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FERTILIZER USE AND THE ADOPTION OF MODERN VARIETIES

IN AN ASIAN RAINFED RICE FARMING SYSTEM

by

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The development of new, higher yielding varieties of rice has been a primary source of growth in food production in Southeast Asia over the past twenty-five years. Modern rice varieties, when grown under irrigated conditions and combined with chemical inputs (especially nitrogen fertilizer) often yield two to three times more than traditional varieties. Utilization of these varieties has been steadily increasing throughout Asia, but mostly in the irrigated areas (Herdt and Capule, 1983).

Farmers in several parts of Asia, particularly those in rainfed areas, have lagged behind in adopting modern varieties, and yields in these areas have remained relatively low. In fact, when one excludes the Philippines, one finds that rainfed rice growing areas of Asia are planted almost exclusively to traditional varieties (Barker and Herdt, 1979). It is commonly assumed that productivity can be increased in these areas by encouraging farmers to adopt modern varieties and use more fertilizer. This view is often reflected in agricultural development programs and in research, extension, and pricing policies.

This paper compares the yield and fertilizer response of modern rice varieties to traditional varieties in a specific rainfed area of South East Asia. Using several years of data from on-farm fertilizer trials conducted in Northeast Thailand, the yield response of modern varieties to nitrogen fertilizer is estimated and compared to that of popular local varieties. The profitability of the varieties and nitrogen fertilizer is evaluated. Contrary to popular conception, modern varieties in this environment offer little significant advantage over traditional varieties. These results also demonstrate the importance of taking into account the wide variety of rice growing conditions typically found in rainfed areas.

Modern Rice Varieties in Thailand

The selection and breeding of rice varieties in Thailand dates back to the establishment of the Rangsit Agricultural Experiment Station near Bangkok in 1916 (Welsch and Tongpan, 1973). This work concentrated on selecting and propagating local varieties that exhibited superior yield and quality performance. Improved-local varieties that were developed in the 1950s are still widely used throughout Thailand, especially in the Northeast Region, alongside traditional varieties that have been selected by farmers over time. With the establishment of the International Rice Research Institute (IRRI) in the early 1960s, Thai rice breeders gained access to a large new source of genetic material. But the first modern varieties developed by IRRI (such as IR8) were of too low quality for export-oriented Thai rice markets.

Crosses between Thai and IRRI varieties resulted in releases that passed quality standards by 1969 (Jackson, Panichapat, and Awakul, 1969). These modern varieties (designated as RD for Rice Research Division) gained some acceptance among farmers in the Central Plain and irrigated valleys in the Northern Region. Adoption was closely associated to the availability of irrigation and drainage facilities (IRRI, 1975). However, as of 1981, only about 10 percent of the rice area in Thailand was being planted to modern varieties (Herdt and Capule, 1983) and virtually none of the areas in the Northeast Region (Office of Agricultural Economics, 1984), where over 95 percent of the rice growing area is rainfed.

In the 1970s, research efforts in the Northeast Region were redirected toward developing new varieties that maintained their photoperiod sensitive trait (Pushpavesa and Jackson, 1979). This trait appeared to be highly desired by farmers in rainfed areas since it enables greater flexibility in planting dates. Farmers could delay planting until enough rain had accumulated in their paddies. Flowering would still occur before the end of the monsoon, however, since this was triggered by day length. By the end of the decade, a few photoperiod sensitive modern varieties were released. Another factor to consider is that most of the rice produced in the Northeast is glutinous ("sticky rice"). This is the staple food of the Thai-Lao ethnic group which is predominant in the Region. In the southern provinces of the Region, where there is a large population of Thai-Korat and Khmer-Soai, nonglutinous rice is preferred. Rice breeders have developed new varieties of each of these genotypes.

Table 1 lists some of the rice varieties developed by the Rice Research Division in Thailand from 1960 to the late 1970s. The varieties with local names (Khaw Dawk Mali and Niaw San Pahtawng) are improved-local varieties which have been fairly widely adopted in the Northeast Region. The first modern variety listed (RD2) is photoperiod insensitive. RD6 and RD15 are modern releases that maintain strong photoperiod sensitivity.

