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PROSPECTS FOR RICE YIELD IMPROVEMENT IN THE POST-GREEN REVOLUTION PHILIPPINES

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Evidence from farm level and experimental data from the Philippines indicates a trend towards stagnation and/or a decline in irrigated rice yields when intensively cultivated, even under scientific management on experiment station. Given current rice technology, there is a minimal yield gap between the experiment station and the "best" irrigated farms in the Philippines. If the current yield frontier does not shift outwards, the long-term prospects are for stagnation and/or decline in farm yield.

The current yield gap is no longer between the farmer and the experimental potential but rather between farmers themselves. This gap between farmers' yields can be explained by differential farmer ability and differential access to irrigation water. The results of the study suggest that the first priority for rice research ought to be the breaking of the current irrigated yield ceiling. It also indicated that the yield gap between farmers can be reduced by carefully targeted extension-training program and improvement of the efficiency and reliability of water delivery to farms in the middle and tail sections of the system.

1. Introduction

The introduction and rapid spread of semi-dwarf high-yielding rice varieties throughout Asia in the late sixties and early seventies resulted in phenomenal output growth (Dalrymple, 1986; Herdt and Capule, 1983). For South and Southeast Asia the aggregate rice output growth rate increased from 2.2 percent per annum during 1955-65 to 3.2 percent per annum during 1965-80. In the Philippines, the annual growth rate of rice output doubled, rising from 2.2 percent in 1955-65 to 4.5 percent in 1965-80 (FAO). Rice output growth rates surpassed annual population growth rates of 2.9 in the Philippines during 1965-80 (IBRD).

There is increasing concern, however, that the growth in aggregate rice output has peaked and is starting to decline (Herdt, 1988; Barker and Chapman, 1988; and Byerlee, 1987). While much of the literature on agricultural development continues to focus on the green revolution and its impact, the post-green revolution phase of declining

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output and productivity growth is already well established in many areas of Asia (Byerlee, 1987). Barker and Chapman (1988) suggest that the productivity declines could occur due to the following reasons: a) the lack of a significant breakthrough in the yield ceiling in Asia since the first modern varieties were released; and b) the decline in irrigation investments and the poor maintenance of existing irrigation infrastructure.

For the irrigated rice producing environments or the so-called "rice bowls of Asia", the post-green revolution phase can be characterized as follows: i) modern variety use is well established and the rate of growth in farm yields is beginning to slow down; ii) land use intensity is high and so is input use especially fertilizers; iii) efficiency of input use is low and hence in association with (i) and (ii), one can anticipate productivity declines in the future.

This paper provides an analysis of Philippine data from the experiment station and farmer fields showing a stagnant yield potential, and a diminished gap between potential and actual farm yields. This analysis finds that the larger yield gap is between farmers, rather than between the farmer and the experiment station. This yield gap between farmers can be attributed to differences in farmer knowledge, ability, and reliability of irrigation water control. Reducing these differences between farmers in knowledge and ability will be the primary sources of productivity growth in the post-green revolution period.

Data Sources for Experiment Station and Farm Household Panels

This paper uses three sets of panel data for irrigated farm households and four sets of panel data from Philippine rice experiment stations. The following farm panel data sets were used: i) a sample of 34 farmers in Laguna, Philippines, monitored from 1966-1987; ii) a sample of 23 households in Nueva Ecija, Philippines, monitored from 1970-1984; iii) a sample of 132 households in Nueva Ecija monitored for the years 1979/80, 1985/86 and 1988. (For a detailed description of the first two data sets see Herdt, 1987). Table 1 provides summary statistics of the variables used in this analysis.

Time-series data on experiment stations' yields were obtained from the Agronomy Department of IRRI for four locations: i) the International Rice Research Institute, (IRRI) Laguna, 1966-1988; ii) the Maligaya Rice Research and Training Center (MRRTC), in Nueva Ecija, 1970-1988; iii) the Bicol Rice and Corn Experiment Station (BRCES), 1970-1988; and iv) the Visayas Rice Experiment Station (VRES), 1970-1988. IRRI and MRRTC are located in the same geo-

Table 1 – Means and Coefficients of Variation of the Variables Used in the Analysis

	Farmers' yield (kg)	Yield frontier (kg)	Ratio of farmers' yield to yield frontier	N (kg)	Pesticide (kgai/ha)	Labor (pre-harv.) (MDS)	Tractor days	Age	Schooling	Family size/ha	Distance from main canal (kms)
N. ECIJA											
1980	4337	7297	0.6	80	1.26	47.5	2.26	46	4.7	5.23	1.16
	(31.3)	(11.4)	(33.6)	(59.2)	(70.6)	(73.2)	(91.8)	(26.8)	(63.7)	(95.2)	(112.9)
1986	4183	7892	0.53	93	1.38	55.8	3.22	46	4.7	6.12	1.16
	(34.4)	(7.7)	(32.9)	(42.9)	(57.3)	(97.3)	(54.8)	(26.8)	(63.7)	(136.2)	(112.9)
1988	4826	8013	0.6	100	1.13	39.7	3.27	46	4.7	5.3	1.16
	(31.3)	(7.0)	(30.4)	(35.4)	(75.9)	(74.6)	(50.4)	(26.8)	(63.7)	(130.6)	(112.9)
LAGUNA											
1966	2532	5216	0.48	14	0.77	61	0.34	60	5.37	3.52	0.20
	(41.2)	(4.4)	(40.3)	(95.0)	(60.8)	(32.3)	(184.4)	(18.6)	(64.7)	(55.2)	(99.8)
1970	3492	5948	0.69	50	0.78	51.6	1.14	60	5.37	3.23	0.20
	(39.5)	(4.7)	(38.9)	(55.9)	(65.2)	(24.6)	(76.6)	(18.6)	(64.7)	(49.8)	(99.8)
1975	3713	6664	0.56	86	0.76	51.5	1.3	60	5.37	3.27	0.20
	(30.8)	(3.0)	(31.0)	(39.4)	(35.8)	(28.0)	(58.6)	(18.6)	(64.7)	(49.6)	(99.8)
1981	4578	7146	0.64	66	0.79	46.4	2.98	60	5.37	3.14	0.20
	(29.7)	(2.7)	(29.2)	(45.5)	(38.9)	(22.9)	(59.0)	(18.6)	(64.7)	(49.4)	(99.8)
1984	4746	7352	0.64	52	0.87	43.5	3.25	60	5.37	3.81	0.20
	(33.5)	(4.1)	(31.5)	(64.5)	(54.7)	(33.4)	(49.0)	(18.6)	(64.7)	(68.6)	(99.8)

