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YIELD CONSTRAINTS AND FERTILIZER MANAGEMENT IN SHALLOW RAINFED TRANSPLANTED AND BROADCAST SEEDED LOWLAND RICE IN THE PHILIPPINES

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ABSTRACT

In 1981, the farm-level constraints research initiated by IRRI in 1974 shifted its emphasis from irrigated rice to rainfed lowland rice. Experiments were conducted in farmers' fields in Tarlac (1981-83, 1986), Camarines Sur (1981-86), and Nueva Ecija (1984-86) to measure the yield gap between farmers' and researchers' inputs, quantify major constraints, and identify appropriate fertilizer management practices for rainfed lowland rice.

Yields of transplanted rice (TPR) with researchers' inputs at the Tarlac and Nueva Ecija sites averaged 4.9 t/ha; in Camarines Sur, the average was 5.0 t/ha. Farmers' inputs gave yields 1.1-1.6 t/ha lower than did researchers' inputs.

Broadcast seeded rice (BSR) yielded lower than did TPR, but yield gaps were similar to those in TPR.

Low N fertilizer level and inefficient timing of application were the major yield constraints in TPR in Tarlac, and in TPR and BSR in Camarines Sur. In Nueva Ecija, the major constraints were poor insect control for TPR and poor weed control for BSR.

Among the improved rices tested, only the early-maturing, promising breeding line IR32307-107-3-2-2 was superior to farmers' varieties—predominantly IR60 (Tarlac) and IR36 (Camarines Sur). The Tarlac and Nueva Ecija sites responded significantly to N application. Applying 30-45 kg N/ha produced high yields when the fertilizer was applied basally and thoroughly incorporated into mud without standing water. The Camarines Sur sites needed N and P fertilizers to increase yields. Across sites, response to applied Zn, either by dipping seedling roots into 2% ZnO suspension or basal incorporation of 20 kg $ZnSO_4$/ha, was not observed in IR36, IR50, IR56, and IR60 grown on soils with pH below 7.0, although the available Zn content was below the 1.0 ppm critical level.

Researchers' split-applied prilled urea was as efficient as deep hand-placed urea supergranules. Yields with researchers' split were superior to those with farmers' method and machine deep placement.

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YIELD CONSTRAINTS AND FERTILIZER MANAGEMENT IN SHALLOW RAINFED TRANSPLANTED AND BROADCAST SEEDED LOWLAND RICE IN THE PHILIPPINES

Shallow rainfed lowland rice, grown mostly in South and Southeast Asia (Barker and Herdt 1979), occupies about one quarter of the world's rice area (Herdt and Palacpac 1983, Huke 1982). The impact of modern rice technology on these areas has been sporadic because research over the past decades has centered on irrigated areas. In the Philippines, 41% of the total rice area is rainfed; only 2 decades after the release of the first high-yielding variety, IR8, 82% of the country's 1.3 million ha of rainfed riceland was planted to modern varieties (MVs) (Table 1). Despite the widespread adoption of MVs, yields in rainfed environments are still low, ranging from 1.2 to 2.4 t/ha. Several factors account for this slow progress, but an important constraint is the scarce research in this area (Barker and Herdt 1979).

Low fertilizer application level is one cause of low yields of fertilizer-responsive MVs in rainfed areas in the Philippines (Alcantara et al 1984, Mandac and Flinn 1985). Fertilizer applied to lowland rice is often inefficiently used by the plant because of irregular moisture supply and improper application method and timing.

Research on constraints to high yield in farmers' fields in the Philippines showed that insufficient fertilizer or inappropriate fertilizer management accounts for one-half to two-thirds of the gap between actual and potential irrigated rice yields (De Datta et al 1979). Soil, variety, season, time of planting, water management, pest and disease control, cropping sequence, and fertilizer sources are the other factors affecting fertilizer use efficiency (De Datta 1981). Since rice is usually transplanted, fertilizer management in irrigated situations can be adopted in shallow rainfed lowlands (Goswami et al 1986).

The farm-level constraints research initiated in 1974 was addressed primarily to irrigated rice-growing environments. In 1981, emphasis shifted to rainfed environments because of the increased attention given to shallow rainfed rice production. Identifying and quantifying the major factors responsible for the yield gap between farmers' and researchers' inputs, and evaluating alternative technologies to increase N use efficiency are two of the major challenges addressed in our farm-level constraints research.

This paper summarizes the agronomic results from the experiments on transplanted (TPR) and broadcast seeded (BSR) lowland rice conducted in three provinces in the Philippines.

Table 1. Rainfed rice areas, percent planted to modern varieties, and average yield of rainfed rice in the Philippines.

Region	Total rice area (thousand ha)	Rainfed lowland rice area			
		Area (thousand ha)	Percent of total rice area	Percent planted to modern varieties	Average yield (t/ha) on rainfed farms
Ilocos	326	144	44	80	1.7
Cagayan Valley	305	68	22	72	1.5
Central Luzon	401	128	32	96	2.1
Southern Tagalog	376	163	43	85	1.9
Bicol	304	122	40	88	1.6
Western Visayas	445	274	62	95	2.2
Central Visayas	105	67	64	71	1.2
Eastern Visayas	191	112	59	79	1.5
Western Mindanao	135	48	36	82	2.1
Northern Mindanao	115	26	23	94	2.1
Southern Mindanao	186	52	28	84	2.0
Central Mindanao	251	86	34	60	2.4
Total	3,140	1,290	41	82	1.9

Source: Bureau of Agricultural Economics, Philippines (1984).

MATERIALS AND METHODS

Three types of experiments were conducted in selected rainfed farmers' fields in Tarlac (1981-83 and 1986), Camarines Sur (1981-86), and Nueva Ecija (1984-86) Provinces: yield constraints in TPR and BSR lowland rice, yield response to fertilizer application, and alternative technologies to increase N use efficiency.

Yield constraints in transplanted and broadcast seeded lowland rice

The yield constraints experiment determined the yield gap between farmers' and researchers' inputs and the yield gap contributions of fertilizer, insect control, and weed control.

The minifactorial approach used consisted of treatments equal to two more than the number of factors being tested: one treatment with all factors at high level, one with all factors at farmers' level, and others having all but one factor at the high level. Other management and cultural practices were at farmers' levels. All farmers' inputs and practices were recorded and carefully simulated in the plots. Researchers' input levels are given in Table 2.

The yield performances of a very early-maturing MV (IR58) and early-maturing (IR32307-107-3-2-2) and medium-maturing (IR14753-49-2, IR19431-72-2, IR10781-75-3-2-2, and IR13146-45-2-3) promising breeding lines were compared with those of farmers' varieties. The test variety was added as a separate treatment grown with farmers' and researchers' inputs or with researchers' inputs alone. The experiment followed a randomized complete block design (RCBD) with two replications.

A separate experiment during the 1986 wet season (WS) evaluated the yield performances of five drought-tolerant, promising breeding lines (IR11418-15-2, IR21015-80-3-3-1-2, IR13240-108-2-2-3, IR21567-18-3-1, and IR26894-37-2-1-3) grown with farmers' (FCP) and researchers' (RCP) cultural practices using a split-plot design with two replications. Cultural practices served as the main plots, and test rices as the subplots.

