day-length, lodging resistance, and responsiveness to fertilization have been successful. As a result large acreages are still planted to the native rice varieties. As the improved varieties of both types have demonstrated their superiority in increasing yield a greater percentage of total area has been accounted for by a relatively limited number of varieties.[10]

Irrigation development.—Rapid development of the irrigation system in Taiwan represented a major facet of the Japanese colonial policy designed to develop Taiwan into a major supplier of rice for the Japanese domestic market. Irrigation investment and irrigated area expanded rapidly from 1900 until completion of the Chianan system in the early 1930's (Table 10).

The major capital investments were in the form of grants, generated primarily out of internal revenues. Japanese government subsidies for Taiwan development extended only from 1896 to 1904 (5). Development, maintenance, and operation of the irrigation systems was placed in the hands of farmers. Between the completion of the Chianan system in the early 1930's and initiation of the Ta-Pu and Shihmen projects in the late 1950's there was very little investment in expan-

[10] The following percentage data illustrate the extent to which rice area was accounted for by a few varieties in 1963.*

	Ponlai rice		Native rice	
	1st crop	2nd crop	1st crop	2nd crop
Most popular variety	19.5	28.2	47.9	18.0
Seven most popular varieties	65.4	63.6	76.8	60.5
Total hectarage	200,623	288,921	112,484	131,111

* Data from S. C. Hsieh and T. H. Lee (9).

TABLE 10.—IRRIGATION IN TAIWAN, 1900–40*

Period	Irrigated land (thousand hectares)			Costs[a] (thousand old Taiwan dollars at 1935–37 prices)		
	Total	Double paddy	Single paddy	Total	Irrigation investment	Irrigation operation
1900	194.7	...	...			
1901–10				15.6	6.2	9.4
1910	332.4	...	...			
1911–20				28.5	9.5	19.4
1920	367.2	246.5	120.7			
1921–30				213.2	81.8	131.4
1930	396.3	292.1	104.2			
1931–40				118.3	24.7	93.6
1940	529.6	324.2	205.4			
1960	525.5	329.0	196.5			

* Data from E. L. Rada and T. H Lee (*22*), pp. 33, 37.

[a] The data on irrigation investment and operating costs are presented in constant dollars in order to emphasize the absolute rise in irrigation investment. Another measure of the magnitude of the irrigation investment in Taiwan is obtained by comparing the current dollar value of irrigation investment with the current value of rice production. The results of this comparison are as follows in per cent:

INVESTMENT AND OPERATIONAL COSTS AS A PER CENT OF THE VALUE OF RICE PRODUCTION IN CURRENT DOLLARS

	Total	Irrigation investment	Irrigation operation cost
1901–10	2.5	1.00	1.50
1911–20	3.55	1.22	2.33
1921–30	18.97	7.31	11.66
1931–40	6.86	1.44	5.42

The data on the current value of rice production is from Taiwan Provincial Food Bureau, *Taiwan Food Statistics* (Taipei), various years.

sion of system capacity. There was, however, very substantial investment by the irrigation associations and individual farmers in the improvement of the efficiency of the distribution systems—in canal development and maintenance, local storage and pumping facilities, land leveling and development—to more effectively use the irrigation water.

It was only in the areas which were fully irrigated that the *ponlai* varieties had a clear comparative advantage relative to the older *indica* varieties. The diffusion of the new varieties would not have occurred as rapidly in the absence of a highly developed irrigation system.

Technical inputs.—The relationship between fertilizer use and the yield of rice depends critically on two factors: (a) The rice variety must have the genetic capacity to respond to higher levels of fertilization in terms of higher grain yield. Vegetative response, typical of most *indica* varieties, tends to induce lodging and is competitive with higher grain yield. (b) Control of the timing and level of water application is also essential. Lack of water control, resulting in either excess or inadequate water, can sharply reduce the response of yields to fertilization. Lack of both fertilizer-responsive rice varieties and effective water control accounts for the fact that farmers in Southeast Asia have, in the past, rarely fertilized rice grown under rainfed conditions even when fertilizer has been available (*30*).

Commercial fertilizers were introduced to Taiwan by the Japanese during the early years of colonization. Major efforts to induce farmers to use fertilizer on rice were not initiated, however, until the *ponlai* varieties were introduced. Use of commercial fertilizers on rice increased by about 50 per cent between the mid-1920's and 1938, remained relatively stable from 1938 until 1943, declined slightly during 1944–47, and increased approximately 5 times between 1949 and 1960 (*22*, p. 141). Except during 1946–50 fertilizer has been available to farmers on relatively favorable terms (*9*).

