Rice-Wheat Yield in Long-term Maximum Yield Trials

R S Narang and M S Gill[1]

Abstract

A long-term yield maximization experiment was conducted from 1986/87 through 1994/95 on sandy loam soil at the Punjab Agricultural University, Ludhiana, India. The experiment comprised of supply of nitrogen (N), phosphorus (P), and potassium (K) to rice and wheat sequence at high levels in balanced amounts, through chemical fertilizers and green manuring to rice, in conjunction with high population stands and plant growth regulators. The results revealed that rice receiving 180-30-30 kg N-P_2O_5-K_2O ha^{-1} through chemical fertilizers alone or partially through green manure gave highest yield (7.2 to 9.6 t ha^{-1}). Likewise, the highest yield realization in wheat was obtained with 180-60-30 kg N-P_2O_5-K_2O ha^{-1} (5.7 to 5.9 t ha^{-1}). Green manuring added equivalent to 60 kg N ha^{-1} without showing any carry-over effect on succeeding wheat crop. Such heavy crop resulted in heavy removal of nutrients. The nutrient uptake of rice at 180-30-30 kg N-P_2O_5-K_2O ha^{-1} was 189–196 kg N ha^{-1}, about 31 kg P ha^{-1}, and 222–227 kg K ha^{-1}. The following wheat removed 132–138 kg N ha^{-1}, about 28 kg P, and 99–105 kg K ha^{-1} amounting to total nutrients removal of 701 to 725 kg ha^{-1}.

The soil fertility monitored after 3 years showed a rapid build-up of available P with positive trend in respect of organic carbon and available K. In the maximum yield research level, the values observed were: 0.40–0.45% of organic carbon, 104–110 $\mu g\ g^{-1}$ available N, 5.76–5.81 $\mu g\ g^{-1}$ for ammoniacal nitrogen, 517–536 $\mu g\ g^{-1}$ for total N, and 11–12 $\mu g\ g^{-1}$ available P of soil in 0–30 cm soil depth as against the first season value of 0.34–0.37%, 78–79, 4.28–4.30, 491–496, and 10.5 $\mu g\ g^{-1}$ respectively. While a decline in available K status was observed from 67–68 to 52–61 $\mu g\ g^{-1}$, there was no response observed to higher level of K_2O. The on-farm research trial (at 126 locations in 5 years) testified the soundness of this technology.

Introduction

The average productivity of rice (1.88 t ha^{-1}) and wheat (2.37 t ha^{-1}) in India is much less than that in advanced countries. But in Punjab, India the average productivity of rice is almost comparable to that of advanced countries (5.6 t ha^{-1} in Punjab as against 5.96 t ha^{-1} in China, 4.58 t ha^{-1} in Japan, and 5.81 t ha^{-1} in Korea). The productivity of wheat is also high (4.1 t ha^{-1}) in Punjab. However, potential yields of these crops are 2 to 3 times higher than these values. The world record yields are 14.5 t ha^{-1} of wheat and 14.4 t ha^{-1} of rice (Cooke 1982). Therefore, it was felt imperative to identify those factors which could promote high-yield realization. Plant growth regulators (PGRs), though, required in small quantity, are very crucial for sustaining high productivity. Height reduction and straw strength are achieved by application of chlormequat chloride (CCC, cycocel) which shortens and strengthens lower internodes (Bridge 1984). Kinetin is an established PGR known to prolong

1. Punjab Agricultural University, Ludhiana 141 004, Punjab, India.

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grain-fill period by delaying senescence.

Maximum yield research (MYR) implies earmarking those production factors which could be easily amenable to agronomic management for realization of high yields. The basic perception in the rice-wheat system is to maintain soil productivity. Green manure contributes directly to the build-up of organic matter and is a good source of nitrogen (N). It also helps in recycling of mineral nutrients and thus sustains the productivity. Keeping in view high productivity, sustainability, and soil health, elaborate long-term studies for yield maximization in rice-wheat system were planned and carried out at the Punjab Agricultural University, Ludhiana, India from 1986/87 through 1995/96.