Yield response to fertilizer application

Rice response to applied N, P, K, and Zn was determined in a replicated RCBD. Nitrogen rate varied from 30 to 90 kg/ha, applied in 2 equal split doses one-half basally broadcast and incorporated (BBI) thoroughly into the mud without standing water, and the remaining half at 5-7 d before panicle initiation (DBPI). Phosphorus (13 kg P/ha) and K (25 kg K/ha) were BBI into the mud without standing water. Zinc treatment consisted of dipping seedling roots into 2% ZnO suspension before transplanting, or basal incorporation of 20 kg $ZnSO_4$/ha. Cultural practices were done at researchers' levels.

Alternative technologies to increase nitrogen use efficiency

In 1982 WS, researchers' split application of prilled urea (PU) was compared with urea supergranules (USG) deep point-placed, and the effectiveness of deep point-placed USG was evaluated under farmers' and researchers' levels of insect control. In 1984-86 WS, fertilizer deep place-

Table 2. Average input levels on broadcast seeded and transplanted rices in 3 Philippine provinces, 1981-86 WS.

Crop establishment method	Input level	Sites (no.)	Fertilizer (kg/ha)			Weed control[a]		Insect control[b]	
			N	P	K	M	C	F	G
			Tarlac (1981-83, 1986)						
Transplanted	Farmers'	37	32	6.2	6.6	0	0.2	1.8	0.1
Transplanted	Researchers'	37	60	13.2	24.9	1.0	1.0	3.1	1.9
			Camarines Sur (Libmanan and San Fernando sites, 1982)						
Broadcast seeded	Farmers'	7	3	0	0	0.4	1.7	1.0	0
Broadcast seeded	Researchers'	7	58	13.2	24.9	1.0	1.9	2.6	1.7
Transplanted	Farmers'	29	10	0.4	1.7	0.6	1.3	2.3	0
Transplanted	Researchers'	29	52	13.2	24.9	0.8	1.0	2.4	1.8
			Camarines Sur (Pili site, 1984-85)						
Broadcast seeded	Farmers'	14	30	0	0	0.5	0.7	1.7	0
Broadcast seeded	Researchers'	14	60	13.2	24.9	1.1	1.3	3.5	2.2
Transplanted	Farmers'	5	11	0	0	0.2	0.6	0.6	0
Transplanted	Researchers'	5	54	13.2	24.9	0.8	1.0	3.2	2.2
			Nueva Ecija (1984-85)						
Broadcast seeded	Farmers'	5	47	12.8	1.7	0	1.0	1.0	0
Broadcast seeded	Researchers'	5	60	13.2	24.9	1.0	1.0	2.8	2.6
Transplanted	Farmers'	27	61	6.2	2.5	0	0.5	1.5	0
Transplanted	Researchers'	27	60	13.2	24.9	1.0	1.0	2.7	2.5

[a]Average no. of mechanical (M) weedings by hand and chemical (C) applications. [b]Average no. of foliar (F) sprays (monocrotophos, azinphos, chlorpyrifos, etc.) and granular (G) applications (carbofuran, etc.) to floodwater.

ment by International Rice Research Institute (IRRI)-designed machines—press wedge for USG and spring auger for PU in 1984, and plunger auger for PU in 1985 and 1986—was evaluated in addition to farmers' and researchers' split PU and hand point-placed USG.

Deep placement of USG by hand and of PU and USG by machines was done at 2-4 d after transplanting in TPR and at 3 d before seeding (DBS) in BSR. USG placement by hand was done by inserting the fertilizer at 10- to 12-cm soil depth in the center of 4 hills for TPR, or at 40- × 40-cm spacing for BSR. The farmers' timing of N application was determined by the most common farmers' practice during the preceding year. For researchers' timing, N was applied in 2 equal split doses: one-half BBI into mud without standing water at 1 d or just before transplanting or at 3 DBS, and the remaining half at 5-7 DBPI.

All treatments received basal applications of 13 kg P/ha and 25 kg K/ha. Weed control and insect control were done at researchers' levels, while other practices were at farmers' levels. The experiment followed a RCBD.

Before treatment, soil samples collected from the upper 15-cm soil layer in several sections of the experimental area were analyzed for chemical and physical properties. A researcher stayed in the study area to monitor farmers' practices and prevailing conditions.

RESULTS AND DISCUSSION

Fertility of test soils

Ponnamperuma (1979) suggested that a productive lowland rice soil should contain at least 0.2% total N, 10 ppm available P, 0.2 meq exchangeable K/100 g soil, and 1.0 ppm available Zn.

The chemical characteristics of the test soils varied within and among study areas. All sites in Central Luzon (66 in Tarlac and 29 in Nueva Ecija) were N-deficient, with values ranging from 0.04% to 0.14% total N. Exchangeable K was generally adequate at the Nueva Ecija sites but deficient at most of the Tarlac sites. Available P was deficient at 19 sites in Nueva Ecija and 30 sites in Tarlac, and available Zn was critically low in both study areas. The study areas in Libmanan, San Fernando, and Pili (Camarines Sur, in the Bicol region) were generally rich in soil N but deficient in P and Zn.

Yield constraints in transplanted and broadcast seeded lowland rices

Farmers' level of inputs and practices. Water buffalo were used by farmers for land preparation mainly in Tarlac and in Libmanan and San Fernando; in Nueva Ecija and Pili, water buffalo and hand tractors were used. Transplanting was common in Tarlac, whereas transplanting and broadcast seeding on puddled fields were practiced at other sites.

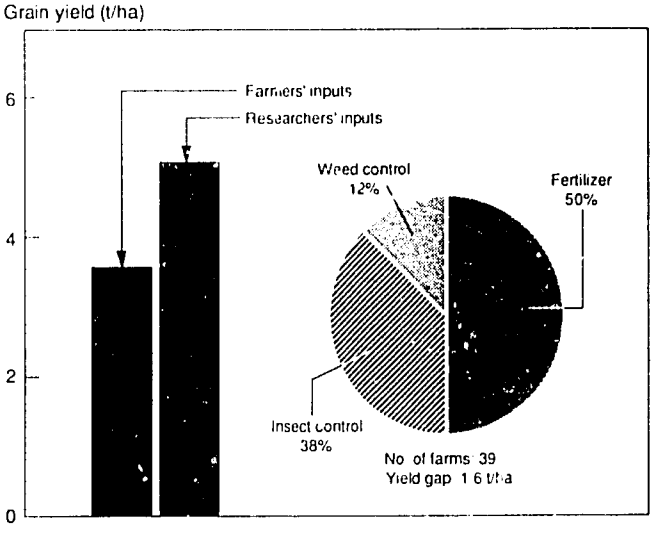
The researchers' levels of inputs at all sites and with all crop establishment methods were considerably higher than those used by the farmer-cooperators (Table 2). Camarines Sur farmers applied very little or no N, and little or no P and K. In Tarlac, farmers applied only about half the N rate used by the researchers. In Nueva Ecija, farmers and researchers at TPR sites applied similar amounts of N.

To control weeds, farmers in Nueva Ecija used mainly chemicals, more on BSR than on TPR. At three sites in Camarines Sur, farmers used mechanical and chemical weed control. Most farmers in Tarlac left their fields unweeded.