Rice yield per hectare did not reach the 1938 peak until 1956. This is clearly related to lack of fertilizer availability. It also seems reasonable to hypothesize that the level of fertilizer application limited the rate of growth of rice yields between the mid-1920's and 1938.

Improved production practices.—The emphasis on production practices has also shifted over time. Early efforts were directed toward diffusion of the better processes already in use. As early as 1908 government regulations with respect to the eradication and prevention of crop diseases and pests were promulgated. Closer spacing of rice seedlings to increase the plant population per hectare was emphasized. Deep plowing was introduced.

With the introduction of the *ponlai* varieties and the emphasis on fertilization in the mid-1920's special efforts were made to promote weed control and good practices of land preparation.

More recently the emphasis has fallen on the development and diffusion of an integrated set of practices ranging from land preparation to harvesting methods. As the yield potentials have continued to rise greater emphasis has also been placed on plant protection, particularly with respect to control of stem borer and blast disease.

THE INSTITUTIONAL CONDITIONS FOR GROWTH

The essential technological and environmental elements for rapid development of the Taiwan rice economy were available by the mid-1920's. Introduction of these elements resulted in increases in yield per hectare of over 2.0 per cent per year until 1938, when Japanese military efforts began to divert resources from development objectives. Since the early 1950's rice yields have again risen rapidly even though the technological and environmental factors were not greatly different from those in the mid-1920's and early 1930's.

In spite of continued varietal development work, it appears that the yield potentials, under optimum environmental and management conditions, have not changed significantly since the late 1920's or early 1930's. It has previously been pointed out that greater fertilizer availability has been one factor permitting closer approximation of average to potential yields. It also seems clear that the evolution of the farmers' associations into effective extension and marketing organizations and the improvement in incentives resulting from the land reform of 1949–52, have played a significant role in the achievement of higher rice yields.

Farmers' associations.—Approximately twenty years elapsed between introduction of the first Japanese rice varieties and the development of the *ponlai* varieties to the point where they were suitable for rapid diffusion. It took roughly twice as long to develop fully effective institutional arrangements for rapid diffusion of new technology, the dissemination of credit, and marketing of agricultural supplies. The efforts to develop institutions to perform these functions have focused on the farmers' associations (*9*).

The first farmers' association was established in Taipei Prefecture in 1900. By 1908 sixteen had been organized to provide a direct link with experiment stations in introducing seeds of new varieties and in dissemination of improved farm practices. The associations also purchased and distributed fertilizer. They came under formal government regulation in 1908, and membership and collection of dues became compulsory. The system was reorganized in 1927. Agricultural improvement stations were established in each prefecture with direct linkage to the prefectural associations. By the early 1930's the associations employed 1,148 agricultural technicians. Their responsibilities had expanded to include extension of new agricultural practices, handling of land rent disputes between landlords and tenants, seed multiplication, fertilizer distribution, and related activities. The associations were again reorganized in 1937 in order to strengthen them in the townships and villages.

While the system of farmers' associations was evolving, cooperatives were being fostered to provide credit to small business and to farms. By the early 1930's the cooperatives had added purchasing, marketing, and warehousing services. Considerable duplication had developed between the activities of the associations and the cooperatives and in 1943 they were combined into a single organization.

After the establishment of Chinese administration, the farmers' associations and the cooperatives were first separated in 1946 and then reunified in 1949. Under the new reorganization steps were taken to decentralize the administration of the associations and to give greater authority to the farmer members.

The period since 1950 has been one of continued development. The credit functions and the handling of farm supplies and marketing of farm products of the old cooperative system were fully integrated with the extension and technical advisory services of the farmers' associations.

A combination of market power and efficient administration combined to make the association an efficient agent of technological change. Both market and nonmarket devices were coordinated to induce the cultivator to adopt the highest-yielding varieties, apply high levels of fertilizer, and adopt labor-intensive production practices directed at achieving rapid increases in yield.

The farmers' association system has evolved from a prewar pattern based very heavily on administrative control from the center down to the individual farmer to a system which relies primarily on a combination of technical information and market incentives in the factor and product markets to induce production decisions on the part of individual farmers.