TABLE 1: RICE VARIETIES IN THAILAND

Variety Name	Photoperiod Sensitivity	Harvest Time date or days	Height cm	Year of Release
Khaw Dawk Mali (NG)	PPS	Nov 15	150	1959
Niaw San Pahtawng (G)	PPS	Nov 26	160	1962
RD2 (G)	PPIS	130 days	115	1969
RD6 (G)	PPS	Nov 21	135	1977
RD7 (NG)	PPIS	125 days	110	1975
RD15 (NG)	PPS	Nov 8	134	1978

G = glutinous variety
NG = nonglutinous variety
PPS = photoperiod sensitive
PPIS = photoperiod insensitive

(Source: World Bank, 1982, Vol. III, pp 48-50.)

Rainfed Rice Production in Northeast Thailand

The Northeast Region of Thailand comprises about a third of the Kingdom's land area and population. About 70 percent of the agricultural land is devoted to paddy rice production which is the major subsistence crop. In the 1983/84 wet season, a record 4.8 million hectares were planted to rice in the Northeast Region. Average fertilizer application on rice is about 35 kilograms of NPK nutrients per hectare, of which 50 to 60 percent is nitrogen (Puapanichya, 1983).

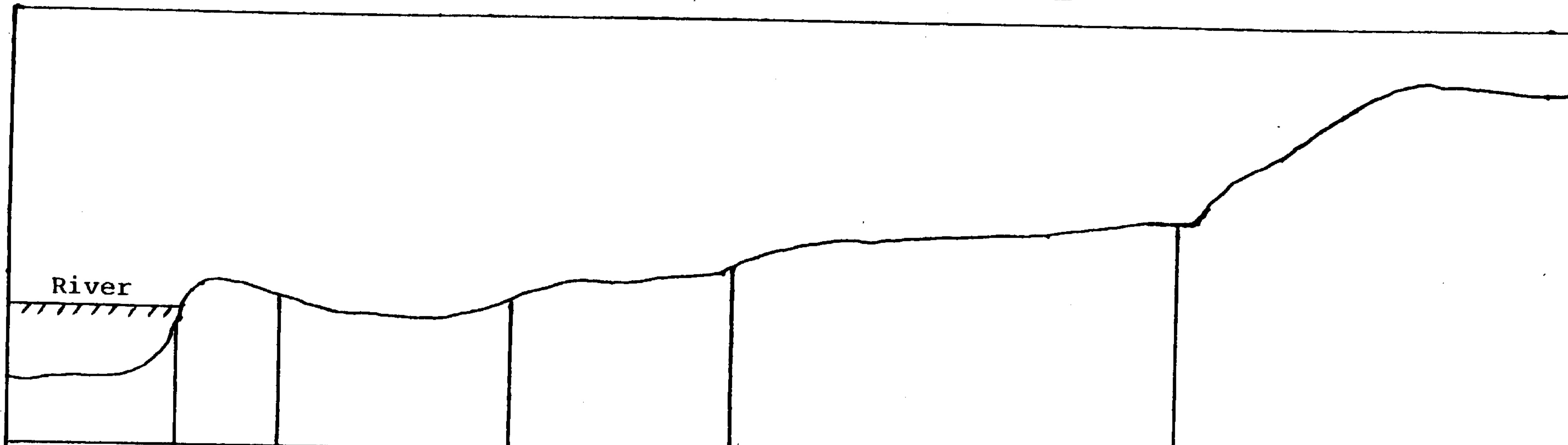
Probably the most severe environmental constraint to rice yields in the Northeast Region is low and erratic rainfall. Fukui (1982) reports, for example, that rice production in the Northeast is among the most highly variable in Asia, largely due to reoccurring drought. Nearly all the rice is produced under rainfed conditions. Completed irrigation projects area able to irrigate only about 200,000 hectares (Mongkolsmai, 1983).

The environmental conditions for growing rice in rainfed areas is quite diverse. Rice paddies located near a river or watercourse may be destroyed due to excessive flooding, whereas paddies located a few meters higher on the watershed may not receive sufficient rainfall or run-off to enable farmers to even plant a crop. Soil characteristics also vary. Lower paddy fields tend to have more clay content which reduces water percolation and seepage. Upper paddies tend to be sandier, and percolation can be quite rapid.

Figure 1 depicts a cross sectional profile of a typical watershed in the Northeast Region. The rice land is terraced to capture and hold rainfall. The lower paddies are the most dependable rice growing areas, and farmers can expect 3 to 4 months of inundated fields (which is necessary for a good rice crop). The upper paddies are more subject to drought and in many years no rice crop can be planted. Rice yields are often below 1 tn/ha. Cash crops (mainly cassava, kenaf and maize) are grown in upland areas.