graphic area and agroclimatic environment as the farm samples in Laguna and Nueva Ecija, respectively.

In each case, the yield from the highest yielding rice cultivar in the long-term nitrogen response trials was used to represent the technological potential. Details on how these trials were set up and how the highest yielding entries are determined can be found in Flinn and De Datta (1984). The nitrogen response trial data provide, for each year, the best approximation of the yield potential under intensive cropping of rice cultivars grown under scientific management and with no input constraints. We thus have time-series data for the four locations on the yield potential of the most outstanding modern rice varieties.

2. Experiment Station and Farmer Yields: Is There an Unexploited Yield Gap?

2.1 Experiment Station Yields as Indicators of Technology Potential

The International Rice Research Institute started releasing modern rice varieties since the mid-1960s. IR 8 was the first of the modern varieties widely grown in Asia. At the time of its release in 1966, IR 8 yielded as much as 10 tons/hectare in the dry season and 6 tons/hectare in the wet season at IRRI's experimental farm in Laguna, Philippines (De Datta, 1979). At that time, farmers in the neighborhood of IRRI growing traditional rice varieties were getting yields of 2.0-2.5 tons/ hectare (*IRRI Annual Report,* 1967). Since its initial release, the yields of IR 8 have been on a declining trend even when grown under scientific management on the IRRI farm. Flinn, *et al.,* (1982) estimate that since 1966 the wet season yields of IR 8 have declined by 0.2 tons per hectare per year and the dry season yields have declined by 0.26-0.47 tons per hectare per year. The most commonly attributed cause of this decline is the greatly increased insect and disease pressure to which IR 8 is not resistant. (Insect and disease infestations have risen with the growth in intensive rice production across Asia.)

Following IR 8, the 33 modern rice varieties that have since been released in the Philippines have better insect and disease resistance, shorter crop duration and, to some extent, better eating quality than IR 8. However, none of the later varieties have been able to match the initial yield potential of IR 8. Indeed, De Datta *et al.* (1979) report that in recent years rice yields of over 9 tons per hectare are rarely recorded at IRRI. Perhaps more disturbing is the observation by Flinn, *et al.* (1982) that the highest yields obtained from the nitrogen response