To control insects farmers at all sites sprayed foliar insecticide at 0.6-2.3 average applications, avoiding the more expensive granular insecticides.

Contributions of test inputs to the yield gap. In TPR, the researchers' yields averaged 5.0 t/ha at all sites (Fig. 1-4). The farmers' average yields were 1.1 t/ha (Nueva Ecija) to 1.6 t/ha (Tarlac and Pili) lower.

In broadcast seeded flooded rice, the researchers' average yields ranged from 4.2 t/ha (Libmanan and San Fernando) to 4.4 t/ha (Nueva Ecija) (Fig. 2-4). The average yield gap varied from 1.2 t/ha (Nueva Ecija and Pili) to 1.7 t/ha (Libmanan and San Fernando). Low fertilizer application level was the main constraint to high yield in TPR in Tarlac and in transplanted and BSR in Camarines Sur. Improved fertilizer management contributed to 50-80% of rice yield improvement at those sites (Fig. 1-3). At TPR sites in Nueva Ecija, where rice tungro virus (RTV) infection was a problem in 1984, improved insect control gave the highest contribution (55%) to the

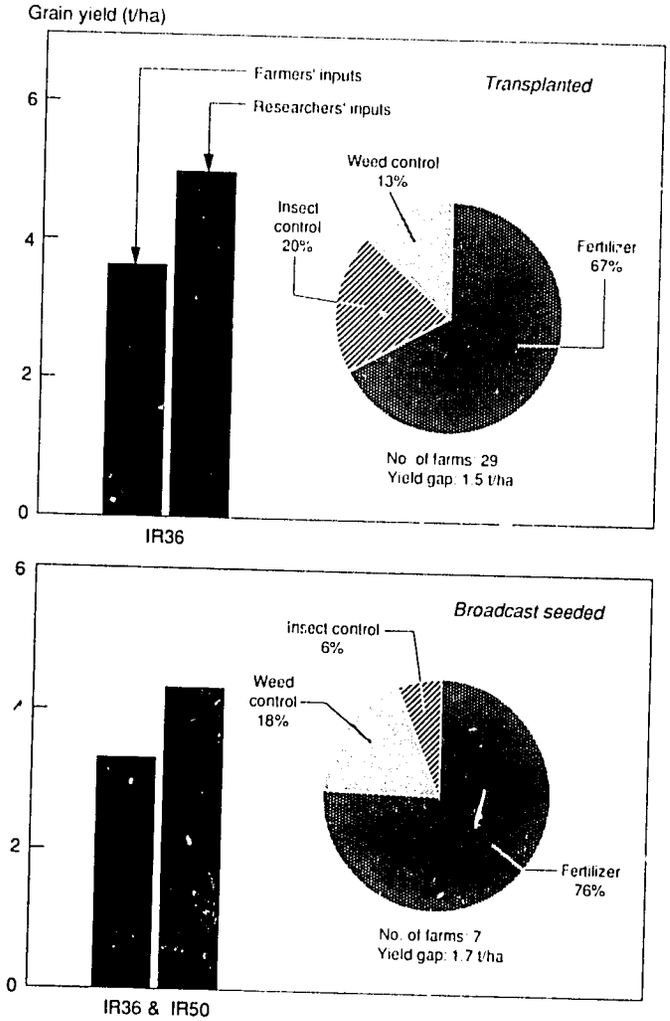


1. Average yields with farmers' and researchers' inputs and relative contributions of fertilizer, weed control, and insect control to improved rice yields on transplanted rainfed farms in Tarlac, Philippines, 1981-83 and 1986 WS.

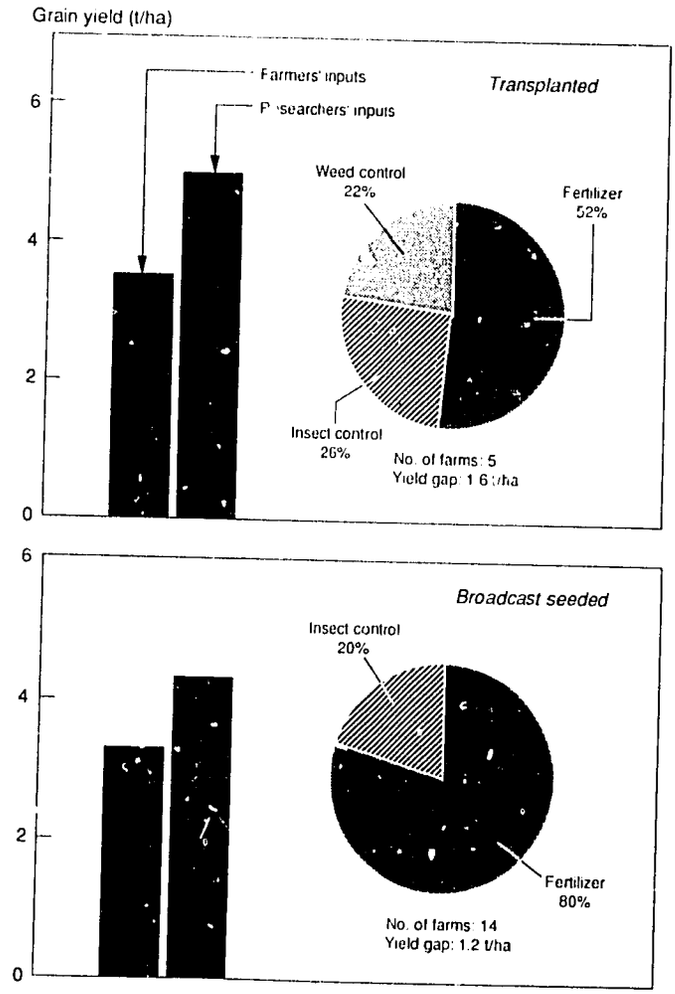
1.1 t/ha yield gap, while improved fertilizer management contributed only 36% (Fig. 4). The contribution of improved weed control to BSR yield varied with location, depending on the level and quality of farmers' weed control. Where farmers' weed control was poor, improved weed control gave the highest contribution (41%) to the 1.2 t/ha yield gap in Nueva Ecija (Fig. 4) and the second highest contribution (18%) to the 1.7 t/ha yield gap in Libmanan and San Fernando (Fig. 2). On the contrary, when farmers' weed control was as effective as the researchers', as at the Pili sites, improved weed control contributed nothing (Fig. 3).

Yield performance of farmers' varieties and promising lines. Farmers in all study areas were responsive to the adoption of MVs. In 1981 and 1982, IR36 was grown by most farmers, and IR50 ranked second. In 1983, the yield performance of very early-maturing IR58 was compared with that of farmers' varieties. Farmers in Tarlac and in Libmanan planted mostly IR56. In San Fernando, IR52 was the dominant variety grown at low elevation, IR36 at intermediate elevation, and IR56 at high elevation. In Libmanan, IR58 yielded significantly lower than did IR56 with FCP and RCP. In low areas in San Fernando, IR58 and IR52 yields were comparable; but at intermediate and high elevations, IR58 yielded significantly lower than did IR36 and IR56, but only with FCP. Results in Tarlac also showed no yield advantage of IR58 over farmers' varieties (Table 3). Rat and bird damage further contributed to the poor performance of IR58, which was due mainly to its shorter growth duration than that of the farmers' varieties.