The schematic representation in Figure 1 presents a framework for analyzing the performance of rice technology in the Region. The yields of different varieties and their response to fertilizer may vary across higher and lower terraces. Grandstaff (1981), for example, reports that farmers plant "lighter" varieties of rice in the upper paddies. Light varieties have a

FIGURE 1: CROSS-SECTION PROFILE OF A TYPICAL WATERSHED IN NORTHEAST THAILAND



Landform	Levee	Low paddy	Middle paddy	Upper paddy	Upland
Soils	Usti-fluvent	ALLUVIAL Tropaquepts	LOW HUMIC GLEY Paleaquults	LOW HUMIC GLEY Paleaquults/Paleustults	PODZOLIC Paleustults
Predominant Crops	Garden Crops	Paddy Rice good yield but with flood risk	Paddy Rice medium risk	Paddy Rice -when rain is plentiful, fallow 7 out of 10 years, high risk and low yields	Cassava, Kenaf, Sugar Cane

Source: KKU-Ford Cropping Systems Project shorter growing season and are sometimes followed by short duration field crops.

The Response of Rice Varieties to Nitrogen Fertilizer

The fertilizer trials used to evaluate modern rice varieties were conducted between 1978 and 1982 by the Department of Agriculture (DOA). DOA Research personnel conducted the fertilizer experiments in farmers' fields, selecting new fields each year. There are four years of data from each site except Ubon, where the trials were only conducted for three years. The general locations of these trials are given by the circles in Figure 2.

Four kinds of rice paddy soils were represented in the trials, all of which were rainfed. One set of trials was conducted in lower paddy areas (PHIMAI soil series), and the others in middle (ROI ET and ROI ET saline series) and upper paddies (UBON soil series) areas.[1] Given the spatial and seasonal diversity in the fertilizer trials, the data should give a good measure of the long run performance of these rice varieties in the Region.

Figure 2 also sketches the areas where glutinous and nonglutinous varieties are most prevalent. Two of the locations (Phimai and Surin) are located in the southwestern part of the region where nonglutinous varieties predominate. Here, three nonglutinous varieties were tested: Khaw Dawk Mali (KDM), RD7, and RD15. Glutinous rice is the dominant type in the other four

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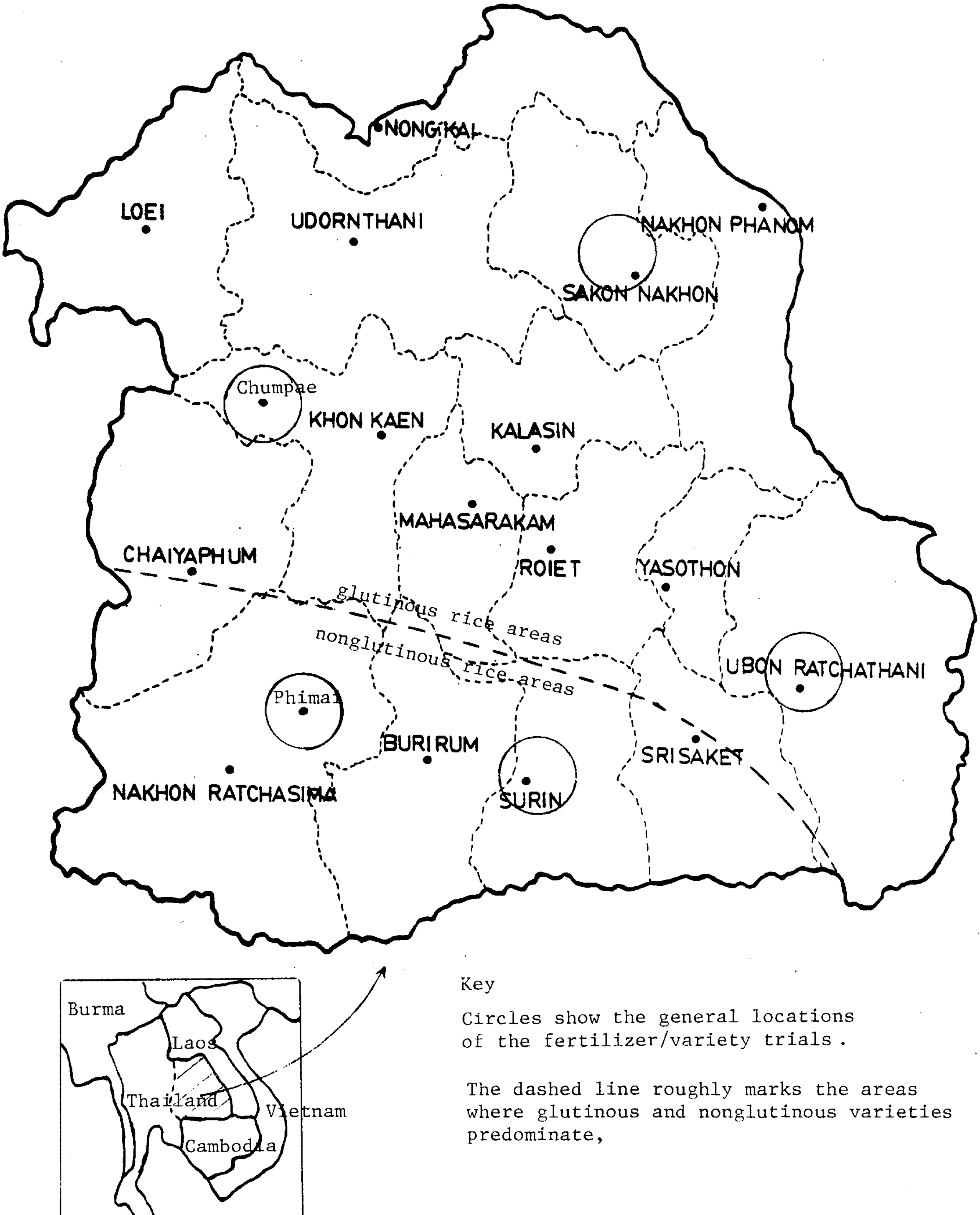
[1]Thai soil classification system given in parentheses.

