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ENVIRONMENTAL AND OTHER FACTORS INFLUENCING THE PERFORMANCE OF NEW HIGH YIELDING VARIETIES OF WHEAT AND RICE IN ASIA

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Introduction

The crop year 1965/66 marked the beginning of the introduction into Asia of the new high yielding varieties of wheat and rice. During this year, India imported 250 metric tons of Mexican wheat seed and Pakistan imported 350 metric tons. In the same year India also imported 1 ton of Taichug (Native) 1 rice seed from the International Rice Research Institute in the Philippines. Fifty tons of seed of the new semi-dwarf variety, IR8, was released by the International Rice Research Institute of the Government of the Philippines in July 1966.

The new varieties of wheat and rice have spread more rapidly in some areas than in others. The dwarf wheat varieties are concentrated principally in India, Pakistan and Turkey. By 1968/69 they occupied 7.4 million hectares or more than 20 per cent of the Asian[1] wheat area. The major areas planted to the new rice varieties are in India, Pakistan, and the Philippines. In 1968/69, 4.7 million hectares or approximately 6 percent of the Asian rice area

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* The XIV International Conference of Agricultural Economists - Minsk, U.S.S.R. (August 24-September 2, 1970).

1 The term "Asia" used in this article does not include Communist block countries.

was planted to the new varieties.[2]

In both absolute and relative terms the new wheat varieties have spread more rapidly than the new rice varieties. Many reasons have been given for this difference. Under the heading "Slow Progress in Rice", an editorial in the Eastern Economist Annual Number 1969 offers the following opinion on the Indian situation:

> (P)rogress in identification or evolution of improved varieties and their introduction on commercial scale have been relatively slow ... (and) taking more time compared with the spread of the improved varieties of wheat. For one thing, problems in cultural practices have arisen in the actual cultivation of these paddies and they are yet to be successfully solved by the farmers themselves. One result is that the benefit of increased production, and therefore, increased remunerativeness is not yet as demonstrable in the case of rice as in the case of wheat. There are, however, signs that these teething difficulties are being overcome although it must be said that a great deal more effective work will have to be done both in the laboratories, on the agricultural farms and demonstration plots, and in seed multiplication and marketing before improved strains come to play their due role in expanding rice production.[3]

The above statement, while not incorrect, focusses on the wrong problem. Available data seem to suggest that the

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2 For a detailed report of area planted to new varieties by country, see Dana G. Dalrymple, Imports and Plantings of High Yielding Varieties of Wheat and Rice in the Less Developed Nations, Foreign Agricultural Service, U.S. Department of Agriculture, Nov. 1969.

3 Eastern Economist Annual Number 1969, New Delhi, India, Dec. 27, 1968, p. 1156.

disparity in performance of wheat vs. rice is due more to the difference in environmental conditions under which the two crops are grown and to differences in prices received by farmers for the crop than to problems of cultivation that need to be solved by farmers themselves. By environment, we refer not only to climate and soil, but also to irrigation facilities, factors over which farmers have very little control. Of course, it is difficult to separate physical environment from social and cultural conditions.

We contend that the major obstacle to the spread of the new rice varieties relative to the new wheat varieties has been the relatively unfavourable set of environmental conditions facing rice. Under typical monsoon Asian conditions, farmers growing rice face a more variable yield response due to uncontrolled factors and hence a higher risk; although under favourable conditions, the potential of the new rice varieties equals or exceeds that of wheat. Extension and farmer knowledge are also important factors contributing to the acceptance of new technology by farmers. However, these factors are less important in explaining differences in diffusion patterns between the two crops, wheat and rice, than they are in explaining differences in adoption of new varieties among farmers of a given crop.

