The Green Revolution in Thailand: With A Bang or With A Whimper?

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I. Introduction

The breeders endowed the high-yielding varieties (HYVs) of rice with short, stiff straws, so that they can produce much higher yields without lodging. This inflexibility may have been, both literally and figuratively speaking, the main cause for the failure of HYVs to acquire a sure foothold in Thailand–a country that has survived and flourished through the ages by developing a unique quality of standing high and bending with the wind. The Green Revolution has not materialized because it has not encountered the appropriate environmental conditions in Thailand–physical, social and economic. We consider this not a cause for distress but a message of hope. Economic, social and to an extent even physical conditions can change in the future and Thailand could still achieve a comfortable increase in rice yields by, say, 25 percent or so. In the meanwhile it missed the current round of the Green Revolution. This is the major theme of this paper. A second theme will also be broadly sketched at the end. It appears that the energy-intensive Green Revolution technology may become inappropriate for a large number of countries where peasant agriculture is the dominant mode of operation. Should the Green Revolution turn brown, there may still be substantial room left for increasing world food supplies by encouraging traditional and intermediate technologies which are used by peasant cultivators. It seems that rice production in Thailand, which is commerical and export-oriented, has for years relied on intermediate technologies to obtain high quality of output at satisfactory yields.

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II. Rice Production and Yields

Being endowed with suitable material resourcs. Thailand has historically produced rice in abundant quantities, large varieties and excellent quality, to provide for her own population and to supply roughly one-sixth of the total rice in the world trade. The country has been a rice exporter since 1855 when the Bowring Treaty with Great Britain opened up Thailand to international trade. By the early 1930's Thailand was exporting 50 percent of its annual production and for some years in the 1960's Thailand overtook Burma as the leading world exporter of rice, being surpassed by the United States in 1967.

The export performance of Thailand has been grounded on a solid comparative (and at times even absolute) advantage in the production of rice. Takase and Kano (1969) refer to the high rice yields in Thailand at the turn of the century which exceeded even those of China, but which steadily declined up to 1960 with the expansion of cultivated land to insufficiently drained and irrigated areas. The records of the Royal Irrigation Department of the Thai Government for the years 1831-1948 indicate that yields as high as 2.2 tons per hectare of paddy were not unusual for the irrigated areas, while the non-irrigated areas yielded between 1.3 and 1.6 tons per hectare. Table 1 presents (scant) historical and more recent statistics on rice acreage, production and yield per hectare for Thailand. It suggests that since the mid 1960s country-wide yields per acre have increased to reach the levels recorded in the beginning of the century, approaching 2.0 tons per hectare. Such yields are respectable, although much lower than the levels obtained in some other countries as it appears in Table 2.

III. Research and High Yielding Varieties

The high yields of rice in Thailand have historically been the product of soil quailty, climatic conditions and, most importantly, of a serious local research effort that led to the adaptation and adoption of the environmentally most suitable varieties. Rice research in Thailand began formally in 1916 when the first rice research station was established at Rangsit. The emphasis was on breeding a large number of strains of traditions varieties, each best suited to the geoclimatic conditions of a specific locality that gave high quality of grain and improved yields. Rice breeding work resumed on an intensive scale in 1950. In 1954 the Ministry of Agriculture established a separate Rice Department with the initiation of hybridization mutation breeding.

The establishment of the International Rice Research Institute (IRRI) in the Philippines, in 1960 marked the beginning of a period

Table 1

Area, Production and Yields for Rice Thailand, 1908-1973
(Rough Rice Basis)

Year	Area Planted (thousand hectares)	Harvested (thousand hectares)	Production (thousand metric tons)	Yield (metric tons per harvested hectare)
1907/08-1908/09		1,319	2,475	1.88
1920/21-1921/22		2,298	4,250	1.85
1946/47-1947/48		3,907	4,974	1.27
1955/56	5,837	5,439	8,529	1.57
1956/57	6,094	5,830	9,649	1.65
1957/58	5,134	4,337	6,478	1.49
1958/59	5,825	5,230	8,233	1.57
1959/60	6,137	5,325	7,873	1.48
1960/61	5,991	5,709	9,112	1.60
1961/62	6,252	5,664	9,510	1.68
1962/63	6,737	6,264	9,883	1.58
1963/64	6,678	6,429	10,651	1.66
1964/65	6,616	6,041	10,977	1.82
1965/66	6,631	6,029	10,719	1.78
1966/67	7,520	7,086	13,895	1.96
1967/68	6,736	5,875	11,192	1.91
1968/69	7,313	6,411	12,034	1.88
1969/70	7,775	7,322	13,463	1.84
1970/71	7,894	7,215	13,401	1.86
1971/72	8,097	7,614	14,201	1.87
1972/73	7,223	6,648	11,669	1.76
1973/74	8,363	7,771	14,898	1.92
1974/75	7,977	7,333	13,380	1.82
1975/76(est)	8,519	8,017	14,091	1.76

Source: Years 1907 to 1948: Hsieh, S.C. and V.W. Rutten, "Environmental, Technological, and Institutional Factors in the Growth of Rice Production: Philippines, Thailand and Taiwan," *Food Research Institute Studies, 8*, No. 3, p. 310, 1967

Years 1955 to 1973: Yuavares Gaesuwan, Ammar Siamwalla, and Delane E. Welsch "Thai Rice Production and Consumtpion Data, 1947-1970,". Bangkok, Kasetsart University (mimeo), 1973

Subsequent Years: Ministry of Agriculture.