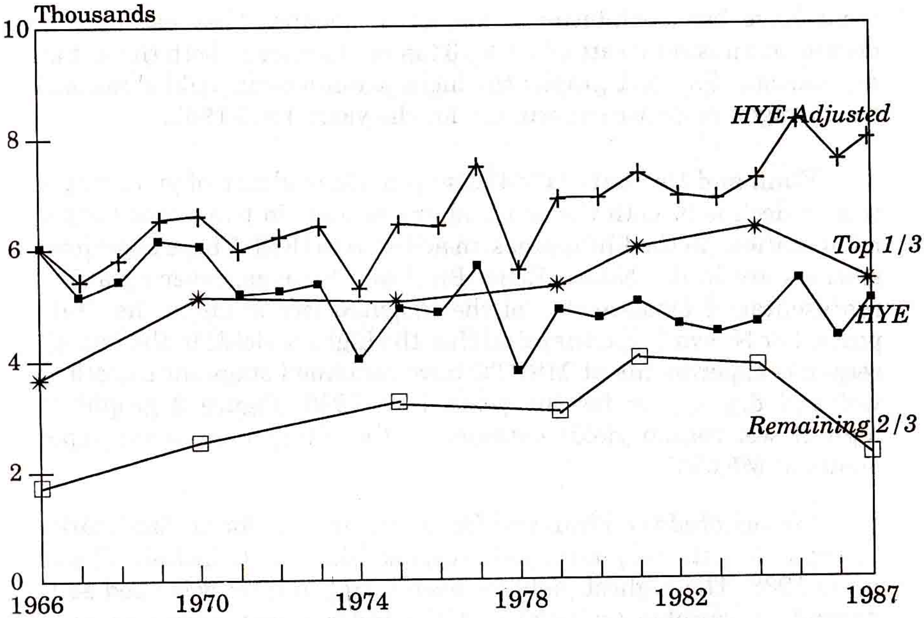

Figure 1 — Trends in HYE & Farmers' Yield, Laguna

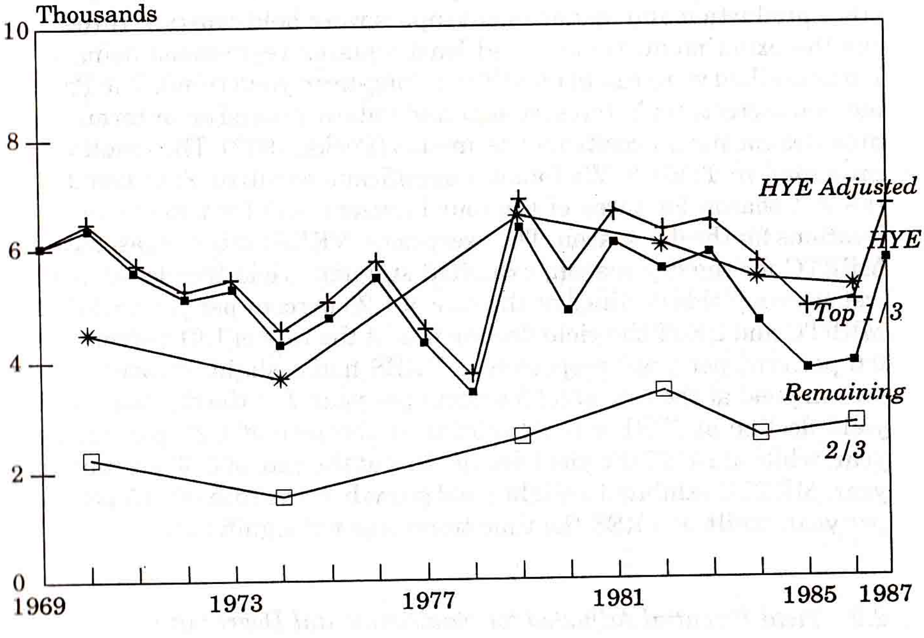

Figure 2 — Trends in HYE & Farmers' Yield, Nueva Ecija

trials have been exhibiting a long-term decline. They estimate the decline at an annual rate of 0.1-0.16 ton per hectare in both the wet and dry seasons. Figure 1 graphs the highest wet season yield obtained in the nitrogen response experiment for the years 1966-1987.

Flinn and De Datta (1984) also provide evidence of yield stagnation or decline in both the wet and dry seasons in three other experiment stations in the Philippines, in addition to IRRI. These experiment stations are in the Nueva Ecija, Bicol and Visayas, covering a fairly representative cross-section of the irrigated rice areas of the Philippines. For Nueva Ecija, they find that the highest yields in the nitrogen response experiments at MRRTC have remained stagnant in both the wet and dry season for the years 1968-1980. Figure 2 graphs the highest wet season yields obtained in the nitrogen response experiments at MRRTC.

We updated the Flinn and De Datta analysis for all four stations by expanding the long-term yield response data set to include all years up to 1988. The highest yield for each nitrogen level was used as the dependent variable (in logs) and the independent variables in the regression were time trend, log nitrogen (kilograms/hectare), the square of log nitrogen and log rainfall. Rainfall was measured in terms of the actual amount from transplanting to two weeks before harvest. All other production and management inputs were held constant throughout the experiment. Generalized least squares regressions using the Parks method were run to identify the long-term yield trend. The Parks method corrects for heteroscedastic and autocorrelated error terms and provides consistent coefficient estimates (Parks, 1967). The results are presented in Table 2. We found a significant negative yield trend for the wet season for three of the four locations and for two of the four locations for the dry season. The exceptions, VRES for both seasons and MRRTC for the dry season, exhibited stagnant yield trends. At IRRI, wet season yields declined at the rate of 1.29 percent per year, while at MRRTC and BEST the yield decline was at the rate of 1.01 percent and 0.6 per cent per year, respectively. VRES had a slight growth in wet season yield at the rate of 0.18 percent per year. For the dry season the yield decline at IRRI was significant at the rate of 1.28 percent per year, while at BEST the yield decline was at the rate of 0.38 percent per year. MRRTC exhibited a slight yield growth at the rate of 0.15 percent per year, while at VRES the time trend was not significant.

2.2 *Yield Potential Adjusted for Environmental Degradation*

The long-term decline in yield potential under intensive irrigated

Table 2 — Estimates of Experiment Station Yield Potential with and without Adjustment for Environmental Degradation.[1]