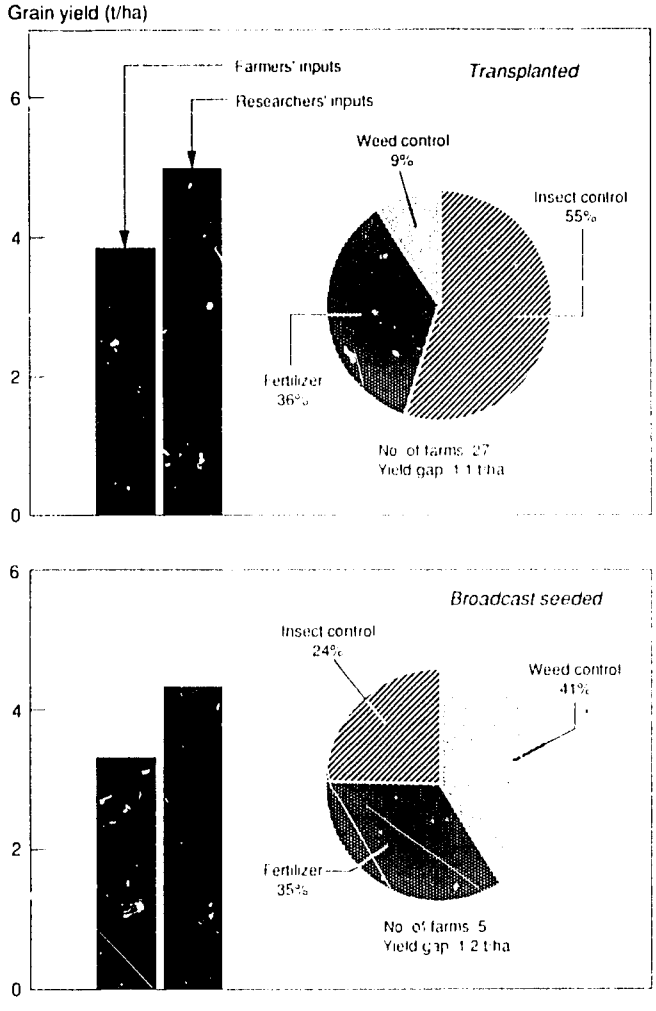
Medium-maturing, drought-tolerant promising lines IR14753-49-2, IR19431-72-2, IR10781-75-3-2-2, and IR13146-45-2-3, tested in 1984 and 1985 WS in Nueva Ecija and in Pili, were not superior to farmers' varieties (mostly IR36 and IR56), irrespective of crop establishment and site (Table 4). They matured more than 2 wk later than did farmers' varieties. Low yields were due to typhoon, rat, and bird damage.



2. Average yields with farmers' and researchers' inputs and relative contributions of fertilizer, weed control, and insect control to improved rice yields on transplanted and broadcast seeded rainfed farms in Libmanan and San Fernando, Camarines Sur, Philippines, 1982 WS.



3. Average yields with farmers' and researchers' inputs and relative contributions of fertilizer, weed control, and insect control to increased rice yields on transplanted and broadcast seeded rainfed farms in Pili, Camarines Sur, Philippines, 1984-85 WS.



4. Average yields with farmers' and researchers' inputs and relative contributions of fertilizer, weed control, and insect control to improved rice yields on transplanted and broadcast seeded rainfed farms in Nueva Ecija, Philippines, 1984-85 WS.

In 1986, early-maturing, drought-tolerant IR32307-107-3-2-2 was tested in Tarlac and Camarines Sur. It significantly outyielded the farmers' varieties, all having similar growth durations (Table 4). The results suggest that growth duration, particularly field duration, should be considered when comparing two or more varieties in farmers' fields.

Yield performance of promising breeding lines. In 1986 WS, yield performances of five other early-maturing and drought-tolerant promising breeding lines with FCP were compared with those with RCP on drought-prone farms in Tarlac and Camarines Sur.

The test rices performed better with RCP than with FCP (Table 5). In both areas, IR13240-108-2-2-3 yielded the highest regardless of cultural practices. In Tarlac, however, the 5.6 t/ha yield of IR21567-18-3-1 with RCP did not significantly differ from that of IR13240-108-2-2-3. IR11418-15-2 also performed well in both areas. IR26894-37-2-1-3 performed well in Camarines Sur but yielded the lowest in Tarlac because of its susceptibility to brown spot and neck blast. Sheath blight and bacterial leaf streak infections on IR21015-80-3-3-1-2 and IR21567-18-3-1 in Camarines Sur also caused low yields.

Yield response to fertilizer application

Response to nitrogen, phosphorus, and potassium. During 1981-83 WS, P and K applications without N significantly reduced yields in Tarlac and Camarines Sur (Tables 6-8), indicating that N was limiting. Akbar et al (1986) reported that more than 75% of the riceland in Southeast Asia is N-deficient. Removal of K did not reduce yields, but removal of P did significantly at the Libmanan (low elevation) and San Fernando (intermediate elevation) sites (Table 7).

Table 3. Yields of farmers' and test varieties on rainfed farms in 3 study areas in the Philippines, 1983 WS.

Location	Elevation	Sites (no.)	Cultural practice	Grain yield (t/ha)		
				Farmers' variety[a]	Test variety[b]	Difference
Tarlac	Low	6	Farmers'	2.8	2.4	-0.4ns
Tarlac	Low	6	Researchers'	4.7	4.5	-0.2ns
Tarlac	High	6	Farmers'	2.8	2.5	-0.3ns
Tarlac	High	6	Researchers'	4.5	4.2	-0.3ns
Camarines Sur						
Libmanan	Low	2	Farmers'	3.4	2.8	-0.6*
Libmanan	Low	2	Researchers'	4.3	3.1	-1.1*
San Fernando	Low	4	Farmers'	5.1	4.8	-0.3ns
San Fernando	Low	4	Researchers'	5.2	5.6	-0.4ns
San Fernando	Intermediate	6	Farmers'	4.7	3.4	-1.3*
San Fernando	Intermediate	6	Researchers'	4.4	4.3	-0.1ns
San Fernando	High	8	Farmers'	4.4	3.3	-1.1*
San Fernando	High	8	Researchers'	5.0	4.9	-0.1ns

[a]Dominant farmers' varieties: Tarlac = IR56 for both elevations; Libmanan = IR56; San Fernando = IR52 for low elevation, IR36 for intermediate elevation, and IR56 for high elevations. [b]Test variety for all sites = IR58. ns = not significant at the 5% level by DMRT. * = significant at the 5% level.

Table 4. Yields of farmers' and test varieties on rainfed farms in 3 study areas in the Philippines, 1984-86 WS.