Material and Methods

Ludhiana is located at 30° 56' N, and 75° 52' E, and is 247 m above mean sea level in semi-arid, subtropical agroclimatic region. The field selected for experimentation had been continuously cropped (5 years) with fodder crops [maize (*Zea mays* L.)-oat (*Avena sativa* L.)] raised with farmyard manure (FYM) and chemical fertilizers. The soil of the experimental field was sandy loam (Typic Ustochrepts), testing low in organic carbon (0.34%), available N (160 kg ha^{-1}), and available potassium (K) (110 kg ha^{-1}), medium in available phosphorus (P) (13.8 kg ha^{-1}), and normal pH (8.2). Zinc (Zn) content was 0.83 mg kg^{-1} in the surface layer (0–15 cm) and 0.54–0.56 mg kg^{-1} in the subsurface. The composition of the top 0–15 cm soil was 16.7% clay, 14.8% silt, and 68.5% sand and cation exchange capacity (CEC) was 11.35 c mol kg^{-1}. The experiment comprised 8 levels of N-P_2O_5-K_2O. Four levels involved applications of chemical fertilizers at the rate of 60-0-0/120-60-60; 60-0-0/180-90-90; 120-30-30/120-60-60; 120-30-30/180-90-90 kg ha^{-1} to rice-wheat along with green manuring to rice, and the other four were at 120-0-0/120-60-60; 120-0-0/180-90-90; 180-30-30/120-60-60; 180-30-30/180-90-90 kg ha^{-1}, all applied through chemical fertilizers alone to both rice and wheat. Two plant population treatments in rice were (i) 44 hills m^{-2} (15 cm × 15 cm); and (ii) 33 hills m^{-2} (20 cm × 15 cm) and in wheat these comprised sowing (i) unidirectionally with 100 kg seed ha^{-1} at a row spacing of 15 cm; and (ii) bidirectionally using 50 kg seed ha^{-1} in one direction and the remaining 50 kg ha^{-1} in another direction, diagonally at 22.5 cm row spacing. Foliar spray of CCC, at the rate of 1 g L^{-1} at maximum tillering (45 days) followed by kinetin spray at 50 mg L^{-1} at grain formation were applied to rice PR 106 and wheat HD 2329; a blank water spray was given in control plot at 500 L ha^{-1}. In all, there were 32 treatment combinations. These were laid out in split plot design in 4 replications. The 8 fertilizer treatments comprised main plots and 4 combinations of 2 plant populations × 2 growth regulators were assigned to sub-plots. The green manure crop (*Sesbania aculeata* Poir.; dhaincha) was seeded at 50 kg ha^{-1}, and buried after 5–6 weeks of growth. The green matter yield was about 20–25 t ha^{-1} and N added was 55–60 kg ha^{-1}.

After 3 years, the experiment was modified in the light of response obtained. The original experiment was split into two simple experiments, II A and II B; i.e., with and without green manuring to rice in rice-wheat system, laid out in a randomized block design with 4 replications. The treatments comprised N-P_2O_5-K_2O at the recommended level (120-30-30 kg ha^{-1}), and 50% and 100% more than the recommended N in combination with recommended and 50% and 100% more than recommended P_2O_5 and K_2O levels in rice after green manuring. In the same plots during *rabi* (postrainy season), levels of [N-P_2O_5-K_2O

(kg ha^{-1})] tried were: 120-60-30 (recommended); 180-60-30; 180-90-45; 180-90-60; 240-90-60; and 240-90-60 + PGR, at uniform plant population of 44 hills m^{-2} (15 cm × 15 cm) in rice and 15 cm spacing in wheat.

In all years, 40-day-old seedlings of rice (PR 106) were transplanted in the first fortnight of June after puddling. The full dose of P_2O_5 (diammonium phosphate) and K_2O (muriate of potash) as per treatment along with 25 kg ha^{-1} of $ZnSO_4$ (5.5 kg Zn ha^{-1}) to rice alone was applied at transplanting. Nitrogen (urea) was applied by broadcasting (when the field was dry) in 3 equal splits: at transplanting, 3 weeks after transplanting, and 6 weeks after transplanting. The herbicide Butachlor® was applied at 3.0 L ha^{-1} after mixing in 150 kg sand, 2–3 days after transplanting. The field was flooded for 15 days after transplanting for establishment of seedlings and to increase efficiency of applied herbicide. Subsequent irrigations were given 2 days after flood water had infiltrated in the soil. The irrigation was withheld 15 days before harvesting.