Land tenure.—A second factor in the rapid growth of yield per hectare during the last decade and a half has been the incentive for more intensive use of purchased inputs, family labor, and land associated with the land reform of 1949–53. The first stage of the program involved a compulsory reduction in rent. The second stage involved purchase and resale of rented land to the tenant. Tenancy declined from 39 per cent to 17 per cent of farm families between 1949 and 1957. The land reform did not involve the breaking up of large estates but rather the transfer of tenant units from ownership of landlords to ownership of cultivators (*28*).

The implications of the land reform for incentives to use purchased inputs and household labor is consistent with the empirical evidence. The rapid increase in fertilizer use on rice reviewed earlier was clearly a joint result of the availability of the fertilizer, a favorable rice-fertilizer barter ratio in relation to the high-potential response of rice output to fertilizer,[11] and the additional incentive associated with an owner-operator system as compared with a share tenure system. Dramatic increases in the multiple cropping index and in labor input per worker were probably even more closely associated with the increased incentives for more intensive use of family labor.[12]

The Taiwan experience is consistent with the proposition that institutional development has to be built up through a process of selection, trial and error, and adaptive research similar to the manner in which new varieties are evolved. Both the agricultural technology and the institutions must be developed, or at least tested and modified, in the location in which they are to be utilized (*19*).

CONSIDERATIONS IN THE DESIGN OF A STRATEGY FOR INCREASING RICE PRODUCTION IN SOUTHEAST ASIA

The analysis of the previous sections can be summarized as follows:

1. Prior to the mid-1920's differences in rice yields among the three countries —Philippines, Thailand, and Taiwan—and among regions within each country were due primarily to differences in the environmental conditions under which rice was grown rather than to technological, economic, and social differences. The dominant environmental factor was irrigation and the precision of water treatment control.

2. With the introduction of the *ponlai* varieties by the Japanese in Taiwan in the mid-1920's technology became a dominant variable in explaining the rapid increase in rice yields in Taiwan and in explaining differences in rice yields between Taiwan and the other two countries. An important factor in the rapid diffusion of the new varieties and the use of higher levels of technical inputs such as fertilizer was the rapid irrigation development in Taiwan which began shortly after 1900 and continued through the 1920's. Achievement of the yield potentials inherent in the new varieties was stimulated by institutional developments, such as (a) the organization of farmers' associations and irrigation associations during the period of Japanese occupation and (b) the successful implementation of the land reform program and the reorganization of the farmers' associations into effective integrated farm supply, credit, and marketing cooperatives following the restoration of Chinese administration after World War II.

[11] The fertilizer-rice barter ratio in Taiwan has been criticized as relatively unfavorable in comparison with some other developing countries. However, given the relatively steep slope of the physical output response relationship for the *ponlai* varieties under irrigated conditions it has been profitable for Taiwan farmers to use relatively high levels of fertilizer on rice.

[12] The changes in farm employment, labor input, and double cropping can be summarized as follows (1911–15 = 100):*

	Number of agricultural workers	Labor input in man days/worker	Multiple cropping index
1911–15	100	100	116
1921–25	98	118	121
1946–50	144	141	151
1956–60	149	198	180

* Data from S. C. Hsieh and T. H. Lee (*9*, pp. 24, 41).

3. In the Philippines and Thailand differences in yield both between the two countries and among regions within each country are still primarily due to differences in environmental conditions under which rice is grown. When differences in season (wet or dry) and water treatment (irrigated, rainfed, or upland) are taken into consideration very little difference in yield is left to be explained by such factors as new varieties, differences in cultural practice, more intensive use of technical inputs, or differences in economic and social institutions.

4. Both the Philippines and Thailand may now be approaching a yield take-off similar to that experienced in Taiwan in the mid-1920's. Yields in the major producing regions in both countries have been rising at about the same rate during the last decade as in Taiwan during the decade following introduction of the *ponlai* varieties. Furthermore, new higher-yielding varieties having a yield potential of at least 6.0 metric tons during the wet season and 8.0 metric tons during the dry season when grown under irrigation with an appropriate complement of technical inputs are now being introduced (*11*).