Support for the above hypothesis is provided in: (1) a comparison of the environmental conditions under which these two crops are grown; (2) a description of the production-response potential for the wheat and rice varieties grown under experimental conditions; (3) a consideration of the economic implications of the uncertainty associated with rice yield response; (4) an analysis of the determinants of technology-acceptance within a cross-section of rice-farmers; and (5) a comparison of the production gains that have been made in the two crops through the 1968/69 crop season.

Environmental conditions for wheat vs. rice

The new Mexican wheat varieties are grown principally in the relatively homogeneous area represented by northern India and West Pakistan. This area has a dry climate, fertile soils, and adequate water supplies from canals and tube wells. Regions such as the Punjab were already showing marked growth in agricultural production (although not in yield per acre) before new varieties were introduced. Approximately two-thirds of the wheat area is irrigated; the new varieties are concentrated on irrigated lands. It has not been uncommon for farmers in these areas to double their yields with the new varieties.

The most favourable rice growing area in Asia is in West Pakistan. Here, like wheat, rice is grown under a dry climate with adequate water supplies. However, the 1.5 million hectares of rice in West Pakistan is only one-eighth of the area of Pakistan and represents a tiny fraction of the rice area of Asia.

Most rice is grown in regions of high seasonal rainfall where, in the absence of good water control, water supplies are uncertain. Figure 1* shows an estimate of the percentage of the rice crop area under specific water resource situations. Only 20 per cent of the rice land is irrigated. Much of this irrigation is done with diversion dam systems. Hence, even the irrigated area is not free from the effects of floods and droughts.

In the large flood plains of South Vietnam, Central Thailand, East Pakistan, and Lower Burma, the new varieties

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* Figure 1 not reproduced here.

are not suited for the deep water conditions. In rainfed and upland areas, the new varieties perform just as well as, or better, than local varieties. However, the potential differences in yield are far less, and in much of this area uncertain rainfall conditions severely limit the use of fertilizer and other cash inputs.

Another environmental problem for rice is the high humidity during the main growing season. The humidity increases the severity of attacks by insects and diseases. Susceptibility to insects and diseases has been largely responsible for the abortive attempts to introduce IR8 into East Pakistan, Malaysia, and Indonesia. The search continues in these countries for a resistant variety with the yield potential of IR8. By contrast, in 1970 a major portion of the rice area in the dry climate of West Pakistan is being planted to the IRRI selection - IR6-156-2-1 (known in Pakistan as Mehran 69) - which has not been named as a variety by the International Rice Research Institute because of its high disease susceptibility in most of the tropics.

<u>The physical production functions</u>

The production response to nitrogen for new and local varieties of rice and wheat are shown graphically in Figures 2, 3 and 4*, and the mathematical equations are presented in Table 1. These functions are based upon experimental results conducted under irrigated conditions. For India the estimates were developed from the data of the

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* Figures 2, 3 and 4 are not reproduced here.

Table 1. Production function for wheat and rice in Asia.[a/]

Country	Variety	Season	Function[b/]
		WHEAT	
India	Sonora-64 (Mexican)		$Y=2232 + 33.78N - 0.101 N^2$
India	Lerma Rojo (Mexican)		$Y=2041 + 30.23N - 0.105 N^2$
India	C-306 (Local)		$Y=2355 + 23.04N - 0.097 N^2$
		RICE	
India	IR8 (IRRI)	Wet	$Y=3033 + 20.89N - 0.0556 N^2$
India	IR8 (IRRI)	Dry	$Y=3768 + 29.27N - 0.0639 N^2$
India	Local	Wet	$Y=2520 + 17.30N - 0.0720 N^2$
India	Local	Dry	$Y=2685 + 23.52N - 0.0846 N^2$
Philippines	IR8 (IRRI)	Wet	$Y=3230 + 28.93N - 0.126 N^2$
Philippines	IR8 (IRRI)	Dry	$Y=3971 + 37.65N - 0.115 N^2$

a/ Wheat functions result of 1966/67 experiments of All-India Coordinated Wheat Improvement Project, average of several locations.