Wheat was sown in the first fortnight of November, by drilling 100 kg seed ha^{-1} at 15 cm row spacing. Half of the N (urea) and all P (diammonium phosphate) and K (muriate of potash) were added at sowing (by drill); the remaining half of the N was applied at crown root initiation along with first irrigation, given at about 4 weeks of growth (top dressed). The weeds were controlled by using 2,4-dichlorophenoxy acetic acid (2,4-D) ester (36%) and isoproturon 75 WP (Arelon®) @ 625 ml + 1250 g ha^{-1}, in 500 L of water applied at 35–40 days of crop growth.

The crop received 4 irrigations based on 100 mm net cumulative pan evaporation (total pan evaporation minus rainfall during season). Both rice and wheat were harvested manually and threshed with a tractor-operated thresher. All the above-ground biomass was removed from the field.

Chemical analysis of the soil was done following Arthur and Sanderman (1977) for total N; Subbiah and Asija (1956) for available N; Olsen et al. (1954) for available P; Hanway and Hoidal (1952) for available K; and Walkley and Black (1934) for organic carbon. The soil samples were drawn from the center of each plot after harvest of each crop, using 7.5 cm post-hole auger and dried in the shade. The total N, P, and K in the plant were estimated by Hesse (1971). The N, P, and K and micronutrients in plants were estimated separately for grain and straw components (oven dried at 60°C) and total uptake was calculated.

Results and Discussion

Grain yield

In the original experiment the highest yield of rice (unhusked) (9.3–9.9 t ha^{-1}) was obtained with recommended dose of N-P_2O_5-K_2O (120-30-30 kg ha^{-1}) + green manuring. These yields were on par with 50% more N and recommended levels of P_2O_5 and K_2O (yields 8.8–9.3 t ha^{-1}) without green manuring in the first two years. During the third year heavy rains were received at the time of harvesting (end of September), which affected yield adversely. Likewise, in all the three years, at low levels of fertilizer (60-0-0 kg ha^{-1}) with green manuring, yield was equal to that in 120-0-0 kg ha^{-1} without green manuring. These yields were significantly lower than the high fertilizer levels by 0.6–1.2 t ha^{-1} (Table 1). Thus green manuring of rice supplied equivalent of 60 kg N ha^{-1}. These results conform findings of Kolar and Grewal (1988) and Meelu et al. (1992).

The results of revised experiment conducted over 6 years revealed that rice grown after green manuring with recommended nutrient level 120-30-30 kg ha^{-1} was at par with 180-30-30 and 180-45-45 kg N-P_2O_5-K_2O ha^{-1} without green

Table 1. Effect of different treatments on grain yield of rice and wheat in rice-wheat system at Ludhiana, India.[1]