FIGURE 2: SITES FOR THE FERTILIZER AND RICE VARIETY TRIALS IN NORTHEAST THAILAND



Key

Circles show the general locations of the fertilizer/variety trials .

The dashed line roughly marks the areas where glutinous and nonglutinous varieties predominate, locations. Niaw San Pahtawng (NSPT), RD2, and RD6 were tested in these areas.

A quadratic fertilizer response function was estimated for each location and soil type. The use of the quadratic functional form facilitates the comparison of these results with published estimates of fertilizer response functions in other rainfed areas of Asia (e.g., Herdt and Capule, 1983, Appendix Table 8). However, the quadratic form tends to bias the nitrogen responsiveness slightly upward (Ackello-Ogutu, et. al., 1985).

The estimated model included intercept and slope dummy variables to represent the effects of modern varieties. This specification allows for the possibility of differences between the improved-local varieties and the modern varieties in base yields (i.e. the yield at no nitrogen fertilizer application) and in the rate of response to nitrogen.

The specification of the complete model is:

$$Y = a + bN + cN^2 + \sum_j r_j R_j + \sum_i \left[d_{i1}MV_i + d_{i2}(MV_i N) + d_{i3}(MV_i N^2) \right].$$

Y is rice yield measured in kg/ha. N is kg/ha of nitrogen fertilizer. R_j is a dummy variable to capture yearly differences in the intercept (j = 1 to 4). MV_i is a dummy variable representing a modern variety (i = 1, 2). The small letters are coefficients to be estimated. The coefficients of the MV_i variables quantify the differences between the improved-local and modern varieties. For example, d_{11} is the difference in base yield between the improved-local variety and the first modern variety. Similarly, the differences in the linear and quadratic response to nitrogen are measured by d_{12} and d_{13}, respectively.

Coefficients d_{21}, d_{22}, and d_{23} measure the differences between the improved-local variety and the second modern variety.

If the fertilizer response function between the local variety and a modern variety is statistically the same, then the coefficients d_{i1}, d_{i2}, and d_{i3} corresponding to that variety are zero. To test this hypothesis, unrestricted and restricted models were estimated and an F-statistic was computed. The restricted model set the d_{ij} coefficients equal to zero. An F-statistic was computed for each modern variety.

Agronomic evidence from rainfed rice growing regions of the Philippines has demonstrated that yield variability tends to increase with fertilizer application (Aragon and De Datta, 1982), suggesting heteroscedasticity in the error term. The presence of heteroscedasticity would result in unbiased but inefficient estimators and significance tests on estimated parameters would be invalid.

The significance of heteroscedasticity was determined by comparing the variance in yield at each level of fertilizer. Details of the procedure can be found in Johnston (1984, p. 298-9). The null hypothesis of equality of variances was rejected for three of the six locations. In these cases, the variance in yield was significantly greater at higher levels of fertilizer. For these three cases, heteroscedasticity was corrected by assuming a quadratic structure to the variance-covariance matrix (i.e. that the variance in yield increases proportionally to the square of the fertilizer level) and the variables in the regression were weighted accordingly.