Rice functions in India result of 1968 experiments of All-India Coordinated Rice Improvement Project, average of several locations.

Rice functions in Philippines result of three years experiments 1966-1968, conducted at Maligaya Rice Experiment Station, Central Luzon.

b/ Y = Yield in kilograms per hectare

N = Elemental Nitrogen in kilograms per hectare.

All-India Coordinated Wheat Improvement Project and the All-India Coordinated Rice Improvement Project.[4] They represent experiments conducted at several locations. For the Philippines, data were obtained from 3 years of experiments conducted at the Government's Maligaya Rice Experiment Station in Central Luzon in cooperation with the International Rice Research Institute.

Figures 2 and 3 and the corresponding equations in Table 1 compare wheat and rice in India. In determining the likely diffusion patterns for wheat vs. rice, it is useful to compare the gaps between the old-variety functions and the new-variety functions. This gap is definitely larger for dry season rice than for wet season rice. But the gaps appear to be not much different for wheat and wet season rice (about the same in the 40 kg. to 200 kg. nitrogen range; a greater gap for wet rice in the 0-40 kg. nitrogen range). Thus, the greatest advantage appears to lie in the shift to the new variety of dry season rice.

It is instructive at this point to examine the price relationship between wheat and rice. In India and Pakistan the price of wheat has been supported well above the world market. The price received by farmers for new varieties of wheat has been close to 50 percent above that for new varieties of rice in both countries (e.g. ₨ 40.50 per quintal for wheat vs. ₨ 28.35 per quintal for rice in West Pakistan). The more rapid gains in wheat production can

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4 See Progress Report of the All-India Coordinated Rice Improvement Project, Vol. 1 and 2, 1968. Indian Council of Agricultural Research, New Delhi, India and Ralph W. Cummings, Jr., Robert H. Herdt, and S.K. Ray, "New Agricultural Strategy Revisited", Economic and Political Weekly, Oct. 26, 1968, pp. A-15 and A-23.

be attributed in part to a more favourable price relationship.

The potential gains in yield and net profit per hectare assuming optimum economic conditions and no risk are summarized in Table 2. The results combine the effect of environmental and price differences. In spite of a more favourable price for wheat, the largest gain in profit is observed for the shift to high yielding varieties of rice in the dry season.

The Indian rice response functions are compared with those for the Philippines in Figure 3 to show the general similarity in yield response and production potential in two widely different geographic areas. (The response functions for IR8 in India are the same for Figure 4 as for Figure 3).

The risk factor

The yield responses shown in the previous section represent potentials in the sense that crops are grown under experimental conditions with presumably superior water management and insect and disease control. Even under these controlled conditions, more uncertainty appears to be associated with yield response for wet season rice than for either wheat or dry season rice. To illustrate this point, the individual functions for 3 years of wet and dry season IR8 in the Philippines are shown in Figures 5 and 6* (these same functions were averaged to compute the Philippines yield responses for IR8 shown in Figure 4)

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* Figures 5 and 6 are not reproduced here.

Table 2. Yield per hectare of grain at the economic optimum (MR = MC) and gain for high yielding vs. local varieties.[a]

		Variety yield		Gain	
		Local	HYV	Yield	Net profit[b]
		(mt/ha)		(mt/ha)	(Rp/ha)
Paddy					
	Wet season	3.6	5.0	1.4	328
	Dry season	4.3	7.1	2.8	685
Wheat		3.7	5.1	1.3	480

a/ Based on response function shown in Table 1 and on the following assumed prices:

Rp. 0.28/kg. paddy, Rp. 0.40/kg. wheat, Rp. 1.10/kg nitrogen

b/ Added return above added fertilizer cost.