Table 2

Comparative Country Data on Rice, 1970

Country	(1) Production (thousand metric tons)	(2) Harvested Area (thousand hectares)	(3) Yield (metric tons per hectare)	(4) Proportion of Area in High Yielding Varieties (HYV)
Burma	8,162	4,809	1.70	4.0
Ceylon (Sri Lanka)	1,616	611	2.65	4.5
China Mainland	102,000	—	3.05	—
India	63,672	37,432	1.70	14.7
Indonesia	17,529	8,186	2.14	11.3
Japan	16,479	2,923	5.64	—
Cambodia (Khmer)	3,814	2,399	1.59	—
Korea, South	5,476	1,209	4.55	—
Laos	916	670	1.37	7.0
Malaysia, West	1,429	525	2.72	24.5
Pakistan	20,014	11,416	1.75	41.7[a]
Philippines	5,343	3,113	1.72	50.3
Taiwan	3,226	776	4.16	—
Thailand	13,401	7,215	1.86	2.1
Viet Nam, North	5,000	2,500	2.00	—
Viet Nam, South	5,716	2,510	2.28	19.3
United States	3,758	734	5.12	—

Notes: [a] West Pakistan only.
Source: Timmer C. Peter and Walter P. Falcon, "The Political Economy of Rice Production and Trade in Asia," Stanford University, Food Research Institute (mimeo), 1973

which brought to the world the Green Revolution and the High Yielding Varieties (HYV) of rice. The latter are characterized by short stems which can absorb larger quantities of fertilizer without lodging (becoming top-heavy); are more responsive to fertilizer at high levels of application; adapt to a broader range of latitudes; mature early, ripening in 120-125 days compared with 150-180 days for older varieties; and are insensitive to the length of daylight and thus can be planted at any time of the year if the prevailing temperature and water supply permit.

HYVs were experimentally grown in various parts of Thailand shortly after their development. IR-8 was released by IRRI in November 1966 and Thailand extensively tested it in both the dry and wet seasons of 1967. It performed well under Thai conditions, exhibiting high yield-fertilizer responsiveness and good plant type. However, its grain quality was inferior to Thai standards and merchants were reported to have discounted its price by 30-40 percent (Welsch and Tongpan (1973)). Thus Thailand did not rush into adoption of the IR varieties, which however, were used extensively in hybridization programs that produced crosses approaching the high grain quality of local varieties.

In December 1969 two Thai varieties were released named (for Rice Department) RD-1 and RD-3. They are characterized by short hight, stiff straw, high response to nitrogenous fertilizers and they are non-photosensitive. The latest Thai release is R-D-5, which is 50 percent taller than RD-1 and RD-3. Moreover, RD-2 is a glutinous variety which is intended for the North and Northeastern regions of Thailand where glutinous rice is very popular.

The adoption of these modified HYVs in Thailand has in general been disappointing. In 1970-71 they occupied a total of 162,000 hectares or 2 percent of the planted area (IRRI (1974b)). Microstudies indicate that they are more commonly planted in the small area of the dry season rice and only to a limited extent in the wet season (Barker and Anden (1975)). The inevitable conclusion is that the increase in yields observed in Thailand since the mid-1960's is independent of the HYVs. The major question that arises concerns the factors that account for the lack of success of the Green Revolution in Thailand.

Aggregate macroeconomic data can go only part way in answering this question. We will rely therefore mostly on micro-studies and specifically on data collected by an IRRI field survey, and by another Ford Foundation sponsored survey carried out by Kasetsart University in collaboration with the Food Research Institute of Stanford University.

The IRRI study was conducted simultaneously in six countries and is reported in Barker and Anden (1975). The Thailand part of the project was carried out in collaboration with Kasetsart University and is reported in (Sriswasdilek, *et al* (1975)). The survey was done in the wet season of 1971 in the provinces (Changwat) of Suphan Buri, in the Lower Central Plains, and covered 150 farms in three villages. The sample was chosen specifically because of the early adoption of HYVs on account of the suitable physical environment.

The Kasetsart-Stanford research was designed to study the production and consumption equilibrium of the agricultural household in Thailand and covered six provinces, namely, Suphan Buri, Phichit, Lop Buri, Nakhon Sawn, Saraburi and Nakhon Ratchasima. The first province, Suphan Buri, is located in the Lower Central Plain where rice is grown almost exclusively and mostly under irrigated conditions. The second province, Phichit, is located in the Upper Central Plain where rice is also grown with some corn. The balance of the provinces grow mostly corn and other corps.

One amphur or district was selected for each province and within each amphur the tambon or communes were classified into two categories on the basis of their distance from the amphur seat. From category one tambon was randomly chosen and two mubans, or villages, were selected from the tambon also on the basis of their distance from the center. The list of farmers within each muban was stratified on the basis of size of holding (less than 20 rai, 20-40 rai. 40-60 rai, 60-80 rai, 80-100 rai and over 100 rai).[1] A random sample of 18-20 farms were from each muban, distributed proportionally to the number of farms in each size of holding. The survey was carried out in 1973 and covers the crop year April 1972 to March 1973.

IV. Varietal Factors and Water Control

A principal reason that constrained the adoption of early HYVs of rice is that they were not suitable for the local or the foreign markets. The traditional Thai standards of high quality, long grain white rice were not met by the early varieties. The situation in Thailand, a rice surplus and major exporting country, was quite different from that in some of the food deficit countries whose decision to encourage 1R-8 was a contributing factor in the early success of the Green Revolution. Thai rice consumers are very discriminating in their tastes and it appears that increased incomes lead to upgrading the quality of rice consumed and to increased rice consumption expenditure. Similarly, attempts to protect existing export markets and foreign exchange earnings are inconsistent with growing low quality grains.