Increasing variance in yields also carries implications for risk efficient choices. If farmers are moderately risk averse then a higher dispersion of outcomes at higher fertilizer levels may cause fertilizer application to fall below profit-maximizing levels. However, empirical analyses of fertilizer use in the Philippines suggest moderate risk aversion will not significantly reduce fertilizer use (Roumasset, 1976; Smith and Umali, 1983).

Table 2 presents the parameter estimates for each of the models. In the models where heteroscedasticity was significant, GLS estimates are presented.

The estimates in Table 2 reveal the importance of taking into account environmental differences in rainfed paddies in evaluating new varieties and fertilizer use. Rice in the lower paddy areas respond fairly well to fertilizer unlike in middle and upper paddies. Base yields (yields without any fertilizer) decline steadily as paddies are located higher on the watershed. Furthermore, the response functions for the modern varieties exhibit the most significant departure from that of the traditional varieties in more favorable paddy areas.

The F-statistics presented in the last column test the significance of the difference between the response functions of traditional and modern varieties. In several cases, modern varieties were not statistically different from the local variety. This result illustrates the difficulty in identifying optimal production rates in a highly stochastic environment. With wide variations in yields from year to year, confidence intervals on parameters tend to be large. One implication is that it may take researchers and farmers several years of trial and experience before they can discover whether a new technique does indeed offer real economic advantages.

TABLE 2: FERTILIZER RESPONSE FUNCTIONS FOR RAINFED RICE

LOCATION	SOIL TYPE	VARIETY	ESTIMATED PARAMETERS a	b	c	F-STATISTIC
Chumpae	lower paddy	NSPT	2275	18.4	-.062	
		RD2	2179	11.9	-.014	1.422
		RD6	2525	16.4	-.049	3.458**
Sakhon Nakhon	middle paddy (saline)	NSPT	2136	5.2	-.019	
		RD2	2281	7.2	-.028	1.935
		RD6	2461	-1.4	.009	1.065
Ubon R.	middle paddy	NSPT	1620	4.2	-.017	
		RD2	1644	5.9	-.018	2.565*
		RD6	1616	5.0	-.021	0.051
Ubon R.	upper paddy	NSPT	1136	5.1	-.039	
		RD2	1212	6.1	-.049	1.062
		RD6	1111	5.6	-.043	0.067
Phimai	lower paddy	KDM	1716	27.0	-.148	
		RD7	1776	34.4	-.118	1.057
		RD15	1272	41.4	-.238	3.145**
Surin	middle paddy	KDM	1526	4.6	-.009	
		RD7	1229	6.8	-.022	4.442**
		RD15	1561	4.9	-.012	0.104

The parameters are the coefficients of the quadratic response function: $Y = a + bN + cN^2$. The intercept term is an average across all the years of the trials. Units are in kg/ha.

The F-statistic tests the null hypothesis that the response function of the RD variety is the same as the local variety.

* 10% rejection level; ** 5% rejection level.

Optimal Nitrogen Fertilizer Application

Thailand has historically followed policies that discourage fertilizer use on rice. Taxes levied on rice exports have on average kept domestic rice prices roughly 25% below world prices, though these taxes have been reduced since 1981 (World Bank, 1985). Furthermore, import taxes on industrial nitrogen have raised domestic prices of fertilizers about 20% above international prices (FADINAP, 1984). The result is a fertilizer-rice price ratio that is among the highest in Asia.

Table 3 compares fertilizer-paddy price ratios for several Asian countries. Of this sample of countries, the real cost of fertilizer use is highest in India, Thailand, and the Philippines. On the other extreme, Japan and South Korea maintain domestic prices that encourage excessive fertilizer use. The figures in Table 3 indicate the kilograms of paddy rice needed to buy 1 kg of nitrogen fertilizer.

But the figures in Table 3 probably underestimates the real cost of fertilizer use in many of the countries. Farm survey data from Thailand, for example, indicates that farmers received about 3 baht/kg of paddy in 1982 (Center for Applied Economic Research, 1984) and paid about 15 baht/kg of nitrogen nutrient in 1981

TABLE 3: COMPARISON OF FERTILIZER COSTS IN ASIAN COUNTRIES, 1977/78

COUNTRY	PRICE RATIO (kg N/kg paddy)
India	3.65
Thailand	3.35
Philippines	3.25
Pakistan	3.00
Indonesia	2.04
Malaysia	1.84
Burma	1.80
Bangladesh	1.58
Taiwan	1.34
Sri Lanka	1.20
South Korea	0.74
Japan	0.46

(Source: World Bank, 1985, p. 19)

even at institutional credit rates (Office of Agricultural Economics, 1982). Including the costs of marketing at the farm level (obtaining fertilizer, threshing grain, for example), will further aggravate the fertilizer/rice price ratio. The actual marginal prices fertilizer and paddy probably imply a fertilizer-rice price ratio between 5 and 10.