Yet despite the yield potential inherent in the new varieties now being introduced there seem clearly to be basic deficiencies in the sequence of development programming which may prevent the Philippines and Thailand from repeating the experience of Taiwan. In Taiwan a major share of the basic investment in irrigation was already completed before the beginning of the biological revolution that lead to the yield take-off in the 1920's. Furthermore, the irrigation development leading to effective water control was a prerequisite to the effective diffusion of the new higher-yielding, labor-intensive, "fertilizer consuming" rice varieties. Institutional innovations such as extension work, farmers' associations, irrigation associations, and land reform followed and complemented both the investment in water control and the technological changes.[13]

In the Philippines and Thailand a reverse pattern is being followed. Efforts to develop agriculture following World War II have concentrated very heavily on institutional development. In the Philippines this effort is currently being supplemented by substantial efforts to develop and introduce high-yielding rice varieties responsive to fertilizer similar to the *ponlai* varieties introduced in Taiwan in the mid-1920's.

Neither the Philippines nor Thailand yet place major emphasis on the development of irrigation systems designed to provide a dependable water supply in both the wet and dry seasons to a major portion of the area devoted to rice production. It seems apparent that this lag of land and water resource development behind the institutional and technological changes will impose serious limitation on achievement of the output potential associated with the technological advances that are now being realized.

A high percentage of the lowland rice in the Philippines and Thailand is grown during the rainy season without irrigation. Under this rainfed system of cultivation, village or provincial average yields rarely exceed 1.5 metric tons per hectare. In fully irrigated areas in both countries, however, in areas such as Cheingmai (Thailand) or Laguna (Philippines) average yields often exceed 3.0 metric tons in the wet season and 3.5 metric tons in the dry season, over fairly

[13] The Taiwan experience is also consistent with the Japanese experience where effective water control also has represented a significant factor in the diffusion of rice production technology (*15*).

substantial areas. On such individual farms as participate in contests, or under experimental conditions, yields of the same varieties under irrigated conditions frequently fall in the range of 4.0–4.5 metric tons in the wet season and 5.0–6.0 metric tons in the dry season (*3, 10*).

A major implication of this analysis is that the factors which permit a province or region to increase its yield from 1.5 metric tons per hectare in the wet season to the levels currently being achieved in the higher yielding areas of each country are primarily beyond the control of the individual farmer in the major rice-producing areas such as central Luzon or central Thailand. Modifications in the environment necessary to achieve effective water control through irrigation and drainage during both the wet and the dry seasons will have to come primarily from public or semi-public agencies capable of organizing resources in a manner that is almost invariably beyond the capacity of individual tenants or farm owners.

A second major implication is that the limitations on environmental control that prevent farmers from achieving the yield potentials of existing varieties will be an equally severe limitation on achievement of the much higher yield potentials embodied in the new varieties now being introduced. These new varieties are even more sensitive than existing varieties to effective environmental control, technical inputs, and management.

The ecology of the monsoon tropics and the factor and product price relationships which characterize current development levels rule out the direct transfers of existing rice production technology from temperate region countries such as Japan and the United States. Even transfer within Southeast Asia, from Taiwan to the Philippines or Thailand, have not been successful.

But it is possible to transfer the propensity and the capacity to focus scientific manpower and other resources on technical problems of economic significance and the skill that comes from having solved similar problems although in a different environment. This involves skill (a) in breeding for fertilizer response, disease resistance, grain quality, and other elements, and (b) in using the local ecological information supplied by soil chemists, physiologists, entomologists, cereal chemists, geneticists, agronomists, economists, and others to select and achieve appropriate breeding objectives and breeding strategy.

The magnitude of the investment required to realize the production potential inherent in the new technology that is being created tends to be substantially underestimated. There will have to be massive investment in the industries that produce the inputs of fertilizer and insecticides; there will have to be massive investment in irrigation if the investment devoted to development of new varieties and production of the technical inputs is to achieve a reasonably high return; and it will be necessary to commit substantial increases in trained manpower to the tasks of management related to the direct investment and to educational work associated with rapid achievement of the production potentials.

Recognition of the complementarity between these infrastructure investments and the investments in research and development to create new production potentials raises a serious question about the validity of the assumption that primary emphasis on research and development could provide a relatively inexpensive route to rapid growth of agricultural production during the early stages of agricultural development.[14] These assumptions typically rest very heavily on analogies with the Japanese experience since the Meiji Restoration in 1868 and on the Taiwan experience after 1900 (*14a*). In both Japan and Taiwan, however, a relatively high percentage of the rice producing areas had already been brought under cultivation before the beginning of the "biological revolution" associated with the heavy use of natural and commercial fertilizer, introduction of higher-yielding fertilizer, responsive rice varieties, intensive use of insecticides and other agricultural chemicals.