Year-to-year variability is particularly marked during the wet season, the main rice-growing period throughout the tropics. During the 1966 wet season at the Maligaya Center, no unusual loss due to unfavourable weather occurred. However, the 1967 wet season crop was severely damaged by a typhoon and a subsequent attack of bacterial leaf blight. Wind damage to the leaves of the rice plant caused by the typhoon encouraged the spread of bacterial leaf blight. IR8 is a particularly susceptible variety and many farmers in the typhoon belt have stopped growing IR8 in the wet season to minimize this loss. The 1968 wet season was also unusual in that Central Luzon experienced a serious drought. For the many farmers who lacked adequate irrigation facilities, the drought led to a reduction in yields and a low or negative return for fertilizer investment. However, at the Maligaya Center, where the water supply was adequate, the best yields were achieved for IR8 at the highest level of fertilizer input, 150 kg/ha of nitrogen.

The contrast between wet and dry seasons as illustrated by these two figures indicates the relatively higher degree of uncertainty that farmers face growing rice during the wet season. The economic implication of this uncertainty was tested through the application of decision-making rules such as the Wald minimax and the Savage regret criterion.[5] The results of this analysis are reported elsewhere,[6] but can be briefly summarized as follows. Given the low

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5 For a discussion of these various decision-making criteria, see R. Duncan Luce and Howard Raiffa, Games and Decisions, Introduction and Critical Survey, John Wiley and Sons, Inc., New York, 1958.

6 See International Rice Research Institute, Annual Report 1968, Los Banos, Laguna, Philippines, 1969.

variability of response in the dry season (Fig.6) the choice of decision-making criteria had little effect on the total return to fertilizer over the 3-year period. However, for the wet season, the outcome is substantially different, with the choice of the conservative Wald minimax criterion eliminating the opportunity for substantial profit.

No one can say quantitatively how the decisions of farmers relate to the various decision-making rules. It is normally assumed that Asian farmers have a high degree of risk aversion although this assumption needs further testing. Apparently, for a major portion of the Asian rice-growing area, uncertainty of yield response equals or exceeds that suggested by Figure 5. Any degree of farmer risk-aversion, therefore, is likely to result in a comparatively slow increase in the use of fertiliser and other inputs. By contrast, one would expect to find rapid input adoption and production increases under response conditions that are analogous to the situation depicted in Figure 6. This appears to be the situation that exists for the high yielding varieties of wheat in northern India and of wheat and rice in West Pakistan.

The role of farmer skills and extension

As previously mentioned, it is difficult to separate physical environment from other factors which can influence the acceptance of new technology. Between crops such as wheat and rice, differences in farmer skills and institutional conditions cannot be easily compared. For rice alone, however, we do have evidence of the relationship between farmer skills, institutions, and environmental factors in the adoption of new varieties. This evidence is based upon an analysis of a cross section of 866 Philippine rice farms.

The farmers were stratified into six groups on the basis of three environmental classes and two extension or cooperatorship categories. Within each group, regressions were run with a dummy dependent variable representing adoption of a new rice variety and the following independent variables: a measure of rice expertise (lagged one year), farm size, a dummy for owner-operatorship, the interest rate on borrowed funds, and (for irrigated farm groups) a dummy for pump irrigation. (Age and schooling were found to be relatively unimportant factors). The results are in Table 3.

The effectiveness of rice expertise and the complementarity of this variable with environment and cooperatorship in the government program constitute the most interesting findings. This can be seen clearly in the expertise coefficient:

	Rainfed	Irrigated Wet Season	Irrigated Dry Season
Non-cooperators	.114	.689	.780
Cooperators	.469	.720	.985

Note that the size of the estimate consistently increases as one passes from less favourable irrigation-season-cooperatorship combinations to more favourable ones. When the coefficient is as high as .9, it implies that knowledge of one additional modern practice, out of the seven, contributes about .9/7 = 13% to the probability of new variety use. In all strata, (1) new variety users were found to have a higher level of expertise than non-users, which was not similarly true for schooling, and (2) cooperators were found to have a higher level of expertise than non-cooperators.