On the production side limited irrigation facilities and ineffective water control in the wet season make HYVs ill-suited environmentally (Barker and Anden (1975), Sriswasdilek, *et al* (1975)). Irrigated land in Thailand is 15.5 percent of the total arable area (Szczepanik (1975), Chapter 4) and rice culture relies mostly on the abundant rainfall of the wet season. For HYVs water need not only get to the paddy, but need also be taken off through drainage systems when excessive. Generally speaking, if sustaind water depths were likely to exceed one-half meter, the farmers would plant traditional varieties rather than HYVs. The former grow and yield well in water as deep as 1.5 meters, with floating rice varieties growing successfully in water depth of three or more meters (Burton and Chungtes (1972)). Attempts are currenty underway to develop HYVs that will stand up well under flooding conditions up to a meter which is common

1 One hectare is equal to 6.25 rai.

throughout much of the Central Plain. This is being accomplished by incorporating an "elongation" goal into varieties of short to medium stature that will permit them to keep above water level when the floods occur. At the same time, photo-period sensitivity is being built back into these varieties that would permit them to ripen at the end of the monsoon season when the floods recede.

V. Fertilizers

Next to water control, fertilizer is the basic fuel of the Green Revolution. The HYVs were bred specifically in order to absorb high quantities of fertilizer without lodging. The fertilizer situation in Thailand deserves special notice.

Table 3 presents the use of total chemical fertilizer nutrients in the period 1950-1970, which were almost exclusively imported, and the percent they constitute in total fertilizer materials utilization, the balance of which mostly represents home-grown manure (Adulavidhaya and Chirapanda (1972)). In 1970 the usage of chemical fertilizers over the country's total cultivated area averaged 10 kgs. per hectare. Nitrogen fertilizer was applied at the rate of 4.4 kgs. per hectare of cultivated land. This makes Thailand one of the lowest fertilizer-using countries in Asia, just outranking Laos, the Khmer Republic, Burma ard Afghanistan (FAO (1973), p. 51).

The use of chemical fertilizer in rice cultivation is even more limited. It is estimated that only 10-20 percent of the 7 million hectares, of rice land received any chemcial fertilizer at all in 1970 and that the rates of application were very low. Burton and Chungtes (Burton and Chungtes (1972)) in a study of farms using mostly HYVs in Suphan Buri province (Lower Central Plain) found that fertilizer utilization averaged 6 kgs. per hectare, with little fertilizer going to traditional varieties and roughly 18 kgs. per hectare going to HYVs. These estimates seem high in comparison to the IRRI study, also concentrating mainly on HYVs, where 9 kgs. of nitrogen per hectare were observed with the range going from 0 to 21 kgs. (Sriswasdilek, *et al* (1975), Table 5). The Kasetsart-Stanford study found that only 54 of the 232 rice producing farms. or 23 percent, were using any chemical fertilizer at all and applying it as the rate of 23.5 kgs. per hectare. Even these rates of utilization are entirely insufficient to produce any significant increase in yields. Table 4 presents yields per hectare by farm size for the entire sample of rice-growing farms of the Lower Central Plain in the Kasetsart-Stanford study and for the two subsets of non-fertilizer using and of fertilizer-using farms. At the low levels of fertilization prevalent in the latter subset of farms, the yields per hectare do not differ significantly from those of the parent sample. In fact, performing a one-tailed t-test revealed that in all cases but one the null hypothesis that the yields per hectare for the non-fertilizer using farms within each size cell are not statistically different from those of the fertilizer-using farms in the same size cell cannot be rejected at the 99 percent level of significance. In three cases, the null hypothesis cannot be rejected at the 95 percent level of significance.

The reason for the low fertilizer use in rice cultivation in Thailand deserves further comment. Unlike other countries of Asia that have exhausted their arable land and have overworked their soils, Thailand can substantially increase its area under rice cultivation while enjoying the blessings of high soil fertility. As a result the increase in rice output observed after World War II is attributed by equal shares to the increase in area under cultivation and the increase in yields (Welsch and Tongpan (1973)). The soil quality has traditionally accounted for the use of little or no fertilizer in the production of rice by Thai farmers.

The extent to which farmers apply fertilizers depends on the marginal physical product and ultimately on the marginal revenue product of fertilizer. Systematic data on the marginal (physical) response of rice to fertilizer application are not available but rough estimates range from 5 to 10 kgs. of rice per kg. of fertilizer, depending on the country and on the level of fertilizer application (Parker and Christensen (1965)). The latter figure of 10 kgs. is the most commonly adopted (optimistic) rule of thumb for yield response to composite fertilizer. The IRRI, on the other hand, has reported a number of experiments and actual field trials, mostly in the Philippines, that propose to determine the marginal rice yields to nitrogen application. A convenient summary of these is presented in Figure 1, from which two observations arise.[2] First, the application of nitrogen per hectare that results in maximum yields, ranges from 60 to 120 kgs. Second, there is a marked difference in the response curves obtained in experiment stations (maximum potential yields) and in farmers' fields (actual farmers' yields). The former are uniformly higher and steeper than the latter.

The profitability of fertilizer application by the farmer depends

2 Some of the underlying data for curves as in Figure 1 are reported in (IRRI (1974b), pp. 66-67). They suggest that for IR8 variety, for example, the marginal yields to low levels of nitrogen application, say less than 60 kgs. per hectare, are small or even negative, and they rise approximately 10 kgs. per hectare for higher levels of fertilizer application. The dry season yields are substantially higher, starting at 10 kgs. per hectare even at low levels of nitrogen application. The difference in yields between dry and wet season is at least partly attributed to the fact that the high level of solar energy in the former is accompanied by low levels of insect and disease incidence, thus allowing for the potential of HYVs to be more fully attained. The reluctance of Thai farmers to apply fertilizer to the wet season rice is most likely well-founded.