Treatment		Grain yield (t ha^{-1})							
		1986/87		1987/88		1988/89		Mean	
R	W	R	W	R	W	R	W	R	W
Fertilizer level									
N-P_2O_5-K_2O (kg ha^{-1})									
60-0-0 (+GM)	120-60-60	9.0	5.1	8.2	5.1	8.2	5.0	8.4	5.1
60-0-0 (+GM)	180-90-90	8.8	5.4	8.1	5.5	8.2	5.4	8.3	5.5
120-30-30(+GM)	120-60-60	9.7	5.0	9.3	5.4	9.4	5.0	9.4	5.1
120-30-30(+GM)	180-90-90	9.9	5.8	9.4	6.1	9.4	5.8	9.6	5.9
120-0-0	120-60-60	8.7	5.0	8.2	4.8	8.2	5.1	8.4	5.0
120-0-0	180-90-90	8.3	5.2	8.2	5.1	8.3	5.3	8.3	5.3
180-30-30	120-60-60	9.3	5.2	8.9	5.4	8.8	5.2	9.0	5.3
180-30-30	180-90-90	9.1	5.7	9.0	5.8	8.9	5.7	9.0	5.7
CD (0.05)		0.8	0.8	0.5	0.2	0.2	0.2	–	–
Crop geometry/plant population									
15 cm × 15 cm	Unidirectional (15 cm apart)	9.4	5.3	9.0	5.4	8.8	5.3	9.1	5.3
20 cm × 15 cm	Bi-directional (22.5 cm × 22.5 cm)	8.8	5.3	8.4	5.5	8.9	5.3	8.7	5.4
CD (0.05)		0.2	NS	0.2	NS	0.1	NS	–	–
Plant growth regulators									
Water spray	Water spray	9.0	5.1	8.5	5.4	8.5	5.1	8.6	5.2
CCC and kinetin	CCC and kinetin	9.2	5.5	8.8	5.5	8.9	5.5	8.9	5.5
CD (0.05)		0.2	0.25	0.2	NS	0.1	0.1	–	–

1. R=Rice; W=wheat; GM=green manure; CCC=cycocel; NS=not significant.

manuring. High level of N-P_2O_5-K_2O application beyond these levels did not seem to be viable as the crop becomes increasingly prone to lodging, insect pest attack, and diseases. Results indicate that rice yield can be accrued up to 7.4 t ha^{-1} with green manure along with recommended level of fertilizer (120-30-30 kg ha^{-1}) (Table 2). When green manure was not used, rice yields were 7.2 t ha^{-1} with 180-30-30 and 7.3 t ha^{-1} with 180-45-45 kg N-P_2O_5-K_2O ha^{-1}. The results confirmed that green manure contributes about 60 kg N equivalent.

The following wheat grown with above-mentioned levels of fertilization showed that the highest yields recorded were with highest dose of fertilizer (180-90-90 kg N-P_2O_5-K_2O ha^{-1}), irrespective of whether the wheat followed normally fertilized rice (120-30-30 kg ha^{-1}) with

Table 2. Effect of fertilizers and green manure on grain yield (t ha^{-1}) of rice and wheat during phase II of the long-term experiment in rice-wheat system at Ludhiana, India.[1]

Treatment N-P_2O_5-K_2O(kg ha^{-1}) Rice	Wheat	1989/90 R	1989/90 W	1990/91 R	1990/91 W	1991/92 R	1991/92 W	1992/93 R	1992/93 W	1993/94 R	1993/94 W	1994/95 R	1994/95 W	Mean R	Mean W
Experiment II A (Without green manure)															
120-30-30	120-60-30	5.8	4.4	7.6	5.2	7.2	5.2	6.7	4.8	6.1	5.1	6.2	4.9	6.6	4.9
180-30-30	180-60-30	6.4	4.7	8.8	5.9	8.4	5.9	6.2	5.3	6.8	6.0	6.7	6.4	7.2	5.7
180-45-45	180-90-45	6.5	4.9	8.9	5.9	8.5	5.8	6.4	5.0	6.9	6.0	6.5	6.4	7.3	5.7
240-60-30	180-90-60	7.2	5.2	8.6	5.9	7.4	5.9	6.3	5.1	6.5	5.9	6.2	6.3	7.1	5.7
240-60-60	240-90-60	7.3	5.4	8.7	5.7	7.6	5.6	6.2	5.0	6.3	4.8	6.2	5.6	7.1	5.4
240-60-60 + PGR	240-90-60 + PGR	7.4	5.5	8.9	5.8	7.4	6.0	6.4	5.1	6.4	4.9	6.3	6.5	7.1	5.6
CD (0.05)		0.5	0.2	0.3	0.4	0.3	0.4	0.2	0.3	0.4	0.4	0.2	0.5	–	–
Experimental II B (With green manure to rice)															
120-30-30	120-60-30	6.3	4.7	9.1	5.3	8.6	5.3	6.3	4.7	6.9	4.7	7.2	5.1	7.4	4.9
180-30-30	180-60-30	6.8	5.1	8.6	5.8	7.5	5.7	6.2	5.0	6.5	5.4	6.9	6.3	7.1	5.5
180-45-45	180-90-45	6.9	5.3	8.6	5.8	7.4	5.7	6.2	4.9	6.6	5.5	7.0	6.4	7.1	5.6
240-60-30	180-90-60	6.9	5.5	8.4	5.8	7.2	5.5	6.1	4.9	6.7	5.4	6.5	6.3	6.9	5.6
240-60-60	240-90-60	7.1	5.7	8.4	5.6	7.6	5.5	6.1	4.9	6.4	4.2	6.6	5.6	7.0	5.3
240-60-60 + PGR	240-90-60 + PGR	7.1	6.0	8.5	5.6	7.6	5.7	6.2	4.6	6.3	4.1	6.6	6.2	7.1	5.4
CD (0.05)		0.4	0.2	0.4	0.3	0.4	0.3	0.2	0.3	0.2	0.4	0.2	0.6	–	–