Table 3. Linear probability functions for use of high-yielding varieties on specified farm type in Central Luzon, 1967/68.

Independent variable a/	Rainfed		Irrig. wet season		Irrig. dry season	
	Non-coop	Coop	Non-coop	Coop	Non-coop	Coop
Expertise	0.114	0.469	0.689	0.720	0.780	0.985
	(0.097)	(0.347)	(0.134)	(0.148)	(0.279)	(0.202)
Interest	-0.096	0.370	-0.001	-0.472	-1.531	-0.522
	(0.093)	(0.494)	(0.006)	(0.349)	(0.692)	(0.377)
Tenure	0.013	-0.160	0.060	0.042	0.109	0.028
	(0.029)	(0.116)	(0.052)	(0.073)	(0.109)	(0.104)
Size	0.005	0.074	-0.022	0.048	-0.083	0.003
	(0.010)	(0.037)	(0.013)	(0.016)	(0.042)	(0.038)
Pump			0.124	0.123	-0.008	-0.103
			(0.063)	(0.077)	(0.192)	(0.125)
Constant	0.053	0.001	0.066	0.048	0.471	0.295
R^2	0.009	0.157	0.130	0.161	0.161	0.183
Sample size	343	69	236	218	89	117

a/ Expertise = the ratio of the number of recommended farm practices used the preceding year to seven recommended practices; Interest = annual interest rate on farm loans with minimum adjusted to 5%; Tenure = 1 if the farmer is an owner-operator and 0 otherwise; Size = area planted to rice in hectares; Pump = 1 if pump irrigated and 0 if gravity irrigated; Dependent variable = 1 if planting high-yielding variety and 0 otherwise.

Source : Mahar Mangahas, An Economic Analysis of the Diffusion of New Rice Varieties in Central Luzon, Ph.D. thesis to be submitted to the University of Chicago, 1970.

The other included variables were of relatively lesser importance. The interest rate coefficient shows the expected negative effect. This effect increases as the environmental setting improves; but there is no indication that the extension program increases its effectiveness. For the most advantageous environment and extension stratum, it is expected that a 10 per cent decline in the interest rate per annum may add some .05 to .15 to the probability of adopting a new rice variety. The effect of owner operatorship is generally positive, but rather small. From the view point of land reform, it appears that the transfer from share tenancy to owner operatorship per se is of lesser importance than such other aspects of the reform program as irrigation and extension system to the tenant. Farm size was found to have a very small effect, supporting the contention that no minimum farm size is necessary for new varieties to be economically acceptable. On a priori grounds, farms with pump irrigation would have more incentive to adopt a new variety than farms with gravity irrigation, on account of greater control over the water supply. However, the results for the pump variable are somewhat ambiguous, mainly on account of a shifting of some farms with pumps to other crops aside from rice during the dry season.

We can identify the contribution of invironment and the extension program, making an adjustment for other variables. This is done by applying the means, taken over the entire sample of the independent variables, identically to the estimated equations of the six strata. The resulting standardized probabilities are given in Table 4. After adjustment, the contribution of irrigation and season to the probability of adopting a high yielding rice variety confirms the thesis of the importance of the environmental factor.

Table 4. Standardized probabilities of high yielding variety use in Central Luzon, by crop type and cooperatorship, crop year 1968/69.

	Rainfed	Irrigated wet season	Irrigated dry season
Non-cooperators	0.074	0.198	0.232
Cooperators	0.264	0.253	0.402

Source : Mangahas, op.cit.

Production achievements

The reasons for production changes are often difficult to determine. It is almost impossible in the short run to separate the increase in production caused by the new varieties and additional inputs from the increase caused by favourable weather. Particularly in India, which experienced severe drought when the monsoons failed in the 1965/66 and 1966/67 crop years, much of the recent increase in production can be attributed to better weather.