Table 3

Total Fertilzer Materials, Chemical Fertilizers, And Chemicals To Total Materials Ratio, Thailand, 1950-1970
(metric tons)

Year	Total Ferilizer Materials (1)	Chemical Fertilizers[a] Nitrogen N (2)	Phosphorous P_2O_5 (3)	Potassium K_2O (4)	Total (2)+(3)+(4) (5)	Chemical Fertilizers as Percent of Total Materials (5)÷(1)·x100 (6)
1950	9,354	1,828	162	32	2,022	21.61
1951	6,465	1,240	108	126	1,474	22.79
1952	17,465	3,324	552	94	3,970	22.73
1953	12,164	2,141	758	283	3,182	26.15
1954	15,386	2,938	879	198	3,515	22.84
1955	24,280	4,221	1,046	408	5,675	23.37
1956	23,429	3,912	1,384	681	5,977	25.71
1957	40,020	6,713	3,021	969	10,703	26.74
1958	29,170	5,228	1,968	575	7,771	26.64
1959	47,639	8,004	4,117	1,782	13,903	29.18
1960	52,163	9,234	3,664	1,958	4,946	28.65
1961	54,757	10,750	4,621	1,462	16,833	30.74
1962	66,465	13,211	6,707	1,889	21,807	32.80
1963	97,375	16,289	10,224	3,011	29,542	30.31
1964	108,977	19,365	12,775	3,442	35,582	32.65
1965	88,943	16,471	11,859	2,965	31,295	35.18
1966	126,357	22,974	18,051	4,357	45,382	35.91
1967	217,944	35,698	27,660	13,313	76,671	35.18
1968	265,487	40,338	37,687	14,163	92,188	39.72
1969	265,628	39,961	41,555	21,457	102,973	38.76
1970	249,609	37,375	37,127	28,457	102,959	41.25
1971	233,404	37,792	28,380	22,367		
1972	367,248	53,440	41,553	38,508		
1973	351,833	44,502	40,255	37,540		
1974	235,093	29,091	26,982	25,831		

Note: [a] Chemical fertilizers are almost totally imported. Domestic production of nitrogen started in 1965 and amounted to 8000 m.t. per year for the period to 1971, increasing to 12000 m.t. after 1972. Paul J. Stangel [1974], "The Likely Impact of Middle East Oil Policies on the Development of the Nitrogen Industry of East and Southeast Asia," USAID/TVA, January (mimeo).

Table 3 (cont.)

[b] Preliminary data

Sources: Tosunthorn Suphan, Praphan Chotinaruemol and Melvin M. Wagner, *Demand for Fertilizer in Thailand*, Kasetsart Economic Report No. 32, Kasetsart University, 1970.

Sriplung Somnuk, *Use of Fertilizer in the Thai Agriculture*, Agricultural Economics Research Bulletin No. 45, B.E. 2514, Division of Agricultural Economics, Office of the Under Secretary of State, Ministry of Agriculture.

Ministry of Agriculture and Cooperatives, Division of Agricultural Economics, "Fertilizer Problems and Fertilizer-Aid Policy to Farmers" (mimeo).

not only on the yield response to fertilizer but also on the relative price of rice to fertilizer. A rice-to-fertilizer price ratio that is greater than one would make the marginal revenue product curves steeper than the marginal physical product curves in Figure 1 and therefore, with other things being equal, the rate of fertilizer utilization would increase. The converse would happen with rice-to-fertilizer price ratios of less than one that would make the marginal revenue product curves flatter than the marginal physical product curves. A rice-to-fertilizer ratio of .2, for example, would reduce a 10-to-1 yield response relationship to a benefit-cost ratio of 2. Given the fact that other costs related to fertilizer application, such as greater need for weeding, are not considered in this benefit-cost ratio, the value of 2 is usually considered as the lowest benefit-cost ratio that would make fertilizer application profitable. The rice-to-fertilizer price ratio varies widely from country to country, with values close to one being the rare (e.g., Japan and South Korea in Asia) and with modal values around .5 (Timmer and Falcon (1973)). For the period 1967-1974 the rice-to-fertilizer price ratio in Thailand, as reported in Table 5. ranged from 0.28 to 0.52. The recently prevailing prices, then, would make the application of fertilizer barely profitable, assuming a yield response ratio between 8 to 10 and a benefit-cost ratio of 2.

Due to the infrequent and low use of fertilizer we have not been able to estimate production function coefficients or input demand function coefficients for fertilizer in Thailand.[3] We constructed instead a composite variable that includes seeds, pesticides, and organic and chemical fertilizers and we estimated (indirect) Cobb-Douglas

3 For the methodology of estimating profit functions, input demand functions and indirect production function elasticities see (Lau and Yotopoulos (1971, 1972)

Table 4

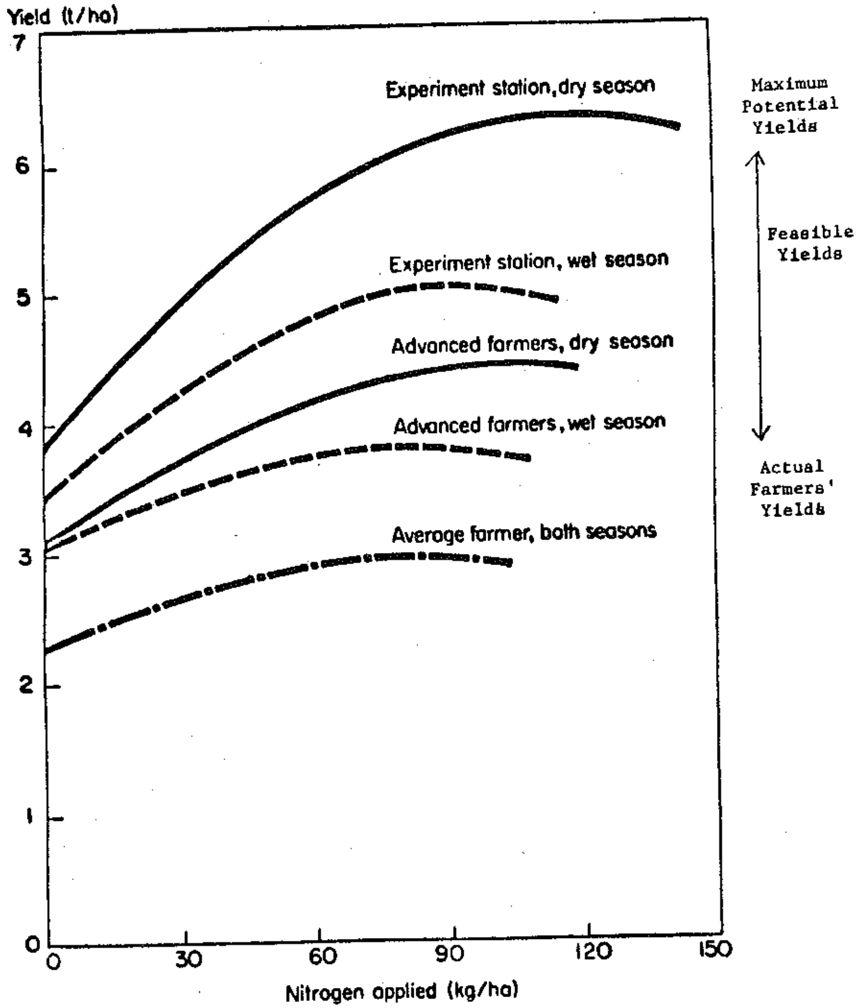
Rice Yield by Farm Size, Thailand, 1971-72
(Kgs. per harvested hectare)