1. R=Rice; W=wheat; PGR=plant growth regulators (cycocel and kinetin).

or without green manuring. The highest yields of wheat achieved with 180-90-90 kg ha^{-1} with and without green manuring were 5.9 and 5.7 t ha^{-1} respectively (Table 1). The harvest index of rice and wheat was 0.48 to 0.50.

The response to P and K was further tested in the second phase for 6 years. The highest yield was obtained with 50% more N (180 kg N ha^{-1}) and with recommended P and K. The crop did not show any response beyond 30 kg P_2O_5 ha^{-1} in rice and 60 kg P_2O_5 ha^{-1} in wheat and to high levels of K_2O (Table 2). On an average of 6 years, the wheat yield obtained with 180-60-30 kg $N\text{-}P_2O_5\text{-}K_2O$ ha^{-1} was 5.7 t ha^{-1} without green manuring and 5.5 t ha^{-1} with green manuring. This shows that the main effect of green manure was confined to rice yield without any carry-over effect to wheat, probably because of heavy removal by the high yield of rice which left the soil exhausted. The yearly variation was mainly because of climate (i.e., rainfall distribution) and lodging as a result of weather aberration and difference in humidity and sunshine hours with severe lodging in the later years being a common feature. Lodging occurred mainly due to weak stem of available genotypes.

A decline in rice yield was observed over time while decline in wheat yield was nominal (about 0.2 t ha^{-1}). The decline in the second phase in rice over the earlier 3-year phase was rather sharp (about 2.0 t ha^{-1}) because of rice being exceedingly prone to larger number of insect pests such as leaf folder (*Gnaphalocrocis medinalis* Guen) and stem borer (*Tryporyza incertulas* Walker). Besides, there was high spikelet sterility due to rains coinciding with anthesis as during 1994 with 118 mm rainfall (+78% over normal) being received in September and lodging under aberrant weather. The decrease in wheat yield was just nominal (0.2 t ha^{-1}); high yields of about 6 t ha^{-1} were obtained continuously in most of the years.

Plant population

Close planting configuration (15 cm × 15 cm) resulted in increased population stand (44 hills m^{-2}) and also rice grain yield (unhusked) over conventional configuration of planting rice at 20 cm × 15 cm giving 33 hills m^{-2} (Table 1). Increase was mainly attributed to better solar utilization and higher efficiency of applied nutrients with more dense plant populations. Similar yield increase with high populations were observed by Rathi et al. (1984) and Raghuwanshi et al. (1986).

Bi-directional sowing of wheat performed on a par with closer planted configuration with rows spaced 15 cm apart, except in one year when bi-directional configuration gave significantly more yield showing, thereby, that for higher plant population stands of wheat, any of these two methods could be adopted.