Province	Crop establishment method	Sites (no.)	Dominant farmers' variety	Grain yield (t/ha)		
				Farmers' variety	Test variety[a]	Difference
			1984 wet season			
Nueva Ecija	Broadcast seeded	3	IR36	4.6	3.2	−1.4*
	Transplanted	16	IR36	4.8	4.8	0ns
Camarines Sur	Broadcast seeded	8	IR56	5.2	5.4	0.2
	Transplanted	2	IR56	6.5	5.5	−1.0
			1985 wet season			
Nueva Ecija	Broadcast seeded	2	C1000	4.2	3.8	−0.4ns
	Transplanted	8	BPI Ri 10, IR36, IR58	5.3	4.3	−1.0*
Camarines Sur	Broadcast seeded	6	IR56	3.3	2.4	−0.9*
	Transplanted	3	IR36, IR56	4.1	3.4	−0.7ns
			1986 wet season			
Tarlac	Transplanted	7	IR60	5.0	5.4	0.4*
Camarines Sur	Transplanted	8	IR36	5.1	5.8	0.7*

[a]Test varieties in 1984: Nueva Ecija = IR14753-49-2 and IR19431-72-2; Camarines Sur = IR19431-72-2; in 1985: Nueva Ecija = IR14753-49-2, IR10781-75-3-2-2, and IR13146-45-2-3; Camarines Sur = IR14753-49-2 and IR19431-72-2; in 1986: Tarlac and Camarines Sur = IR32307-107-3-2-2. ns = not significant at the 5% level by DMRT. * = significant at the 5% level.

Table 5. Yields of drought-tolerant promising breeding lines with farmers' (FCP) and researchers' (RCP) cultural practices on rainfed farms in 2 areas in the Philippines, 1986 WS.

Breeding line	Duration (d)	Grain yield[a] (t/ha)			
		Tarlac (4 sites)		Camarines Sur (3 sites)	
		FCP	RCP	FCP	RCP
IR11418-15-2	109	4.3 b	5.1 b	2.7 ab	4.1 b
IR21015-80-3-3-1-2	114	3.6 c	4.9 c	2.5 b	3.5 c
IR13240-108-2-2-3	109	4.6 a	5.7 a	3.0 a	4.7 a
IR21567-18-3-1	117	4.3 b	5.6 a	2.5 b	3.4 c
IR26894-37-2-1-3	107	2.8 d	2.6 d	2.8 ab	4.1 b

[a]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 6. Yield response to N, P, and K applications on rainfed farms in 3 study areas in the Philippines, 1981 WS.

Location	Sites (no.)	Grain yield[a] (t/ha)			
		NPK	PK	NK	NP
Tarlac	10	6.2 a	5.5 b	6.0 a	6.0 a
Camarines Sur					
Libmanan	3	3.3 a	3.4 a	3.1 a	3.2 a
San Fernando	13	5.2 a	4.1 c	4.6 b	5.0 a

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. Fertilizer levels: 80 kg N/ha, 13 kg P/ha, and 25 kg K/ha.

Fertilizer use efficiency depended largely on water availability during the rice-growing period. Trials at the Libmanan sites in 1981 and 1983 underwent alternate wetting and drying at various growth stages, resulting in similar low yields for all treatments (Table 6,8). Irregular rainfall distribution in rainfed fields caused frequent drying and reflooding, hence N loss through sequential nitrification and denitrification (Macrae et al 1968, Ponnamperuma and Ikehashi 1979).

Table 7. Yield response to N, P, and K applications on rainfed farms in 3 study areas in the Philippines, 1982 WS.

Location	Elevation	Sites (no.)	Grain yield[a] (t/ha)			
			NPK	PK	NK	NP
Tarlac	Low	7	4.8 a	3.9 b	4.4 ab	4.6 a
Tarlac	High	7	5.1 a	4.0 b	4.6 ab	4.6 ab
Camarines Sur						
Libmanan	Low	9	4.5 a	3.6 c	4.2 b	4.3 a
Libmanan	High	3	4.8 a	3.9 b	4.6 ab	4.6 ab
San Fernando	Low	4	3.9 a	3.6 a	3.7 a	3.7 a
San Fernando	Intermediate	10	5.4 a	4.1 c	4.6 b	5.1 a
San Fernando	High	10	4.7 a	3.7 b	4.6 a	4.6 a

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. Fertilizer levels: 58 kg N/ha, 13 kg P/ha, and 25 kg K/ha. N rate at high elevation sites in Libmanan was reduced to 48 kg/ha.

Table 8. Yield response to N, P, and K applications on rainfed farms in 3 study areas in the Philippines, 1983 WS.

Location	Elevation	Sites (no.)	Grain yield[a] (t/ha)			
			NPK	PK	NK	NP
Tarlac	Low	5	3.7 a	3.0 b	3.4 ab	3.6 ab
Tarlac	High	5	4.7 a	4.2 b	4.5 a	4.7 a
Camarines Sur						
Libmanan	Low	3	3.5 a	3.3 a	3.0 a	3.5 a
San Fernando	Low	6	4.4 a	5.1 a	4.4 a	4.6 a
San Fernando	Intermediate	8	4.7 a	4.8 a	4.6 a	4.6 a
San Fernando	High	6	4.4 a	4.2 a	4.5 a	4.5 a

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. Fertilizer levels: 60 kg N/ha, 13 kg P/ha, and 25 kg K/ha.

Table 9. Yield response to N, P, and K application on broadcast seeded and transplanted rice on rainfed farms in 3 study areas in the Philippines, 1984-86 WS.

Province	Crop establishment method	Sites (no.)	Grain yield[a] (t/ha)				
			No fertilizer	N	NK	NP	NPK
			1984 wet season				
Nueva Ecija	Broadcast seeded	1	3.1 c	4.6 ab	4.5 ab	4.9 a	4.6 ab
	Transplanted	8	3.8	4.8	4.6	4.6	4.7
Camarines Sur	Broadcast seeded	6	3.3	4.5	4.7	4.7	4.7
	Transplanted	2	4.2	4.8	4.7	5.2	5.5
			1985 wet season				
Nueva Ecija	Broadcast seeded	1	3.1 b	4.0 a	3.8 a	4.0 a	3.7 ab
	Transplanted	12	4.2	5.2	5.1	5.4	5.3
Camarines Sur	Broadcast seeded	8	1.8 d	2.2 c	2.2 c	2.7 ab	2.9 a
	Transplanted	6	2.8	3.7	3.8	3.9	4.1
			1986 wet season				
Tarlac	Transplanted	7	3.6 b	4.8 a	–	4.8 a	5.0 a
Camarines Sur	Transplanted	8	4.1 b	5.2 a	–	5.6 a	5.5 a

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. DMRT for some is not shown due to farm-to-farm variability. Fertilizer levels: 60 kg N/ha, 13 kg P/ha, and 25 kg K/ha.

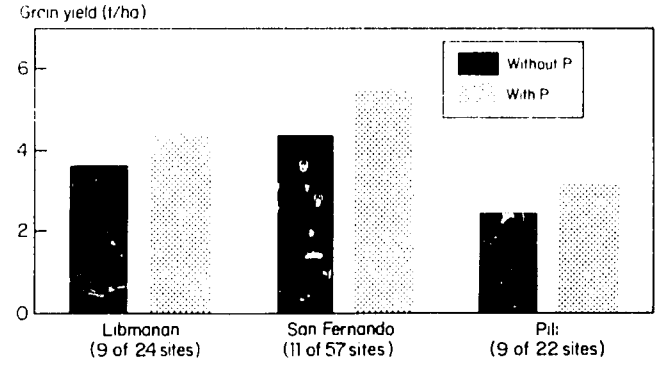
Adverse weather also affected fertilizer efficiency. Typhoons hit the trials in San Fernando in 1982 (low area) and 1983 (all sites), resulting in a poor response to complete fertilizer application (Table 7,8). In 1984-85 WS in Nueva Ecija and in 1986 WS in Tarlac, N was limiting in both BSR and TPR. At new sites in Pili in 1984-85 WS, N and P appeared limiting (Table 9).