This failure to develop an effective water storage, transportation, and drainage system for rice production in the monsoon areas of Southeast Asia at an earlier stage in development was due to a major extent to the differences in physical geography. Both Japan and Taiwan are characterized by short river valleys and narrow coastal plains which lent themselves to locally organized, small-scale, labor-intensive irrigation and drainage works. Water typically did not have to be transported over long distances. In contrast to Japan and Taiwan the major rice producing areas of Southeast Asia are characterized by broad river valleys and plains. Under these conditions, the physical geography dictates the organization of large national systems. The construction of such systems lends itself to much more capital intensive patterns of investment in water storage, transportation, and drainage in contrast to the relatively labor-intensive system employed during the early stage of development in Japan and even Taiwan.

Clearly, the investment requirements for growth of the agricultural input sectors and for infrastructure development in the rice-producing countries of South and Southeast Asia will be very high over the next several decades.[15] Furthermore, these investments will be competitive with other development goals. Unfortunately, investment in research and development has not opened up a new low-cost route to the rapid growth of agricultural output in those areas. It can provide one of the essential elements in a total program to achieve increases in agricultural production.

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[14] B. F. Johnston and G. S. Tolley (*13*) indicate that "initial emphasis should be placed on innovations that do not require large increases in the use of purchased inputs. This means emphasis upon the development and introduction of innovations such as high-yielding varieties, improved crop rotation, optimum spacing and time of planting, and a better seasonal distribution of the work load" (*13,* p. 369). This advice does not appear relevant in the tropical rice producing regions of South and Southeast Asia. Without massive investment in irrigation these innovations will not result in higher productivity.

[15] For a discussion of irrigation costs in the Philippines and other Southeast Asian countries, see Levine (*18*) and President's Science Advisory Committee (*29*).

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APPENDIX NOTE

SOURCES OF DATA FOR RICE AREA, PRODUCTION, AND YIELD

Philippines

Area figures through 1952/53 are for area planted, for area harvested thereafter. Yield figures reflect this change. Production figures are in terms of rough rice (paddy) all years; here shown in metric tons, but sometimes also officially reported in cavans (sacks) of 44 kilograms.

1902/03, Census Office of the Philippine Islands, *Census of the Philippine Islands: 1918,* Vol. III (Manila, 1921); 1908/09, J. S. Camus, *Rice in the Philippines* (Dept. of Agr. and Natural Resources Bulletin No. 37, Manila, 1921). Data up to 1920 are also reported: 1909/10–1924/25, Bureau of Commerce and Industry, *Statistical Bulletin of the Philippine Islands* (Manila, 1926), No. 8 and earlier issues; 1925/26–1952/53, Dept. of Agr. and Natural Resources, *Philippine Agricultural Statistics,* Vols. I and II (Manila, 1955 and 1956); 1953/54–1958/59, Dept. of Agr. and Natural Resources, *Crop and Livestock Statistics* (Quezon City, 1958/59), and earlier issues; 1959/60–1963/64, Dept. of Agr. and Natural Resources, Bureau of Agricultural Economics, *Rice: Area, Production and Yield Per Hectare by Region* (Quezon City, mimeo, 1964), and earlier years. Data in Table 3 and Chart 5 are from the 1960/61 issue, the only issue to give this much detail.

Thailand

In all years area figures are for area harvested, and production in terms of rough rice.

Ministry of Agriculture, Department of Rice, *Annual Report on Rice Production in Thailand, 1965* [in Thai] (Bangkok), and earlier issues. Historical data for 1959 and earlier years in Chart 1 are from the 1959 issue.

Taiwan

Area figures are for area harvested all years. The authors have converted production and yield figures, officially reported in terms of brown rice, to rough rice (paddy) equivalent at 1.312 metric tons rough per metric ton brown, corresponding to an extraction rate of 76.2 per cent.

Taiwan Provincial Food Bureau, *Taiwan Food Statistics, 1965* (Taipei), and earlier issues. Historical data for Chart 1 are from the 1964 issue, pp. 2–3. Various issues give data for Hsiens (counties), Chens or Hsiengs (townships) by season (1st and 2nd crops) for 1952 and later years.