Lower Central Plain

Farm Size (Planted Area)	All Region		All Farms		Non-Fertilizer Using Farms		Fertilizer-Using Farms	
	Number of Farms (1)	Yields (2)	Number of Farms (3)	Yields (4)	Number of Farms (5)	Yields (6)	Number of Farms (7)	Yields (8)
Less than 20 rai (3.24 hectares)	37	1943.3 (846)	25	2130.4 (820)	18	2160.7 (883)	7	2053.8 (685)
20 to 40 rai (6.47 hectares)	73	1767.2 (884)	53	1872.9 (909)	27	1646.8 (878)	26	2108.2 (896)
40 to 60 rai (9.71 hectares)	52	1642.5 (881)	27	2025 4 (892)	15	1953.8 (1000)	12	2115.0 (769)
60 to 80 rai (12.95 hectares)	40	1518.9 (655)	19	1501.0 (654)	15	1432.4 (665)	4	1757.4 (682)
80 to 100 rai (16.19 hectares)	14	1270.0 (988)	4	1478.8 (334)	2	1274.4 (382)	2	1682.6 (147)
Greater than 100 rai (16.19 hectares)	16	1012.4 (536)	6	1161.9 (444)	3	798.1 (267)	3	1525.7 (158)
Small Farms (less than 40 rai)	110	1826.5 (872)	78	1955.6 (885)	45	1852.5 (907)	33	2096.5 (846)
Large Farms (greater than 40 rai)	122	1476.3 (807)	56	1716.0 (800)	35	1592.4 (856)	21	1921.7 (666)

Notes: Numbers in parentheses are standard deviations.
Stars indicate rejection of the null hypothesis that the average yields of columns (6) and (8) are not statistically different. One star indicates significance at the 95 percent level and two stars at the 99 percent level of the one-tailed test.

Figure 1: Representative Nitrogen Response Curves for Modern Varieties of Rice in the Philippines.



Source: International Rice Research Institute (1974). "The Implications of World Fertilizer Situation for New Rice Technology," (June, mimeo).

Table 5

Thailand: Rice and Fertilizer Prices, 1967-1974[4]

Year	Price of Rice Paddy (baht per kg.)[b]	Price of Fertilizer (baht per kg.)	Rice-to-Fertilizer[a] (baht per kg.) Price ratio	Agricultural Product	Price Index (1967—69=100) Fertilizer
1967	1.18	2.56	0.46	108	105
1968	1.13	2.43	0.47	101	100
1969	0.80	2.30	0.38	91	95
1970	0.77	2.38	0.32	85	98
1971	0.62	2.25	0.28	74	93
1972	0.90	2.42	0.37	91	99
1973	1.49	2.87	0.52	139	158
1974[c]	2.00	6.00	0.33	174	242
1975[d]	2.60				
1976[e]	2.90				
1977[f]	2.50				

Notes: [a] Mixed fertilizer (N-P-K)
[b] The official exchange rate is 20 baht to a dollar.
[c] Price in June.
[d] Price in March.
[e] Price in November.
[f] Price in January.

Source: Ministry of Agriculture and Cooperatives, Division of Agricultural Economics [1975], "Fertilizer Problems and Fertilizer-Aid Policy to Farmers" (mimeo).

4 An international index of commodity prices shows both the price of milled rice and the price of urea tripling between 1972 and early 1974 (IRRI (1974 b)). However, since early 1974 the price of rice has decreased by about 20 percent. This is consistent with recent reports from the Philippines according to which the rice to fertilizer price ratio has declined from .6 in 1973 to .2 in 1975 (*Far Eastern Economc Review*, March 28, 1975).

Table 6

Indirect Estimates of Input Elasticities
and Related Statistics
(31 Farms, Lower Central Region)

Variable	Production Coefficient	Mean Value	Price (baht)	Marginal Revenue Product
Value of Output (kg)	—	17,335.00	1.27	—
Labor (mandays)	0.302	473.64	12.63	11.05
Animal (days)	0.047	74.56	9.79	10.93
Mechanical (hours)	0.005	16.60	43.97	67.88
Seed-Fertilizer (kg. equivalent)	0.059	52.53	20.18	19.47
Fixed Assets (baht)	0.242	8925.50	—	.47
Land (hectares)	0.285	8.11	—	609.41

Note: The profit function from which the indirect input elasticities are derived was estimated by including five dummy variables from the six villages that were sampled in the province of Suphan Buri.

production function elasticities for a sample of 31 farms that cultivate HYVs of rice in the Lower Central Plain. The results are reported in Table 6. The (indirect) production function coefficient of seed-fertilizer is 0.059, implying a marginal productivity of the seed-fertilizer composite input of 19.47 baht per kg. The profit function elasticity of demand for seed-fertilizer is −1.11; and the cross-elasticity of fertilizer with respect to the price of output is 1.90 (Adulavidhaya. *et al* (1975)). If the marginal revenue product and the price reported in Table 6 are representative, the rule of thumb that assumes a yield response of rice to fertilizer of 10÷1 is grossly exaggerated in the case of Thailand. One must keep in mind, however, that the input reported in the table is a composite of seed, chemicals and fertilizer.