In P-deficient soils in Camarines Sur, P deficiency symptoms appeared in BSR and TPR. Applying 13 kg P/ha gave an additional yield of 0.8 t/ha in 9 of 24 trials in Libmanan, 1.2 t/ha in 11 of 57 trials in San Fernando, and 0.8 t/ha in 9 of 22 trials in Pili (Fig. 5). All sites responsive to P had Olsen soil P values below the 10 ppm critical limit suggested by Ponnamperuma (1979) for a productive lowland rice soil.

Across all areas, K application (25 kg/ha) did not significantly increase yield, suggesting that farmers may keep production costs down by not applying K. Results suggest that only N should be applied in Nueva Ecija and Tarlac, whereas N and P should be applied in Camarines Sur to improve yields.

Response to increasing levels of applied nitrogen. In 1981 WS at the Tarlac and San Fernando sites, applying 40 kg N/ha appeared adequate to achieve high yields (Table 10). The farmers did not obtain any significant response to applied N because of low application levels. At Libmanan, yields were low and did not increase with increasing N level because of water shortage. In 1982, when the study areas were classified according to elevation, yields did not further increase at N rates higher than 44 kg/ha (Table 11). The low yields obtained in low-lying areas in San Fernando were comparable at all N rates because of frequent flooding.

During 1984-85 WS, 30 kg N/ha fertilizer application appeared adequate in TPR and broadcast seeded lowland rice at the new sites in Nueva Ecija and Camarines Sur. Rates higher than 30 kg N/ha gave only modest yield increases (Table 12).



5. Rice yields responded significantly to applied P (13 kg/ha) on rainfed farms in Libmanan, San Fernando, and Pili, Camarines Sur, Philippines, 1981-85 WS.

Table 10. Grain yields with farmers' and increasing levels of applied N on rainfed farms in 3 study areas in the Philippines, 1981 WS.

Location	Sites (no.)	Grain yield[a] (t/ha)			
		Farmers' level	No fertilizer	40 kg N/ha	80 kg N/ha
Tarlac	10	5.3 b	5.5 b	6.1 a	6.2 a
Camarines Sur					
Libmanan	3	2.8 b	3.4 a	3.4 a	3.3 a
San Fernando	13	4.3 b	4.1 b	4.9 a	5.2 a

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. Farmers' level of N (kg/ha): Tarlac = 13, Libmanan = 0, San Fernando = 12.

Response to zinc application. In Tarlac, IR36, IR50, IR56, and IR60 were grown by most of the cooperating farmers; in Camarines Sur, IR36 and IR56; and in Nueva

Table 11. Grain yields with farmers' and increasing levels of applied N on rainfed farms in 3 study areas in the Philippines, 1982 WS.

Location	Elevation	Sites (no.)	Grain yield[a] (t/ha)				
			Farmers' level	29 kg N/ha	44 kg N/ha	58 kg N/ha	87 kg N/ha
Tarlac	Low	9	3.1 b	4.6 a	4.8 a	4.8 a	4.9 a
Tarlac	High	9	3.0 b	4.4 b	4.9 a	4.9 a	5.0 a
Camarines Sur							
Libmanan	Low	7	3.8 c	4.4 b	4.5 ab	4.8 ab	4.9 a
Libmanan	High	5	3.3 c	4.1 b	4.3 ab	4.3 ab	4.7 a
San Fernando	Low	5	3.3 a	3.7 a	3.7 a	3.8 a	3.7 a
San Fernando	Intermediate	10	4.4 d	4.9 c	5.3 b	5.5 a	5.7 a
San Fernando	High	9	3.5 c	4.5 b	4.8 ab	5.0 a	5.0 a

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. Farmers' level of N (kg/ha): Tarlac, low elevation = 32, high elevation = 23; Libmanan, low elevation = 8, high elevation = 13; San Fernando, low elevation = 6, intermediate = 14, high elevation = 2.

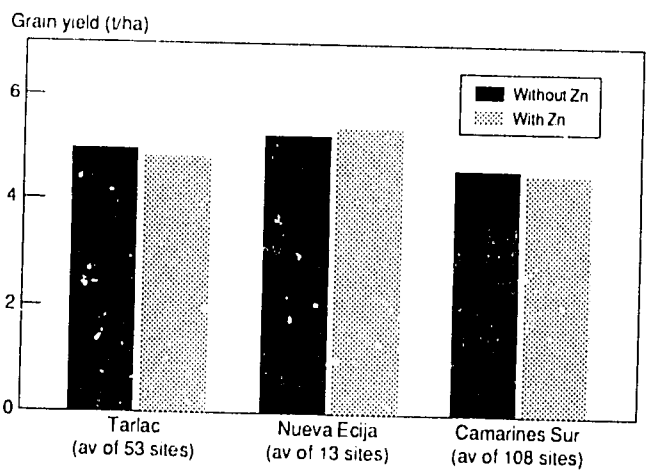
Table 12. Grain yields at increasing levels of applied N on broadcast seeded and transplanted rice on rainfed farms in 2 study areas in the Philippines, 1984-85 WS.

Province	Crop establishment method	Sites (no.)	Grain yield[a] (t/ha)			
			No fertilizer	30 kg N/ha	60 kg N/ha	90 kg N/ha
			1984 wet season			
Nueva Ecija	Broadcast seeded	1	3.1 b	4.1 a	4.6 a	4.8 a
	Transplanted	8	3.8	4.3	4.7	4.8
Camarines Sur	Broadcast seeded	6	3.3	4.3	4.7	4.9
	Transplanted	2	4.2	5.4	5.5	5.5
			1985 wet season			
Nueva Ecija	Broadcast seeded	1	3.1 b	3.5 ab	3.7 ab	3.8 a
	Transplanted	12	4.2	5.0	5.3	5.1
Camarines Sur	Broadcast seeded	8	1.8	2.6	2.9	2.9
	Transplanted	6	2.8	3.8	4.1	4.2

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. DMRT for most is not shown because of farm-to-farm variability.

Ecija, IR36 and IR60. While Ponnamperuma (1979) suggested that productive lowland rice soils should contain at least 1.0 ppm available Zn, available Zn in the soil at almost all sites was below 1.0 ppm. Zinc application, either as a seedling root dip in 2% ZnO suspension or as basal incorporation of 5-20 kg $ZnSO_4$/ha, gave no additional yield over the untreated check (Fig. 6).

High soil pH is also a characteristic of Zn-deficient soils. Sites with pH 6.8 and higher were found mainly in San Fernando (20 of 57 sites), particularly at low elevation, and in Nueva Ecija (8 of 25 sites). IR36, IR50, IR56, and IR60 grown on soil with pH below 7.0 did not respond to applied Zn even though the soil Zn content was below 1.0 ppm. Cayton et al (1984) suggested that critical levels of available Zn based only on soil tests must be reinvestigated, since varietal differences, the supply of certain nutrients, and the chemistry of irrigation water affect soil Zn kinetics and plant Zn metabolism.