	IR8		Highest Yielding Entries		Highest Yielding Entries (adjusted)	
BEST DS						
Intercept	8.4615***	(0.0545)	8.5531***	(0.0427)	8.5531***	(0.0427)
Time	-0.0501***	(0.0012)	-0.0038***	(0.0015)	0.0463***	(0.0015)
N	0.0808***	(0.0041)	0.0627***	(0.0047)	0.0627***	(0.0047)
N-square	-0.0138***	(0.0020)	-0.0054***	(0.0016)	-0.0054***	(0.0016)
Rainfall	0.0860***	(0.0091)	0.0183***	(0.0062)	0.0183***	(0.0062)
IRRI DS						
Intercept	7.8740***	(0.0829)	8.3245***	(0.0400)	8.3245***	(0.0400)
Time	-0.0589***	(0.0060)	-0.0128***	(0.0007)	0.0461***	(0.0007)
N	0.0578***	(0.0038)	0.0185***	(0.0065)	0.0185***	(0.0065)
N-square	0.0022	(0.0031)	0.0174***	(0.0022)	0.0174***	(0.0022)
Rainfall	0.4261***	(0.0222)	0.0591***	(0.0075)	0.0591***	(0.0075)
MRRTC DS						
Intercept	8.3630***	(0.0255)	8.4599***	(0.0133)	8.4599***	(0.0133)
Time	-0.0058***	(0.0015)	0.0015**	(0.0006)	0.0072***	(0.0006)
N	0.0437***	(0.0060)	0.0396***	(0.0018)	0.0396***	(0.0018)
N-square	0.0097***	(0.0022)	0.0117***	(0.0008)	0.0117***	(0.0008)
Rainfall	-0.0324***	(0.0035)	-0.0170***	(0.0027)	-0.0170***	(0.0027)
VES DS						
Intercept	8.4904***	(0.0657)	8.4680***	(0.0424)	8.4680***	(0.0424)
Time	-0.0130***	(0.0050)	0.0018	(0.0015)	0.0149***	(0.0015)
N	0.0412***	(0.0058)	0.0419***	(0.0040)	0.0419***	(0.0040)
N-square	0.0003	(0.0029)	0.0064***	(0.0012)	0.0064***	(0.0012)
Rainfall	-0.1121***	(0.0336)	-0.0160**	(0.0078)	-0.0160**	(0.0078)
BEST WS						
Intercept	8.7444***	(0.4582)	8.4752***	(0.0744)	8.4752***	(0.0744)
Time	-0.0383***	(0.0046)	-0.0062***	(0.0005)	0.0322***	(0.0005)
N	0.0735***	(0.0038)	0.0490***	(0.0017)	0.0490***	(0.0017)
N-square	-0.0289***	(0.0035)	-0.0135***	(0.0009)	-0.0135***	(0.0009)
Rainfall	-0.0219	(0.1013)	0.0210**	(0.0106)	0.0210**	(0.0106)
IRRI WS						
Intercept	7.6015***	(0.5760)	9.2048***	(0.1364)	9.2048***	(0.1364)
Time	-0.0517***	(0.0112)	-0.0129***	(0.0008)	0.0388***	(0.0008)
N	0.0207***	(0.0053)	0.0291***	(0.0059)	0.0291***	(0.0059)
N-square	0.0076***	(0.0025)	0.0018	(0.0027)	0.0018	(0.0027)
Rainfall	0.1283	(0.1301)	-0.1029***	(0.0205)	-0.1029***	(0.0205)
MRRTC WS						
Intercept	9.7061***	(0.0373)	9.8753***	(0.0159)	9.8753***	(0.0159)
Time	-0.0167***	(0.0003)	-0.0101***	(0.0002)	0.0066***	(0.0002)
N	0.0426***	(0.0015)	0.0318***	(0.0012)	0.0318***	(0.0012)
N-square	-0.0085***	(0.0008)	-0.0039***	(0.0012)	-0.0039***	(0.0012)
Rainfall	-0.3098***	(0.0072)	-0.1933***	(0.0011)	-0.1933***	(0.0011)
VES WS						
Intercept	8.9748***	(0.1466)	7.8505***	(0.1346)	7.8505***	(0.1346)
Time	0.0093***	(0.0019)	0.0018*	(0.0011)	0.0075***	(0.0011)
N	0.0497***	(0.0059)	0.0374***	(0.0021)	0.0374***	(0.0021)
N-square	-0.0021	(0.0020)	0.0016	(0.0017)	0.0016	(0.0017)
Rainfall	-0.1848***	(0.0314)	0.0925***	(0.0193)	0.0925***	(0.0193)

[1] Dependent variable: log yield/hectare.

*Significant at 10% level; **significant at 5% level; ***significant at 1% level.

Values in parenthesis are standard errors.

rice production can be attributed to either a degradation of the paddy environment or a decline in the genetic potential of the breeding materials used for generating cultivars. Degradation of the paddy environment under intensive cropping can occur due to one or more of the following causes: 1) increased pest pressure, 2) rapid depletion of soil micro-nutrients, and 3) changes in soil chemistry brought about by intensive cropping and the increased reliance on low quality irrigation water.

The rate of environmental degradation can be measured by the rate of decline in yield over time, holding variety and input levels constant. In order to do this we need yield time series on one particular variety. At IRRI and at MRRTC the variety grown each year since the start of the long-term yield experiment is IR-8. We therefore have twenty years of data for IR-8 at IRRI and eighteen years for MRRTC. Linear regression equations were estimated for IRRI and MRRTC using generalized least squares techniques for pooling time series and cross-section data. The results are provided in Table 2. The independent variables in the regression were: log nitrogen, square of log nitrogen, a time trend and log rainfall.

A significant decline in IR-8 yields was observed for all locations for the dry season and three of the four locations for the wet season. The long-term wet season decline of IR-8 yield at IRRI is at the rate of 5.17 percent per year, while at MRRTC it is at the rate of 1.67 percent per year. The corresponding dry season yield declines per annum are 5.89 percent for IRRI and 5.17 percent for MRRTC. The long-term performance of IR 8 at BEST and VRES is found in Table 2.

To obtain the yield potential adjusted for the environmental degradation we compensated the highest yields in the long-term experiment for all four locations with an amount equal to the annual rate of decline in IR-8 yield. After adjusting yields for environmental degradation we found that the highest yields have been increasing significantly in all locations for the dry and the wet season. The highest wet and dry season yields at IRRI have been increasing at annual rates of 3.88 percent and 4.6 percent, respectively. For MRRTC the wet season time trend after adjustment for environmental degradation is 0.66 percent per year and the dry season trend is 0.72 percent per year. *These results imply that the rate of degradation of the paddy environment is greater than the rate of growth in the yield potential, hence the long-term declining trend in the highest experiment station yields.* These results also contradict the alternative view that the cause of the declining yield potential is an erosion of the genetic potential of the breeding materials.

2.3 *Philippine Rice Farmer Performance: 1966-1988*

For assessing farm performance over time relative to the experiment station, one can use national average yield time series, provincial or regional yield time series or farm panel data. Herdt (1988) and Barker and Herdt (1985) point out that the national average yield is not a relevant point of comparison with experimental yields because the former is pooled across a heterogeneous set of rice growing environments and seasons while the latter is representative of the most favorable lands in the country. Average yield data from the provinces in which the experiment stations are located are a better approximation while farm-level data are the best option. Comparability between the farmer and the experiment station is high in these cases because both of them face similar physical and agroclimatic environment.

Compared with the Philippine national average rice yield in 1987 of 2.65 tons per hectare, the technological potential of 6 tons per hectare suggests a yield gap of 3.5 tons per hectare. Experimental yield potential data from the IRRI farm were compared with the farmer sample in Laguna, while the yield potential data from MRRTC were compared with the Nueva Ecija farmer sample. These comparisons reveal a yield gap of around 1.2 tons per hectare. Sample average yields over time are given in Table 1. Since farm data were not available for the other two Philippine locations (BEST and VRES), they were excluded from further analysis.