Plant growth regulators

Spray with CCC, followed by kinetin, improved yields of rice and wheat by 0.2–0.4 t ha^{-1} (Table 1). Beneficial effect of PGR in rice was large particularly in third year when heavy rains just a week before rice harvest affected the crop adversely. Likewise, beneficial effect of PGR in wheat was also highly dependent on climate. It was pronounced when temperature during maturation phase was low and weather mild and favorable (as in 1986/87 and 1988/89). The effect of PGR in wheat in 1987/88 however, was not expressed when temperature rose abruptly, resulting in early forced maturity. In subsequent 6 years, PGR applied along with very high level of fertilizer of 240 kg N ha^{-1} did not show any significant response (because of considerable lodging in this treatment).

Only the second order interaction (fertilizer level × crop geometry × PGR) was significant for rice and wheat in 2 out of 3 years (1986/87 and 1988/89). The highest yield was recorded with highest level of nutrient, close spacing, and application of CCC and kinetin. However, these being costly and their effect being highly environment-dependent, their use is likely to be very restricted.

Nutrient uptake

In the first phase of the experiment, nutrient uptake by rice at the highest level of fertilization (with and without green manuring) was 189–196 kg N ha^{-1}, 31 kg P ha^{-1}, and 222–227 kg K ha^{-1} giving an average of about 448 kg ha^{-1} removal of primary nutrients (N-P-K) by a crop with grain yield of 9–10 t ha^{-1} (Table 3). In contrast the uptake at the recommended level of fertilization (60 kg N with green manure and 120 kg N without green manuring) showed nutrient removal of 160 kg N, 26 kg P, and 193 kg K ha^{-1}. Obviously, high fertilization at high populations which enabled the crop to absorb 69 kg more nutrient ultimately led to realization of high yields.

The following wheat absorbed 116 to 132 kg N, 24.0 to 28.0 kg P, and 189 to 222 kg K ha^{-1}, thus indicating independent effect of nutrient on wheat. The average total uptake of N-P-K in rice-wheat system varied from 576 kg ha^{-1} to 724 kg ha^{-1}, depending upon the yield levels achieved. Such a heavy removal and good harvest thus imply proper replenishment through a well thought of fertilization management program.

Soil fertility status

Soil fertility status was monitored at the end of 3 years cycle in the first phase of experiment and over 5 crop seasons in the next phase of experimentation. The results revealed that in general the soil productivity improved. The values of organic carbon, available P and K varied from 0.34% to 0.37%, available P from 20.6 kg ha^{-1} to 24.4 kg ha^{-1}, and available K from 118 kg ha^{-1} to 138 kg ha^{-1}, as against initial values of 0.34% organic carbon, 13.8 kg P ha^{-1}, and 110 kg K ha^{-1}. Also heavy removal of Zn, iron (Fe), and manganese (Mn) was observed by high yield of rice and wheat. Therefore, it may become imperative in the coming years to supplement fertilization with micronutrient supply.

In the second phase, the effect of rice-wheat cropping system on soil productivity revealed that organic carbon, total N, available N, available P, and available K improved in green manure as well as in chemical fertilizer series (treatments). The increase in maximum economic yield levels 180-30-30 and 180-60-30 N-P_2O_5-K_2O kg ha^{-1} to rice and wheat ranged from 1.1 to 2.72 times. In general, increase in green manure series was more than in chemical fertilizer series (Table 4). The organic carbon in green manure series improved by 16.2% and in chemical fertilizer series by 11.8% in 0–30 cm soil layer under normal fertilizer levels to rice and wheat. There was a corresponding improvement in organic carbon under maximum economic yield in this region (Kolar and Grewal 1989). The extractable-K declined over time with high fertilizer level (due obviously to higher uptake than annual accrual) (Hegde and Dwivedi 1992).