6. Yields with and without Zn application in 3 rainfed areas in the Philippines, 1981-86 WS.

Alternative technologies to increase nitrogen use efficiency

Aragon et al (1984) reported that severe and prolonged water stress reduced fertilizer response and grain yield in rainfed trials.

In 1982 WS, researchers' split-applied PU and deep point-placed USG gave similar yields, irrespective of N rate, site, and elevation (Table 13). Drought stress during the reproductive phase affected the efficiency of both researchers' split-applied PU and deep-placed USG in Tarlac and in high areas at the Libmanan sites. In San

Table 13. Effect of N source and application method on grain yield of rainfed lowland rice in 3 study areas in the Philippines, 1982 WS.

Treatment[b]	Grain yield[a] (t/ha)						
	Tarlac		Camarines Sur				
			Libmanan		San Fernando		
	Low elevation (9 sites)	High elevation (9 sites)	Low elevation (7 sites)	High elevation (5 sites)	Low elevation (5 sites)	Intermediate elevation (10 sites)	High elevation (9 sites)
			29 kg N/ha				
Researchers' split application of PU	4.6 a	4.4 bc	4.4 b	4.1 b	3.7 a	4.9 b	4.4 b
Point-placed USG	4.6 a	4.2 c	4.7 ab	4.4 ab	3.8 a	5.1 b	4.5 b
			58 kg N/ha				
Researchers' split application of PU	4.8 a	4.8 ab	4.8 ab	4.3 b	3.8 a	5.5 a	5.0 a
Point-placed USG	4.6 a	4.8 ab	5.0 a	4.6 ab	3.8 a	5.6 a	5.0 a
			87 kg N/ha				
Researchers' split application of PU	4.9 a	5.0 a	4.9 a	4.7 ab	3.7 a	5.7 a	5.0 a
Point-placed USG	4.8 a	5.0 a	5.0 a	4.9 a	3.7 a	5.6 a	4.9 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. [b]PU = prilled urea applied as ½ basal and incorporated without standing water, and ½ at 5-7 d before panicle initiation; USG = urea supergranules hand-placed at 10- to 12-cm soil depth at 2-4 d after transplanting.

Table 14. Yield performance of point-placed USG at 2 insect control levels on rainfed farms in 3 study areas in the Philippines, 1982 WS.

Insect control level	Grain yield[a] (t/ha)						
	Tarlac		Camarines Sur				
			Libmanan		San Fernando		
	Low elevation (9 sites)	High elevation (9 sites)	Low elevation (7 sites)	High elevation (5 sites)	Low elevation (5 sites)	Intermediate elevation (10 sites)	High elevation (9 sites)
			29 kg N/ha				
Farmers'	3.6 c	3.6 d	4.0 c	3.8 c	2.9 b	4.7 c	4.1 c
Researchers'	4.6 ab	4.2 bc	4.7 ab	4.4 ab	3.8 a	5.1 b	4.5 b
			58 kg N/ha				
Farmers'	4.3 b	4.1 cd	4.4 bc	4.2 bc	3.0 b	5.2 b	4.4 b
Researchers'	4.6 ab	4.8 ab	5.0 a	4.6 ab	3.8 a	5.6 a	5.0 a
			87 kg N/ha				
Farmers'	4.1 b	4.0 cd	4.5 b	4.4 ab	3.2 b	5.2 b	4.6 a
Researchers'	4.8 a	5.0 a	5.0 a	4.9 a	3.7 a	5.6 a	4.9 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT.

Fernando, low and comparable yields in the low-lying areas were due mainly to frequent flooding.

The quality of insect control also influenced the performance of deep-placed USG. Deep-placed USG with researchers' insect control generally gave higher yields than did USG with insect control at farmers' level at any N rate or elevation (Table 14). Insects common in the study areas were whorl maggot, caseworm, leaffolder, and stem borer.

Deep placement in reduced soil is considered the most efficient method of increasing N fertilizer efficiency in lowland rice (De Datta et al 1983). This is due to low N (urea + NH_4^+-N) losses evidenced by low total floodwater N (Cao et al 1984, De Datta 1986).

In the rainfed areas of Nueva Ecija and Camarines Sur in 1984-86, neither hand point-placed USG nor machine deep-placed USG or PU was superior to researchers' split-applied PU, where the first dose was thoroughly incorporated into the puddled soil without standing water, irrespective of N rate or crop establishment method (Tables 15-17). From International Network on Soil Fertility and Fertilizer Evaluation for Rice data from 1981 to 1983, Mamaril et al (1986) found that deep-placed USG was better than best-split PU in only 15 of 33 N-response trials in rainfed lowland areas in 7 countries.

In Nueva Ecija, RTV infection in three of five transplanted trials in 1984, typhoon damage on BSR trials in 1985, and early lodging during ripening caused by strong

Table 15. Effect of N source and application method (58 kg N/ha) on grain yield of broadcast seeded and transplanted rice in 2 rainfed areas in the Philippines, 1984 WS.

N source[a]	Application method	Grain yield[b] (t/ha)			
		Nueva Ecija		Camarines Sur	
		Broadcast seeded (1 site)	Transplanted (5 sites)	Broadcast seeded (3 sites)	Transplanted (3 sites)
–	Control	3.4 c	3.3 e	4.6 b	4.9 d
PU	Farmers' split[c]	3.8 bc	3.8 d	5.3 a	6.4 bc
PU	Researchers' split[d]	4.5 ab	4.3 abc	5.2 a	6.7 ab
PU	Researchers' split[e]	4.7 a	4.5 a	5.3 a	6.7 ab
PU	Spring auger[f]	3.8 bc	3.9 cd	4.9 ab	6.1 c
USG	Hand placement[g]	4.6 a	4.4 ab	5.1 a	7.0 a
USG	Press wedge[h]	4.3 ab	3.9 cd	5.1 a	6.1 c
USG + PU	Hand placement + topdressing (5-7 DBPI)	4.2 ab	4.0 bcd	5.4 a	7.0 a

[a]PU = prilled urea, USG = urea supergranules. [b]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. [c]For Nueva Ecija at 10 d after seeding (DAS) or d after transplanting (DT) and past panicle initiation; for Camarines Sur at 15 and 45 DAS, and at 15 and 30 DT. [d]2 equal applications: basal broadcast and incorporated (BBI) under farmers' water management, and at 5-7 d before panicle initiation (DBPI). [e]2 equal applications: BBI without standing water, and 5-7 DBPI. [f]Push type; application was at 3-4 d before seeding (DBS) for broadcast seeded rice (BSR) and at 2-4 DT for transplanted rice (TPR). [g]Done by inserting USG at 10-to 12-cm soil depth spaced 40 X 40 cm at 3-4 DBS for BSR and among alternate 4 hills at 2-4 DT for TPR. [h]Application was at 3-4 DBS for BSR, and at 2-4 DT for TPR.

Table 16. Effect of N source and application method on grain yield of broadcast seeded and transplanted rice in 2 rainfed areas in the Philippines, 1985 WS.