For illustrative purposes, in addition to comparing average farmer yield with the experiment station yield potential for a particular year, we split the farmer yield sample into two sub-samples. The first sub-sample consists of the top one third highest yields in the sample for a particular year. The mean of this group represents the 'best' annual yield for that particular farmer sample. The second sub-sample consists of the remaining two thirds.

Figures 1 and 2 provide a comparison of the top one third and the remaining two thirds farm yields with the experiment station yields for Laguna (1966-87) and for Nueva Ecija (1970-86), respectively. Experiment station yields are given with and without adjustment for environmental degradation. Consider first the farmer and experiment station yields in Laguna for the years 1966-1987 (wet season). In 1966 the gap between the IRRI farm and the top third of the Laguna farm yields was approximately 2.2 tons/hectare. As Figure 1 shows, this difference declined rapidly and by 1978 the top third yields on the Laguna farms were matching the yields on the IRRI farm. Comparisons between farmer and experiment station yields for Nueva Ecija for the years

1970-86 (wet season) show a similar pattern. In 1970 the gap between the top third farms in Nueva Ecija and the MRRTC farm was approximately two tons. This gap diminished to less than half a ton within a decade. Since 1986, the top third farm yields have matched experiment station yields.

Long-term farm level data are not systematically available for the dry season and therefore the above comparisons cannot be made as definitely. We do have panel data for 132 farmers in Nueva Ecija for the dry seasons of 1980, 1986 and 1988. These data, although subject to strong year effects, do indicate a yield gap of less than half a ton between the experiment station and the top third farm yields.

Comparison of farmer and experiment station yields, after adjustment for environmental degradation, indicates a negligible difference between the two. For Laguna, the gap between the environment adjusted yield potential and the top third farmer yields was 2.2 tons/hectare in 1966 (wet season). By 1984 this gap was reduced to 0.6 tons/hectare (Figure 1). Corresponding wet season data for Nueva Ecija show that the yield gap between the farmers and the environment adjusted yield potential declined from 1.8 tons/hectare in 1970 to -0.2 ton/hectare in 1986 (Figure 2).

Based on the above analysis the following generalization is possible: Given current rice technology, there is a *minimal yield gap between the experiment station and the 'best' irrigated farms in the Philippines. If the current yield frontier does not shift outward, the long term prospects are for stagnation and / or a decline in the top third farm yields*.

How have the yields on the remaining two thirds of the sample fared, relative to the top third farm yields during this time period? Wet season yield comparisons for Laguna and Nueva Ecija show a significant yield difference between the two groups of farms for each of the years studied. In Laguna the top third and the remaining two thirds farms started off with a yield difference of 1.8 tons/hectare in 1966 (Figure 1). Through the 1970s and until 1981 the gap between the two groups remained at around 2 tons/hectare. Since then the gap seems to have widened, becoming 2.8 tons/hectare in 1984 and 3 tons/hectare in 1987.

The difference between the top third and the remaining two thirds farm yields for wet season Nueva Ecija has remained at around two tons per hectare, over the years 1970-1986 (Figure 2). The dry season yield difference in Nueva Ecija has also been at around 2.2 tons/hectare.

The above results provide a contrast to the results of the studies on the "Farm level Constraints to High Rice Yields", conducted at IRRI between 1974 and 1977 (IRRI, 1979; Herdt and Mandac, 1981). In the yield constraints studies, potential farm yield was identified by conducting researcher-managed yield experiments on farmer fields and comparing them to actual farmer yields obtained through farmer management. These studies found for Nueva Ecija a wet season yield gap of 0.9 ton/hectare and a dry season yield gap of 2.0 tons/hectare. The corresponding gap between potential and actual yields for Laguna was 1.7 tons/hectare for the wet season and 2.0 tons/hectare for the dry season. Herdt and Mandac (1981) conclude that these 'modest' yield differences between the potential and actual yield can be attributed to technical and allocative inefficiencies. Our results show that ten years later, at least a third of the farmers in the two areas have yields that match the technological potential. The yield gap in Laguna and Nueva Ecija is not between the farmer and the experimental potential but rather between farmers themselves. We argue in the next section that this yield gap between farmers can be explained by differential farmer ability and differential access to irrigation water.

3. Sources of Further Productivity Growth on Irrigated Rice Farms

In the preceding section it was argued that in irrigated rice farms the gap was no longer between the experimental yield potential and observed farm yields but rather between farmers themselves. If the rice technology potential continues to remain stagnant, then the future gains in productivity would have to come from bridging the 'between-farmer's yield gap. In this section we attempt to identify the factors that contribute to the 'between-farmer' productivity differences and to quantify the means by which these differences can be reduced in the future.

3.1 Determinants of Farmer Performance

In order to identify the sources of productivity differences between farmers we first need to rank farms in terms of their performance. This ranking can be obtained either by fitting a frontier production or profit function to farm data or by using experimental data to directly estimate the efficient or frontier function. The latter, known as the 'engineering approach', was used by Herdt and Mandac (1981). Since we have data on the experimental yield potential for each location we created a ranking procedure that utilizes this information. We defined an index of farmer performance index as the ratio of farmer yield to the farmer-specific yield potential. The farmer performance index is a continuous variable that indicates the extent to which the farmer has been able to exploit the yield potential. If the farmer performance index is one, then the farmer's yield matches the yield potential; if the performance index is less than one then the farmer faces an unexploited yield potential. The farmer performance index is a measure of the farmer's technical efficiency.

Farmer-specific yield potential was determined by estimating the yield potential for each farmer at his current fertilizer use. The coefficients in the last column of Table 2 were used in the estimation procedure.