These results can be compared with parallel estimates obtained for Taiwan. The (indirect) Cobb-Douglas production function coefficient of the composite organic-chemical fertilizer input (excluding seed) was 0.10; the profit function elasticity of demand for fertilizer ranged from −1.22 to −1.24; and the cross-elasticity of fertilizer with respect to the price of output ranged from 1.10 to 1.30 (Yotopoulos, *et al* (1976)). The two cases of Taiwan and Tailand can now be compared. The high coefficient of fertilizer in the production function, the relatively elastic response of factor utilization to own price, and the elastic cross elasticity with the price of output suggest that at the levels of utilization that exist in Taiwan both input and output price affect the demand for fertilizer. In Thailand the production coefficient of fertilizer is lower as compared to Taiwan, and the cross elasticity of demand of seed-fertilizer with respect to the price of output is much higher. Returning to Figure 1 we observe that if the same rice yield response curve to fertilizer, were applicable to both countries, Thailand with low levels of fertilizer utilization would have been operating on a steeper portion of the curve than Taiwan where more fertilizer is being used. The estimated production coefficients of seed-fertilizer for both countries, however, imply that the marginal response curve for Thailand is lower than that for Taiwan throughout. Two reasons account for that, both of which offset for the impact of low fertilizer use in Thailand. First, the HYVs are widespread and the yields are higher in the case of Taiwan. The underlying physical marginal product curves must therefore be steeper. Second, the rice-to-fertilizer price ratio is higher in Taiwan than in Thailand. The marginal revenue product curves for Thailand, as reported in Table 6, must therefore be flatter. It appears that a change in the price structure that exists in Thailand would be amply reflected in increased utilization of the fertilizer composite input.

VI. Farm Size, Quality of Management and Intensity of Cultivation

Rice responds to intensive cultivation and especially so the HYVs. The applciation of fertilizer feeds both the rice and the weeds and the HYVs with their dwarf stature and many leaves create an ideal environment for the rapid multiplication of leafhoppers, planthoppers and the sheath blight organism. Without proper management the potential of serious crop losses is great.

> The level of rice management in Thailand has been traditionally low (Sriswasdilek (1975). p. 248).
> Weeds are found almost everywhere. Hand weeding is common, but the amount of weeding is generally inadequate to control the weeds. Insecticides are rarely used. Fertilizer is applied at very low levels. Rats are a major problem, finding excellent living accommodations in the unweeded banks of the canals and in the trees and and hills often found in the paddy fields. This low level of management is partly explained by the high cost of inputs and the relatively large farm size (4 to 6 ha.) which leads to an extensive mode of farming.

To the extent that the quality of management reflects underutilization of labor per unit of land, it is a correlate of the relative land-labor ratio. Countries with large size of holdings and relatively low population pressure have a higher implicit price of labor than countries with small farm size and large number of economically active persons per hectare. The average farm size in Thailand is much higher than in the rest of Asia, and land is relatively equitably distributed among owner operators. This was accomplished by the policy of making public lands freely available for land occupancy. To the extent that the low cost and easy-to-develop agricultural lands have already been brought into use, the land/man ratio may become less favorable in the future (Fuhs and Vingerhoets (1972) p. 39). At present, however, with an average farm of 3.5 hectares and with 3.9 economically active persons per holding (Szczepanik (1975), Chapter 4, Table 2) Thailand has the most favorable land/labor ratio in Asia. When it comes to rice cultivation, the average holding is even larger, with 6 hectares in the IRRI study and 6.72 hectares in the Kasetsart-Stanford study.

A comparison of different farm size groups in Table 4 reveals that yields per hectare decrease with size. In a two-tailed t-test the null hypothesis that there is no difference in the yields of small and large farms in the Lower Center Plain was rejected at the 95 percent level of significance. The inverse relationship of yields per hectare and size of farm is probably a reflection of the higher intensity of cultivation that small farms obtain by the application primarily of more labor per unit of land. It appears from Table 4 that an increase in yields of 10 to 15 percent is possible by land reform that would affect the large farms and increase the number of farms that cultivate 40 rai or less.

VII. Yields per Acre and Biophysical Constraints to HYVs

Surprising as it may sound, the emphasis on yields per acre is a recent phenomenon. Through the ages food production has increased by opening up new lands to cultivation. Only as population pressure built up and the best quality of land was gradually exhausted higher yields became the route to increasing food supplies. The Meiji Restoration in Japan may have marked the chronological and geographical origin of this historic development. It is fortunate that the exhaustion of land has coincided with the explosion of agricultural science that is commonly referred to as the chemical-biological revolution. Thus yields per acre came to occupy center stage in the world food production.

The HYVs have largely been promoted on the basis of the *Maximum potential yields* achieved at experiment stations. These may well be three times or more the *actual farmers' yields* obtained with traditional varieties, but they also are an inappropriate standard for comparison. Most experiment station are located on soil that is ideal for rice production while most farmers are less fortunate. Most farmer have no access to irrigation water. Furthermore farmers have to pay prices for available inputs such as labor, fertilizer, chemicals. rat fences and bird boys, which is an entirely different matter from the zero cost that is imputed to inputs in agronomic experiments. Promoting the HYVs on the basis of the superiority of the maximum potential yields is overselling which leads to belied expectations and to backlash. The Green Revolution has certainly suffered from oversell.