Farmers' field trials

In order to disseminate MYR technology, adaptive trials were carried out on the fields of progressive farmers. The MYR technology in rice comprised testing of response to fertilizer levels 180-30-30 kg N-P_2O_5-K_2O ha^{-1} and high population stands of 44 hills m^{-2} with crop geometry of 15 cm × 15 cm against recommended level and 33 hills m^{-2} (20 cm ×

Table 3. Effect of different fertilizer treatments on nutrient uptake (mean of 3 years) during Phase I (1986–89) of the long-term experiment on rice-wheat system at Ludhiana, India.[1]

Treatment (N-P_2O_5-K_2O kg ha^{-1})		Nitrogen		Phosphorus		Potassium		Zinc		Manganese		Iron	
		R	W	R	W	R	W	R	W	R	W	R	W
Rice	Wheat	kg ha^{-1}						g ha^{-1}					
60-0-0 + GM	120-60-60	162	119	26	25	196	90	185	120	1585	178	1977	1219
60-0-0 + GM	180-90-90	163	130	26	26	196	99	190	131	1697	199	1996	1256
120-30-30 + GM	120-60-60	196	119	31	25	224	89	238	118	1797	181	2160	1333
120-30-30 + GM	180-90-90	196	138	31	28	227	105	245	136	1852	213	2228	1402
120-0-0	120-60-60	156	116	26	24	189	85	224	117	1964	189	2172	1226
120-0-0	180-90-90	159	127	25	26	190	94	232	124	1950	215	2240	1278
180-30-30	120-60-60	188	122	30	26	221	87	239	115	2058	197	2311	1357
180-30-30	180-90-90	189	132	31	28	222	99	240	135	2095	228	2369	1341

1. R=Rice; W=wheat; GM=green manure.

Table 4. Effect of maximum economic yield fertilizer levels on soil fertility status under rice-wheat rotation over 5 crop seasons in Experiment II A and II B at the Punjab Agricultural University, Ludhiana, India.[1]

Fertilizer series[2]	Soil depth (cm)	NFL[3]					MEYL[4]				
		I	II	III	IV	V	I	II	III	IV	V
Organic carbon(%)											
GMS	0–30	0.37	0.39	0.40	0.42	0.43	0.37	0.40	0.41	0.43	0.45
	30–60	0.26	0.27	0.29	0.29	0.30	0.26	0.28	0.29	0.30	0.31
CFS	0–30	0.34	0.36	0.36	0.38	0.38	0.34	0.34	0.38	0.39	0.40
	30–60	0.25	0.26	0.27	0.28	0.29	0.26	0.26	0.28	0.29	0.30
Available nitrogen ($\mu g\ g^{-1}$)											
GMS	0–30	72	75	74	75	81	79	90	98	104	110
	30–60	50	51	53	57	57	52	53	53	58	59
CFS	0–30	69	71	68	62	60	78	89	92	94	104
	30–60	50	50	50	51	50	50	52	54	56	57
Total nitrogen ($\mu g\ g^{-1}$)											
GMS	0–30	490	501	509	519	535	491	506	502	510	517
	30–60	272	279	283	289	293	275	284	280	284	290
CFS	0–30	486	495	520	535	554	496	498	511	522	536
	30–60	271	275	288	291	297	273	278	282	287	294
Available P ($\mu g\ g^{-1}$)											
GMS	0–30	10.5	11.0	11.3	12.3	12.8	10.5	11.3	11.9	11.7	12.0
	30–60	6.3	6.5	6.5	6.7	6.8	6.3	6.4	6.5	6.6	6.7
CFS	0–30	10.5	11.0	11.9	11.7	11.8	10.5	10.0	10.0	10.7	11.0
	30–60	6.3	6.3	6.5	6.7	6.8	6.3	6.3	6.5	6.5	6.7
Available K ($\mu g\ g^{-1}$)											
GMS	0–30	69	67	67	65	63	68	66	64	64	61
	30–60	47	48	49	50	50	47	43	48	49	49
CFS	0–30	68	64	60	59	56	67	64	68	54	52
	30–60	46	47	47	48	48	46	47	47	47	48

1. Crop season I=Rice 1990; II=Wheat 1990/91; III=Rice 1991; IV=Wheat 1991/92; and V=Rice 1992.
2. GMS=Green manure series; CFS=Chemical fertilizer series.
3. NFL=Normal recommended fertilizer level of 120-30-30 and 120-60-30 kg N-P_2O_5-K_2O ha^{-1} for rice and wheat respectively.
4. MEYL=Maximum economic yield level at 180-30-30 and 180-60-30 kg N-P_2O_5-K_2O ha^{-1} for rice and wheat respectively.