Table 5 shows the changes in production occurring in the areas with the largest plantings of new varieties. The right hand column of the table indicates the percentage increase in production for the 1968 crop season as compared with the period 1960 to 1964. The year 1968/69 was the

Table 5. Changes in production of wheat and rice for selected Asian countries, 1960/61 to 1968/69*

Crop and country	1960-64	1965	1966	1967	1968	Increase 1960-64 to 1968
	(1000 metric tons)					(%)
			WHEAT			
India	10,809	12,290	10,424	11,393	16,540	53
W.Pakistan	4,065	4,625	3,916	4,334	6,477	58
Asia	52,247	56,388	51,904	58,370	64,239	23
World	231,758	247,500	285,500	277,190	308,012	33
			ROUGH RICE (PADDY)			
India	53,105	46,500	45,707	59,300	59,701	12
E.Pakistan	14,754	15,718	14,308	16,698	16,958	15
W.Pakistan	1,783	2.026	2,100	2,306	3,126	75
Philippines	3,883	4,033	4,165	4,560	4,583	18
Asia	141,787	138,060	138,355	159,053	162,209	14
World	161,000	159,000	161,000	183,000	186,620	16

* Source : U.S. Dept. of Agriculture and Government of Pakistan

first crop year in which a substantial area was planted to new high yielding varieties. Although official data are not yet available, early reports suggest that the 1968/69 production levels will be equalled or exceeded for both wheat and rice in 1969/70.

As noted previously, the percentage of the area planted to new wheat varieties in Asia is considerably greater than that planted to new rice varieties. The production gains in wheat have been remarkable, and are only matched by the performance of rice in West Pakistan. Table 6 presents a comparison of the annual yields of wheat and rice in West Pakistan.

Conclusions

Data have been presented to support the hypothesis that differences in environmental conditions have been mainly responsible for the outstanding performance of the new wheat as compared with the new rice varieties. The typical environmental conditions under which the two crops are grown differ markedly. The production functions suggest that the potential response of the high yielding rice varieties is equal to that for the new wheat varieties under the same environmental condition. However, given the difference in growing conditions for dry climate wheat and rice as compared with rice in the monsoon, not only the degree of response but the year-to-year variability in response must influence the farmer's willingness to apply inputs. While price has played an important role, favoring wheat over rice, the wide differences that can be observed in production gains to date give support to the importance of environment.

Data are not available by which abilities or knowledge of rice farmers may be compared to that of wheat

Table 6. Average annual yield of wheat and rice in West Pakistan, 1960/61 to 1968/69.

Year	Yield (Maunds per acre)[1]	
	Wheat	Rice
1960/61	8.9	9.5
1961/62	8.8	10.1
1962/63	9.0	10.0
1963/64	9.0	10.1
1964/65	9.4	10.8
1965/66	8.2	10.2
1966/67	8.8	10.5
1967/68	11.6	11.4
1968/69	11.6	14.2
1969/70	-	16.1*

1 One maund is equal to 82.28 pounds

* First estimate

Source : Government of Pakistan.

farmers. The analysis with respect to rice adoption on Philippine farms does indicate, however, that such abilities have a quantitatively significant contribution towards diffusion of new varieties. Since there is a high degree of complementarity between the environmental setting and farmer expertise, these results provide further grounds for support of the environmental-importance hypothesis.

Acceptance of this hypothesis has important policy implications for Asian countries. Sustained gains in rice production can be achieved principally by reducing the risk and uncertainty facing farmers. Continued effort will be required to improve and expand irrigation and drainage facilities. At the same time, more attention will need to be given to improvement of production potential under rainfed and upland conditions. It will also be necessary to invest adequate research funds in the development of insect and disease resistant varieties. Resistant varieties for the long run appear to offer a more fruitful approach than emphasis on insecticides which for the individual farmer are expensive and offer uncertain benefits. Coupled with the above programs, some form of crop insurance scheme would be desirable. Unfortunately, it would be difficult to administer in most Asian countries.