In this section we attempt to explain differences in farmer performance in terms of differences in the level of variable input use; differences in farm-level water control; and differences in the quality of technology use and efficiency of input management (due to differences in farmer ability and/or supervision time). The above variables are related to the farmer performance index through a translog function as described below.

Farmer characteristics and reliability of access to irrigation water determine the quality of technology use and input use efficiency. The farmer characteristics examined are family size per hectare, age of household head, and schooling of household head. Family size per hectare represents the degree of specialization in farm tasks and the supply of supervision labor. Age (a proxy for experience) and schooling of the household head represent the stock of knowledge and the farmer's ability to effectively use increasingly knowledge-intensive technologies. Distance from the main irrigation canal is an indicator of the reliability of water access and is expected to be negatively associated with farmer performance.

The estimation equations are provided below for Laguna and Nueva Ecija:

$$1.\quad \ln(R) = \alpha_o + \sum_{i=1}^{4} \alpha_i \ln x_i + 1/2 \sum_{i}^{4} \sum_{j}^{4} \delta_{ij} \ln x_i \ln x_j + \sum_{r=1}^{4} \beta_r Z_r + 1/2 \sum_{r=1}^{4} \sum_{s=1}^{4} \sigma_{rs} \ln Z_r \ln Z_s$$

$$+\sum_{i=1}^{4}\sum_{r=1}^{4}\rho_{ir}\ln x_i \ln Z_r$$

2. $$S_i = \alpha_i + \sum_{j=1}^{4}\delta_{ij}\ln x_j + \sum_{r=1}^{4}\rho_{ir}\ln Z_r,\ i = 1,\ldots 4$$

3. $$S_z = b_r + \sum_{s=1}^{4}\sigma_{rs}\ln Z_s + \sum_{i=1}^{4}\rho_{ir}\ln X_i$$

where :

$$R = Y_k / y_k = \frac{\text{actual yield of farmer } k \text{ in period } t}{\text{yield potential specific to farmer } k \text{ in period } t}$$

X_1 : nitrogen (kg) per hectare
X_2 : pesticides used (active ingredient kg/hectare)
X_3 : pre-harvest labor (days/ha)
X_4 : tractor use (days/ha)
Z_1 : family size per hectare
Z_2 : age of household head
Z_3 : years of schooling of household head
Z_4 : distance from irrigation canal (km)
S_i : farmer performance elasticity relative to the *i*th variable input
S_z : farmer performance elasticity relative to the *r*th farmer characteristic

Elasticities of Farmer Performance with Respect to Variable Inputs

Fertilizers: Although the dependent variable is standardized by the level of fertilizer use, nitrogen enters on the right hand side of the equation also because of the productivity impact of the interaction between nitrogen and the other variable inputs and/or farmer characteristics. In other words, the total effect of nitrogen on farmer performance depends on the levels of other variable inputs used by the farmer and on the farmer's human capital stock, as per equations 2, and 3. For instance, the total effect of nitrogen on farmer performance could increase with higher pesticide use or with higher human capital stock of the farmer. Therefore, the results presented below indicate the impact of the interactions between fertilizers and other variable inputs, rather than the impact of fertilizers per se.

Tables 3 and 4 indicate that both across time, and across locations, the relative importance of fertilizer as a determinant of farmer performance has declined. Changes over time in farmer performance elasticities for Laguna and Nueva Ecija are presented in Tables 3 and 4, respectively. For Laguna, farmer performance elasticities with respect to fertilizer use rose between the 1966-1975 period and have been

Table 3 – Farmer Performance Elasticities Over Time for Laguna

	1966	1970	1975	1981	1984
Fertilizer	0.0347***	0.0565***	0.0648***	0.0566***	0.0542***
	(0.0106)	(0.0095)	(0.0091)	(0.0123)	(0.0130)
Pesticide	0.3312***	0.1099***	0.0487	0.0054	-0.0130
	(0.0431)	(0.0390)	(0.0519)	(0.0402)	(0.0538)
Pre-harvest labor	-0.6660***	-0.3105***	-0.2045**	0.0689	0.1073
	(0.0992)	(0.0713)	(0.0825)	(0.0883)	(0.0737)
Tractor days	0.1416***	0.0597***	0.0404***	-0.0051	-0.0329
	(0.0226)	(0.0203)	(0.0179)	(0.0231)	(0.0266)
Family size	0.0456	0.01649***	0.2116***	0.1689***	0.1450**
	(0.0502)	(0.0485)	(0.0407)	(0.0431)	(0.0547)
Age	-0.3894***	-0.1415	-0.0932	0.0623	0.0650
	(0.0930)	(0.0969)	(0.1118)	(0.0893)	(0.1107)
Schooling	-0.1927***	-0.2248***	-0.2372***	-0.1969***	-0.2046***
	(0.0360)	(0.0363)	(0.0279)	(0.0252)	(0.0305)
Distance from	-0.0986*	-0.1262**	-0.1370***	-0.1160**	-0.1165**
irrigation canal	(0.0500)	(0.0501)	(0.0470)	(0.0458)	(0.0502)

Values in parentheses are standard errors.