Table 4 calculates the fertilizer rates that maximize net income at price ratios of 10, 5 and 2 based on the parameter estimates in Table 2. Net income is measured in kilograms of paddy rice (net of fertilizer costs). The varietal choice that maximizes net income under each price scenario is also indicated. These results assume that the market price is the same for each variety. In many instances the rice quality and straw production (used for livestock feed) from modern varieties is below that of traditional varieties. The RD varieties used in these trials, however, appear to maintain roughly the same quality standards (Jackson, Panichapat and Awakul, 1969).

In the most unfavorable price scenario, fertilizer is only profitable in the lower paddies. Fertilizer begins to be profitable in the middle and upper paddies when the price ratio falls to 5.

Though modern varieties appear to be the optimum choice in each environment and under each set of prices, these results suggest that selection of modern varieties will increase if the price environment is more favorable. At a fertilizer-paddy price ratio of 10, differences in net incomes between traditional and modern varieties is negligible in all but the lower paddies.

These differences are accentuated when the price ratio falls, however, increasing the incentive to adopt a modern variety. But even under the most favorable price scenario, modern varieties increase net income only by about 10 to 15 percent.

TABLE 4: OPTIMAL VARIETAL CHOICE AND FERTILIZER USE IN RAINFED PADDIES

LOCATION paddy	VARIETY	OPTIMAL N FERTILIZER (R=10)	(R=5)	(R=2)	NET INCOME (R=10)	(R=5)	(R=2)
Chumpae lower	NSPT	68	108	132	2560	2999	3360
	RD2	68	246	354	2243	3029	3929 !
	RD6	65	116	147	2734 !	3188 !	3583
Sakhon N. middle	NSPT	0	5	84	2136	2137	2271
	RD2	0	39	93	2281	2324	2522 !
	RD6	0	0	0	2461 !	2461 !	2461
Ubon R. middle	NSPT	0	0	65	1620	1620	1691
	RD2	0	25	108	1644 !	1655 !	1855 !
	RD6	0	0	71	1616	1616	1723
Ubon R. upper	NSPT	0	1	40	1136	1136	1198
	RD2	0	11	42	1212 !	1218 !	1298 !
	RD6	0	7	42	1111	1113	1186
Phimai lower	KDM	57	74	84	2204	2534	2772
	RD7	103	125	137	3037 !	3607 !	4000 !
	RD15	66	76	83	2308	2664	2903
Surin	KDM	0	0	144	1526	1526	1714
	RD7	0	42	109	1229	1266	1491
	RD15	0	0	121	1561 !	1561 !	1736 !

R = fertilizer/rice price ratio.

Net income measured in kg/ha of rice remaining after subtracting the cost of fertilizer.

! marks the varietal choice that maximizes net incomes under each price scenario.

Summary and Conclusions

Unlike rice production in irrigated areas of Asia, rice yields in rainfed environments have not changed appreciably over the past two decades. This paper compared the response to nitrogen of modern rice varieties to improved-local varieties in Northeast Thailand, an area where rice production is almost entirely rainfed. Given the wide range in rainfed rice-growing conditions, the paper evaluated the performance of each variety in lower, middle and upper paddies separately.

At typical farm-gate price levels, the application of nitrogen fertilizer is economical only in lower paddy areas. Fertilizer was not economical in the middle or upper paddy areas using either the improved-local or modern varieties. If farm prices of nitrogen fertilizer and rice were adjusted to reflect world prices, however, fertilizer demand in the middle paddy areas would probably increase. There would also be a greater incentive to switch to modern varieties. But even under favorable prices, switching to modern varieties will not increase net incomes by more than 10 to 15 percent.

The limited potential for yield growth from modern varieties in rainfed environments carries important implications for agricultural research and development policies. Programs that attempt to extend modern varieties and fertilizers to rice producing environments that lack good water control are unlikely to meet much success. Increasing the price incentives to farmers is one way to intensify production. It may be worthwhile to give more attention to other research strategies, such as breeding for pest resistance or improving cropping system management.

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