Still, after discounting the maximum potential yields for the effects of the experiment station's environment, the gap between the *maximum feasible yields* in farmers' environment and the *actual farmers' yields* is substantial—it is estimated at 0.5 ton of grain per hectare (Jennings (1974)). The size of this gap. and the possibility of closing it will finally determine the success or failure of the Green Revolution.

The gap between actual and maximum feasible yields has two components. First, is the portion that is due to bio-phyical constraints: failure of weather, problems with soil, and seed varieties, cultural practices, water control, weeds, insects, and so on. Second is the portion attributed to socioeconomic constraints, such as institutions, traditions, economic behavior, land tenure systems, risk aversion, input availability, knowledge. Distinguishing between the two components of the gap in actual and feasible yields in farmers' fields will put in a realistic perspective what one can expect from the HYVs and will give a precise idea of the constraints that are binding to increasing yields.[5]

This paper has mostly concentrated on biophysical constraints—water control, varietal factors, fertilizers, management practices—in a descriptive way. It is hard to quantify the conjoint effect of all these factors. As an extreme approach, we considered only biophysical factors that became fully binding and resulted in a total loss of certain planted acreage—be it because of the failure of the monsoons, flooding, insects, epidemics or the use of inappropriate varieties. This can be expressed in a percent form as 100 minus the percentage of the ratio of harvested to planted acreage. By running a regression of yields (Y) per acre (in metric ton) on this damage variable (D) and a time trend (T), from the data in Table 1 we determine what was the decrease in yields in harvested acreage that was not to the set of biophysical factors that caused total loss of certain planted acreage. The following regressions were obtained (with t-values in parentheses).

5 Work on distinguishing among these factors is currently in progress at IRRI. I have borrowed the terminology above from this work.

Central Plain, Thailand

$$Y = 1.674 - 0.014\,D + 0.028\,T \qquad R^2 = 0.724$$
$$\qquad\quad (-8.050) \quad (23.773)$$

Whole Kingdom, Thailand

$$Y = 1.543 - 0.005\,D + 0.023\,T \qquad R^2 = 0.664$$
$$\qquad\quad (0.442) \quad (28.344)$$

For the period 1955/56 to 1972/73 for which annual yields are given in Table 1, the loss of one percent of planted acreage led to a loss in the yields of harvested area anywhere from 5 to 14 kgs. per hectare. This is a substantial loss in yields considering the fact that the average loss in acreage planted during the period was 9 percent. Furthermore, the regressions suggest that the annual trend in productivity increase over the period was about 2.5 percent, implying a decreasing rate of growth from about 1.6 percent at the beginning of the period to 1.3 percent at the end.

VIII. Socioeconomic Constraints and the Diffusion of Inappropriate Technology

The literature is strewn with references to "second" and "third generation" problems of the Green Revolution that encompass the indirect economic and social effects emanating from the new technology and from the direct effect of increased yields. Repetition here would certainly lack in variety. I would like instead to make some observations on patterns of input utilization that may constitute inherent contradictions in the Green Revolution.

The camparison of three cases, extreme in many respects, of high productivity agriculture may be instructive in studying the socioeconomic constraints of chemical-biological agriculture and the prospects for the application of intermediate agricultural technology. The United States, Taiwan and Egypt are all examples of highly developed, productive agriculture, with yields of basic food gains per hectare of 3570 kgs., 3721 kgs. and 3940 kgs., respectively (Owens (1974)). The dissimilarities in the three cases are evident from Table 7. Judged from the average size of holdings, U.S. farms are giants in comparison to the pygmie-size farms of Taiwan and Egypt. Mechanization also is extreme in the United States and relatively low in Taiwan, with Egypt in between. The converse is true for labor intensity of production.

A striking similarity is also revealed in the table: the use of fertilizer per hectare is rather high in comparison to other countries of the world, including Thailand. Fertilizer is only one of a set of high-energy inputs that are intensively used in all three countries in the example, and especially in the United States. Others are: machinery, irrigation, insecticides, herbicides, drying, electricity, transportaion, etc.[6]

The energy-intensive mode of agricultural production, as represented by the examples of the United States, Taiwan and Egypt, has certainly been the beneficiary of the low relative prices of energy that prevailed until recently. Will the future prices, of energy in general and of fertilizer in particular, prove equally conducive to the high-technology chemical-biological agriculture? Compared to the historical lows of 1972, world fertilizer prices roughly tripled by early 1974. So did the price of rice initially, and subsequently declined. This change alone may at best imply that the utilization of fertilizer for rice production may have not decreased. Where its use was warranted by the level of its physical marginal product, it will stilll be so. The same change, however, implies that fertilizer cannot be relied upon for further increasing the world food supplies. This could have happened only if the relative price of fertilizer to rice had decreased. Is there a prospect that this happens in the future?

Crystal-ball-gazing about future fertilizer trends is a treacherous

Table 7

Comparative Agricultural Statistics,
Four Countries

Country	Average Size of Holdings (Hectares)	Economically Active Persons per Hectare	Irrigated Area as Percent of Arable Land	Tractors (per Thousand Hectares)	Fertilizer Nutrients (Kgs. per Hectare)	Yields of Basic Food Crops (Kgs. per Hectare)
Thailand	3.5	1.09	15.5	2.76	3.9	—
Egypt	1.6	1.67	98.8	53.84	111.9	3940
Taiwan	1.3	2.21	57.6	5.00	256.7	3721
U.S.A.	122.5	0.009	8.5	110.47	64.1	3570

Source: Szczepanik, Edward F. *Agricultural Policies at Different Levels of Development*. Rome, FAO (mimeo). 1975.