Table 4 – Farmer Performance Elasticities Over Time for Nueva Ecija

	1980	1986	1988
Fertilizer	0.0209**	0.0711***	0.0487***
	(0.0120)	(0.0108)	(0.0107)
Pesticide	0.0702***	0.-323***	0.0126
	(0.0091)	(0.0076)	(0.0077)
Pre-harvest labor	-0.0293***	-0.0002	0.0059
	(0.0159)	(0.0093)	(0.0073)
Tractor days	-0.0258***	0.0043	0.0227***
	(0.069)	(0.0068)	(0.0063)
Family size	-0.0980**	-0.046***	-0.0174***
	(0.0107)	(0.0072)	(0.0064)
Age	-0.2134***	-0.0722***	-0.0406***
	(0.0291)	(0.0227)	(0.0197)
Schooling	-0.0024***	-0.0320***	0.0565***
	(0.0102)	(0.0091)	(0.0097)
Distance from	-0.0085*	-0.015**	-0.0200***
irrigation canal	(0.0063)	(0.0065)	(0.0063)

Values in parentheses are standard errors.
*** Significant at 1% level
** Significant at 5% level
* Significant at 10% level

gradually declining since then. For Nueva Ecija, elasticities have declined between 1986 and 1988. The declining importance in recent years of the level of fertilizer use in determining farmer performance can be explained by the already high levels of fertilizer used in these areas. For Nueva Ecija, the 1988 average nitrogen application per hectare is approximately 100 kilograms. Between 1980 and 1988, nitrogen application in Nueva Ecija increased at an average of 20 kilograms per hectare.

Pesticides: Our results indicate that in areas where varieties resistant to pest damage are commonly used, the relative importance of pesticides in determining farmer performance has declined over time. Where resistant varieties are not commonly used, the importance of pesticides as farmer performance determinants has increased over time.

For both Laguna and Nueva Ecija the elasticities of farmer performance with respect to pesticides declined over time. In Laguna, marginal increments in pesticide use beyond the mean have not resulted in a significant increase in farmer performance since 1975, while in Nueva Ecija, declining trends in the response of farmer performance to incremental pesticide use have been observed between 1980 and 1988. Pest-resistant varieties started to be released since the mid-1970s (IRRI, 1985), during which the relative importance of pesticides in preventing pest damage has declined.

Labor use: Where direct seeding has begun to replace transplanting as the primary method of crop establishment, the relative importance of labor as a determinant of farmer performance has declined over time. In Laguna and Nueva Ecija, manual transplanting and weeding are the norm; therefore, the total amount of pre-harvest labor per hectare continues to be an important determinant of farmer performance. Substantial labor savings accrue to farmers who switch from hand transplanting of 20 to 30 day old seedlings to directly broadcasting rice seeds into the paddy. Farmer performance elasticities with respect to labor have increased over time.

Tractors: Differential use of tractor power input between farmers has not had a differential effect on farmer performance in most cases. Consider the case of Laguna first. The relative importance of tractor use in determining farmer performance has declined steadily since 1966. After 1981 an increase in tractor power input has not resulted in a significant improvement in farmer performance. Nueva Ecija is an exception, where incremental tractor power use continues to improve farmer performance.

Human Capital, Irrigation Access and Farmer Performance

In addition to the variable inputs, farm and farmer characteristics such as family size per hectare, schooling, age of household head, and distance from the main irrigation canal have significant effects on farmer performance. These variables affect the quality of technology use and hence, the productivity of variable inputs. The results show that the importance of farm and farmer characteristics in determining farmer performance has increased over time (Tables 3 and 4). We also show that the efficiency of variable inputs, particularly fertilizers and pesticides, is directly affected by these variables (Tables 5 and 6).

In most cases the importance of family size/hectare, farmer age and schooling as determinants of farmer performance has increased over time. Education and farming experience (age as a proxy) improves the farmer's ability to acquire and process information on particular

Table 5 – Elasticity of Farmer Performance Relative to Fertilizer Use

		Fertilizer N. Ecija	Fertilizer Laguna
Family size	2	-0.00627	0.0280**
	5	0.088286***	0.0911***
	8	0.136792***	0.1235***
	11	0.169657***	0.1455***
	14	0.194546***	0.1621***
Age	23	-0.20632***	0.0490***
	33	-0.08297***	0.0525***
	43	0.007463	0.0551***
	53	0.078906***	0.0572***
	63	0.137963***	0.0589***
Years of schooling	0	-0.16336***	0.1610***
	2	0.014005	0.0738***
	4	0.055045***	0.0537***
	6	0.079052***	0.0419***
	8	0.096086***	0.0335***
Distance from irrigation canal	0	0.094868***	0.0450***
	1	0.024922	0.0011
	2	-0.00914	-0.0122
	3	-0.02322**	-0.0199***
	4	-0.03320	-0.0254***

Table 6 – Elasticity of Farmer Performance Relative to Pesticide Use

		Pesticide N. Ecija	Pesticide Laguna
Family size	2	0.013745**	0.0349
	5	0.031497***	0.1444***
	8	0.040603***	0.2006***
	11	0.046773***	0.2386***
	14	0.051445***	0.2674***
Age	23	-0.03309***	-0.0258
	33	-0.00530	0.0177
	43	0.015064**	0.0496*
	53	0.031157***	0.0748**
	63	0.044460***	0.0956***
Years of schooling	0	-0.10368***	-0.0135
	2	0.005920	0.0720**
	4	0.031281***	0.0917***
	6	0.046116***	0.1033***
	8	0.056642***	0.1115***
Distance from irrigation canal	0	0.002894	0.1008***
	1	0.032205***	0.1459***
	2	0.041029***	0.1594***
	3	0.046191***	0.1674***
	4	0.049853***	0.1730***

technologies and to adapt them to their specific circumstances. Family size per hectare indicates the farmer's access to supervision labor. The increasing importance of human capital variables in explaining between-farmer productivity differences attests to the growing complexity of rice production in Asia. Byerlee (1987) argues that the productivity gains in the post-green revolution era will come from more efficient use of existing inputs to exploit the genetic potential of existing varieties. These "second generation technologies" (such as better fertilizer incorporation technologies, integrated pest management, etc.) are more knowledge-intensive and location-specific than the modern seed-fertilizer technology that was characteristic of the green revolution. Productivity gains accrue to farmers who have the ability to learn about the new technologies, discriminate among technologies offered to them by the research system, adapt the technologies to their particular environmental conditions, and provide supervision input to ensure the appropriate application of the technology.