N source[a]	Application method	N applied (kg/ha)	Grain yield[b] (t/ha)			
			Nueva Ecija		Camarines Sur	
			Broadcast seeded (2 sites)	Transplanted (11 sites)	Broadcast seeded (5 sites)	Transplanted (6 sites)
–	Control	0	3.3 d	3.8	2.6 g	3.4
PU	Farmers' split[c]	29	3.9 abc	4.3	3.0 cde	3.8
PU	Researchers' split[d]	29	4.4 a	4.7	2.9 def	4.3
PU	Plunger auger[e]	29	3.8 bc	4.6	2.9 def	4.1
USG	Hand placement[f]	29	3.8 bc	4.7	2.9 def	4.2
USG	Press wedge[e]	29	3.6 bc	4.4	2.8 f	3.9
PU	Farmers' split[c]	58	4.2 ab	4.6	3.1 bcd	4.1
PU	Researchers' split[d]	58	4.4 a	4.9	3.1 bcd	4.6
USG	Hand placement[f]	58	3.6 cd	5.1	3.3 bc	4.5
PU	Researchers' split[d]	87	4.0 abc	5.1	3.5 a	4.8

[a]PU = prilled urea, USG = urea supergranules. [b]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. DMRT for transplanted rice (TPR) sites not shown due to farm-to-farm-variability. [c]Commonly used timing of N application by farmers in the study areas during WS: at 15 d after seeding (DAS) or d after transplanting (DT) and past panicle initiation in Nueva Ecija, at 15 and 35 DAS or DT in Camarines Sur. [d]2/3 basal broadcast and incorporated without standing water and 1/3 at 5-7 d before panicle initiation. [e]Machine placement 3 d before seeding (DBS) for broadcast seeded rice (BSR) or at 2-4 DT for TPR. [f]At 10- to 12-cm soil depth, hand-placed at 3 DBS for BSR and 2-4 DT for TPR.

winds in 1986 contributed to the poor efficiency of hand-placed USG. Drought stress in 1985 in Camarines Sur caused low yields with hand-placed USG. In both study areas, IRRI-designed fertilizer applicators performed poorly, which may be attributed to either nonuniform delivery rate or shallow application, the fertilizer being not fully covered with mud.

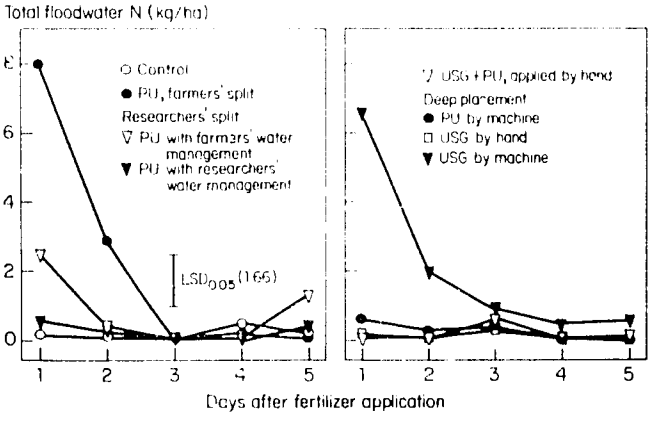
The farmers' split application of urea was generally inferior to the researchers' split and to hand point-placed USG. Aragon et al (1984) reported similar observations.

Broadcasting N fertilizer into floodwater results in extensive N losses to the atmosphere through surface water (Craswell and De Datta 1980). In Nueva Ecija in 1984 WS, the researchers' split application of PU with basal incorporation without standing water gave higher yields, although not significantly, than did the researchers' split with basal incorporation under farmers' water management (usually 3-5 cm standing water) (Table 15). In 1 TPR trial, floodwater samples collected at 1400 h the day after fertilizer application contained 0.6 kg N/ha (urea + NH_4^+-N) with the researchers' split (good water management) and 0.2 kg N/ha with deep hand-placed USG. Samples with the farmers' split application of fertilizer, deep-placed USG by press wedge, and the

Table 17. Effect of N source and application method on grain yield of transplanted rice in 2 rainfed areas in the Philippines, 1986 WS.

N source[a]	Application method	N applied (kg/ha)	Grain yield[b] (t/ha) Nueva Ecija (5 sites)	Grain yield[b] (t/ha) Camarines Sur (4 sites)
–	Control	0	3.9 e	4.0 e
PU	Farmers' split[c]	29	4.9 cd	4.6 d
PU	Researchers' split[d]	29	5.1 bc	5.1 b
PU	Plunger auger[e]	29	4.7 d	5.1 b
USG	Hand placement[f]	29	5.2 ab	4.9 bc
USG	Press wedge[e]	29	4.8 d	4.7 cd
PU	Farmers' split[c]	58	5.0 c	4.8 bcd
PU	Researchers' split[d]	58	5.3 ab	5.6 a
USG	Hand placement[f]	58	5.4 a	5.6 a
PU	Researchers' split[d]	87	5.4 a	5.6 a

[a]PU = prilled urea, USG = urea supergranules. [b]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. [c]At 15 d after transplanting (DT) and past panicle initiation in Nueva Ecija, at 15 and 50 DT in Camarines Sur. [d]2/3 basal broadcast and incorporated without standing water, and 1/3 at 5-7 d before panicle initiation. [e]Machine placement at 2-4 DT. [f]At 10- to 12-cm soil depth, hand-placed at 2-4 DT.



7. Total floodwater N (NH_4^+-N + urea N) at 1400 h as affected by N source and application method on a rainfed farm in Nueva Ecija, Philippines, 1984 WS. PU = prilled urea, USG = urea supergranules.

researchers' split with standing water during basal incorporation of urea contained 8.0, 6.5, and 2.5 kg N/ha, respectively (Fig. 7), suggesting high N losses, presumably through NH_3 volatilization, with these methods. These results were similar to those observed at IRRI under irrigated conditions, emphasizing the importance of proper water management and basal incorporation before transplanting in increasing N use efficiency in lowland rice (De Datta 1986).

CONCLUSIONS

The farm-level constraints and fertilizer management research on transplanted and broadcast seeded shallow rainfed lowland rice from 1981 in Tarlac and Camarines Sur to 1984 in Nueva Ecija found the following:

- Low fertilizer application level or inefficient timing was the major constraint to high yield in TPR at the Tarlac sites, and in both TPR and BSR at the Camarines Sur sites. At the Nueva Ecija sites, the major constraints were poor insect control for TPR and poor weed control for BSR.
- The early-maturing promising breeding lines IR32307-107-3-2-2 and IR13240-108-2-2-3 can be grown in drought-prone farms to improve rainfed rice production.
- At the Tarlac and Nueva Ecija sites, 30-45 kg N/ha can produce high yields, provided that the fertilizer application is timely, with the basal N dose thoroughly incorporated into the mud without standing water. Farms at the Camarines Sur sites need both N and P to increase yields.
- IR36, IR50, IR56, and IR60 grown on soils with pH below 7.0 gave no response to applied Zn, even though the available Zn content was below the 1.0 ppm critical level.
- In normal or adverse weather, the researchers' split-applied PU is as efficient as deep hand-placed USG. Generally, the researchers' split is superior to the farmers' method and to deep placement by machines. These farm-level results are highly relevant, since the Philippines' dependence on purchased inputs has caused considerable concern at all levels.

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