6 In U.S. agriculture, the use of energy inputs more than tripled since 1945, amounting to 7.1 million kilocalories per hectare of corn n 1970 (Ramachandran and Bhatnagar (1974)). This amount of energy is equivalent to 200 gallons of gasoline per hectare of corn. About 37 percent of this total represents fertilizers, the use of which increased eleven-fold since 1945. An even greater proportion of energy use is represented by the fertilizer utilization in the other two cases.

occupation. Only three points will be timidly made in passing. First, the world fertilizer use more than doubled in the period 1962 to 1972, reaching 80 million tons by the end of the period: nitrogen use more than tripled in the same period (Donaldson (1974)). Second, projections to 1980 predict a production gap of roughly 30 million tons, or one third the total use requirements of about 100 million tons (Hughes and Pearson (1975)). Third, it is also predicted that the heavy concentration in fertilizer use among few countries will continue. Developed countries that accounted for 84 percent of total fertilizer consumption in 1972 will account for 74 percent in 1980 (Donaldson (1974)). Furthermore, two-thirds of the fertilizer share of LDCs by 1980 will be accounted for by six countries – India, Brazil, Turkey, Pakistan, Mexico and Korea (IRRI (1974a)). These predictions, if accurate, suggest in the least that the availability of fertilizers, which has been taken for granted in the past, must be questioned in the future. Without fertilizers the impact of the Green Revolution will be dissipated and the prospects of providing adequate food for the world's population will be bleak–unless other technologies are found.

This raises the question of the availability of intermediate technology and of the appropriateness of international technological transference. To an economist, at least, steeped in the Heckscher-Ohlin tradition of comparative advantage, it appears suprising that the United States, Taiwan and Egypt, countries with vastly differing endowments, and levels of wealth, use a similar, energy-intensive mode of agricultural production. Can high yields be obtained by means other than intensive use of fertilizer? What is the optimal trade-off between increasing yields and increasing energy consumption?

When energy resources become in short supply and costs soar alternatives may be needed to generate high yields while reducing energy inputs. Table 4 has demonstrated the conventional truth that as farm size decreases and labor is applied more intensively, yields increase. The application of intermediate technology that is better adapted to the endowments of the small farmer–the farmer who has, in the present context, abundant family labor, scarce capital, and who obtains purchased inputs at high costs–would further increase yields. There seems to be enough room left for the imaginative application of such technology in LDCs. Chemical fertilizers can to a large extent be substituted by organic fertilizers.[7] In cattle-rich countries

7 The current fertilizer requirements of corn in the United States, which amount to 94 kgs. per hectare (of total nitrogen, phosphorous and potassium nutrients) can also be provided by one year's production of manure by either one dairy cow, two young fattening beef cattle, nine hogs or 84 chickens (Ramachandran and Bhatnagar (1974)). "In addition to the nutrients manure adds to the soil, it adds organic matter which increases the number

like India, where animal dung is used as fuel, the new price configuration of energy inputs may give an impetus to the adoption of plants which will provide the fuel value, and will also preserve the dung slurry to be used as a nutrient in place of chemical fertilizers [Sankar (1974), p. 29].[8] Labor intensiveness can also substitute to some extent for more fertilizer application as is the case with "mud-balling" which greatly improves the utilization of a given quantity of fertilizer. The costly HYV fertilizer technology could be replaced by a simpler seed-inoculant approach which would also overcome the severe transportation and distribution constraints of fertilizer that are most binding to the small farmer. Nitrogen fixation in the plant would also overcome the transportation and distribution constraints of fertilizer. Green manuring can similarly replace large quantities of fertilizer, although it is and extensive to a certain degree and may not be well adapted to the requirements of small farmers [Webster anl Wilson (1966), p. 184-188]. Finally relay planting of the type practiced in Taiwan before agriculture ran into severe labor shortage problems is ideally suited for certain LDCs since it is extremely labor and land intensive, raising five crops per year on one piece of land.

Emphasis on intermediate technologies, especially the ones that largely bypass the market mechanism such as the use of organic fertilizers, presents at times serious organizational and practical problems. As compared to chemical fertilizer, for example, organic manures are bulkier and less easily transported, poorer in nutrients, and unless properly processed they can lead to health problems. These costs are real and they must be seriously considered. On the other hand, the dissemination of purchased intermediate inputs through the market mechanism also involves serious resource costs that must be considered when one examines the potential of intermediate technologies. The utilization of purchased intermediate inputs often requires a minimum farm size, specialization and trading and also involves building an elaborate economic, social and legal infrastructure: transportation networks, extension services, land tenure reform, price supports, insurance for the farmer against weather risks and corp failures cooperatives that work, savings and credit systems, laws relating to contracts, property and liability, high integrity in public administration, and so on.

of beneficial bacteria and fungi in the soil, make plowing easier, improves the water holding and percolation capacity of the soil, reduces soil erosion, improves the ratio of carbon to nitrogen in the soil" (Ramachandran and Bhatnagar (1974), p. 446)).

8 "If all the animal dung is used in biogas plants in India, about 10^{11} million m^3 of BTU/Scft gas can be generated per year, which can meet all the energy needs for cooking for the entire population and at the same time provide about 4 million tons of nitrogenous fertilizers which is about twice the nitrogenous fertilizer presently being produced from oil products (Ramachandran and Bhatnagar (1974), p. 29).

IX. Summary and Conclusions

A number of "success" stories connected with the Green Revolution have been fully described in the literature. The example of Thailand, a country where the Green Revolution has had only minimum impact, may also be instructive in suggesting the constraints—economic, social and political—that the adoption of the HYVs faces, and some of the risks that such adoption may imply.

One of the more serious handicaps of the Green Revolution technology may well be that it relies heavily on operating capital, and especially on purchased high-energy intermediate inputs. As such it may be largely inappropriate for the economic position and the initial endowments of peasants. The peasant is the family producer who owns his small plot of land, relies exclusively on family labor, organizes agricultural production around the consumption needs of the family, and only secondly produces marketable surpluses when money is required to buy the few items outside the ambit of self-sufficiency. The peasant is only marginally wired to the circuits of the market mechanism and therefore cannot use the market as a purveyor of agricultural inputs. To the extent that peasants constitute half of mankind, intermediate technologies that are better suited to their needs and initial endowments must be considered seriously.

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