15 cm spacing). In wheat, MYR treatment was 180-60-30 kg N-P_2O_5-K_2O ha^{-1} with bi-directional sowing (22.5 cm × 22.5 cm) against recommended level of fertilizer with unidirectional sowing at 22.5 cm spacing. The crop was completely managed by farmers and all other inputs with respect to irrigation, weed control, insect pests, and disease management

were applied as per recommendations of the State University.

The results (average of 76 trials in rice and 50 trials in wheat conducted over five years in different districts of Punjab) revealed that MYR technology resulted in 13.2% increase in rice yield (average yield 7.7 t ha^{-1} against 6.8 t ha^{-1}) and 18.4% increase in wheat yield (5.8 t ha^{-1} against 4.9 t ha^{-1}) over recommended practices, giving a net increase of 1.8 t grain ha^{-1} yr^{-1} (Table 5).

Conclusion

The highest grain yield of rice (7.2 to 9.6 t ha^{-1}) and wheat (5.7 to 5.9 t ha^{-1}) in a sequence were obtained over a period of 9 years with 180-30-30 and 180-60-30 kg N-P_2O_5-K_2O ha^{-1}, respectively. Use of green manure saved 60 kg N ha^{-1}. The total removal of NPK in rice-wheat system at high level of fertilization varied from 701 kg ha^{-1} to 725 kg ha^{-1}. Soil fertility monitoring at the end of each crop over 5 crop seasons showed a steady build-up of 0.40–0.45% organic carbon; 104–110 $\mu g\ g^{-1}$ available N; 517–536 $\mu g\ g^{-1}$ total N, and 11–12 $\mu g\ g^{-1}$ available P as against the base values of 0.34–0.37%, 78–79 $\mu g\ g^{-1}$, 491–496 $\mu g\ g^{-1}$, and 10.5 $\mu g\ g^{-1}$ soil respectively under 180-30-30 and 180-60-30 kg N-P_2O_5-K_2O ha^{-1} to rice-wheat sequence.

Constraints

Time series analysis of the yield performance of rice-wheat sequence grown on the same site (1986 through 1995) shows that in the second phase, the yield of rice declined by nearly 2.0 t ha^{-1} (from 9.3 t ha^{-1} to 7.3 t ha^{-1}). The scrutiny of the factors revealed that low yield of rice during the second phase was mainly due to the advancement of the transplanting period to the hot month of May by farmers in the neighborhood. The increased availability of rice in surrounding fields led to production of several generations of stem borer and leaf folder. This often damages timely (mid-June) planted rice.

The rice cv PR 106 has high spikelet sterility (22.3%) which occasionally tends to assume serious proportion, particularly when crop pollination coincides with delayed September rains which result in pollen washing. Besides, this variety is susceptible to 2 out of 4 races of bacterial leaf blight with susceptibility rating of 9 on the scale 0–10. In spite of being released in 1976, it is still under cultivation, being the only variety available with high market preference and wide adaptability. It has now become vulnerable to various biotic and abiotic stresses and needs replacement.

Even though, until now HD 2329 wheat had shown a stable performance but is now becoming susceptible to new races of yellow and brown

Table 5. Results of on-farm rice-wheat Maximum Yield Research Trials in Punjab, India.

Treatment	Grain yield[1] (t ha^{-1})	
	Rice	Wheat
Recommended practices	6.8	4.9
Maximum yield research technology[2]	7.7	5.8
Increase (%)	13.2	18.4

1. Mean of five years.
2. Average of 76 trials in rice and 50 trials in wheat.

rust and to lodging under high fertility and intensive management in an aberrant weather.

The single most important factor limiting realization of sustained high stable yields through application of MYR technology seems to be the absence of suitable high fertilizer-responsive, high potential cultivars of rice and wheat with high-lodging resistance for growing under intensive management which include use of high fertilizer and high population densities. There is a need to focus on breeding and screening varieties at high level of inputs (200 to 250 kg N ha^{-1}) instead of breeding selected varieties for performance at moderate levels of inputs (100–120 kg N ha^{-1}) only.

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