Distance from irrigation canal: The importance of distance from the main irrigation canal as a determinant of farmer performance has also increased over time for both the Philippine locations. For given input levels and farmer characteristics, farmers farther away from the canal are less productive than farmers closer to the canal. The successful adoption of technologies that increase input efficiencies requires adequate and timely water supply which, of course, is inversely related to the distance from the irrigation canal.

To illustrate how the efficiency of variable inputs is affected by farm and farmer characteristics, we examined the impact of changes in these variables on farmer performance elasticities with respect to fertilizers and pesticides (Tables 5 and 6). The results imply that marginal improvements in farmer performance with respect to fertilizer use will come more from improving the quality of fertilizer application (better timing and incorporation techniques) rather than increasing the quantity of fertilizer applied. Similarly, marginal improvements in farmer performance with respect to pesticide use will come from the judicious and discriminate use of pesticides rather than increasing the quantity of pesticides applied.

Table 5 shows the changes in farmer performance elasticities with respect to fertilizer due to changes in farmer characteristics such as family size/hectare, age, schooling, and distance from the main canal. By varying each of the farmer characteristics while holding all other inputs constant we were able to evaluate the impact of that particular characteristic on performance elasticity with respect to fertilizer. The results are highly consistent across locations. As family size per hectare increases, the elasticity of farmer performance with respect to fertilizer use increases. This could indicate either an increased level of specialization within the family, and/or an increased level of supervision in fertilizer application.

Age and schooling have similar positive effects on fertilizer productivity and hence on farmer performance, across all but one location. The exception is Laguna where the negative effect of schooling is explained by a few outliers with low levels of schooling. Fertilizer productivity is enhanced when timing of application and fertilizer incorporation are appropriately done. The switch from broadcasting fertilizers to more carefully controlled application techniques requires knowledge and skill.

The distance from the main irrigation canal has a negative effect on the elasticity of farmer performance with respect to fertilizer use, in all cases. In the other cases, productivity of fertilizers decreases as the reliability of water control declines; this occurs with distance from the irrigation canal.

Changes in the elasticity of farmer performance with respect to pesticide use, due to changes in farm and farmer characteristics, are presented in Table 6. Farmer characteristics had a significant positive effect on the elasticity of farmer performance with respect to pesticide use, in most cases.

Marginal increases in family size per hectare had a significant positive effect on farmer performance elasticities with respect to pesticides. Larger family size per hectare implies a higher degree of specialization in tasks such as pest monitoring and pesticide application, and greater supply of supervision labor for pest management activities.

The results with respect to age were mixed. Age of the household head had a positive effect on farmer performance elasticities for Nueva Ecija but not for Laguna. Schooling had a positive effect on farmer performance for both locations. These results imply that farmers with better schooling and greater experience (measured by age) are more adept at using knowledge-intensive techniques in pest management. One would expect these farmers to be better able to identify pest population, determine damage thresholds and to make timely spray decisions. These results are consistent with the findings of Pingali and Carlson (1985) on the effects of human capital variables on pesticide use in the United States.

Distance from the main irrigation canal had a positive effect on farmer performance elasticities with respect to pesticides, for all locations. As distance from the main irrigation canal increases, the rice plant is relatively more susceptible to drought and weed stress. Weeds are less of a problem in areas with good water control than in areas of poor water control. When plants are subject to the above stresses they are less able to withstand insect damage. Therefore, even if insect infestation levels are the same for fields both close to and farther away from the canal, the susceptibility to insect damage increases with distance from the canal (Litsinger, et al., 1988). Hence, the use of pesticides is higher as the distance from the main irrigation canal increases.

4. Summary and Conclusions

1. Evidence from Laguna and Nueva Ecija indicates that there is a trend towards stagnation and/or a decline in irrigated rice yields

when intensively cultivated, even under scientific management on experiment stations. The important point here is that the more recent varieties have started off with a lower yield potential than the earlier varieties such as IR 8.

2. The results imply that the rate of degradation of the paddy environment is greater than the rate of growth in the yield potential, hence the observed long-term declining trend in the highest experiment station yields.

3. Given current rice technology, there is a minimal yield gap between the experiment station and the top third irrigated farms. If the current yield frontier does not shift outwards, the long term prospects are for stagnation and/or a decline in the top third farm yields.

4. The current yield gap is not between the farmer and the experimental potential but rather between farmers themselves – the top third and the remaining two thirds. This yield gap between farmers can be explained by differential farmer ability and differential access to irrigation water, rather than by differences in input use.

5. Productivity gains in the post-green revolution era will come from more efficient use of existing inputs to exploit the genetic potential of existing varieties. These "second generation technologies" (such as better fertilizer incorporation technologies, integrated pest management, etc.) are more knowledge-intensive and location-specific than the modern seed-fertilizer technology that was characteristic of the green revolution. Productivity gains accrue to farmers who have the ability to: learn about the new technologies discriminate among technologies offered to them by the research system, adapt the technologies to their particular environmental conditions, and provide supervision input to ensure the appropriate application of the technology.

6. The first priority for rice research ought to be the breaking of the current irrigated yield ceiling. If the current stagnation in experiment station yield is not broken, the implications for future national production trends and the economic viability of rice production are serious.

7. The results suggest that the yield gap between farmers can be reduced by carefully targeted extension-training programs. Such training programs become particularly important as the incremental gains in productivity are achieved by adopting increasingly knowledge-intensive technologies. However, there are costs associated with such pro-

grams but an analysis of the benefit-cost ratio of such efforts is beyond the scope of this paper.

8. The results also suggest that productivity gains could be made by improving the management of irrigation systems, especially in terms of improving the efficiency and reliability of water delivery to farms in the middle and tail sections of the system.

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