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OUTPUT:INPUT RATIOS AND APPARENT BALANCES OF N, P AND K INPUTS IN A RICE-WHEAT SYSTEM IN NORTH-WEST INDIA

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SUMMARY

Output:input ratios and apparent balances for nitrogen (N), phosphorus (P) and potassium (K) were measured in a rice-wheat system at Modipuram (29.4°N, 77.46°E, 237 m asl), India, under two planting densities ($P_1 = 200 \times 200$ mm for rice, 230 mm row spacing for wheat, and $P_2 = 200 \times 100$ mm for rice, 150 mm row spacing for wheat), and two levels of fertilizer NPK (100% F = recommended levels of fertilizer N, P and K for each crop, i.e. 120 kg N, 26 kg P and 33 kg K ha^{-1}, and 150% F = 150% of the recommended levels) with and without 5 t ha^{-1} farmyard manure (M) to each crop. After two cycles of the rice-wheat rotation at a fixed site, N and K balances were negative for all treatments, but P balance was negative only in plots treated with P_1 + 100% F treatment. The largest yield in the system, 15.7 t ha^{-1}, was obtained in plots receiving P_2 planting density with 150% F + M treatment, and the smallest (13 t ha^{-1}) in plots of P_1 planting density with 100% F treatment. In plots with the largest yield, total removal of NPK was 659 kg ha^{-1} (310 kg N, 62 kg P and 287 kg K ha^{-1}), and in plots with the smallest yield, NPK removal was 411 kg ha^{-1} (188 kg N, 34 kg P and 189 kg K ha^{-1}). At these nutrient uptakes, output:input ratios were 0.74 for N, 0.57 for P and 1.80 for K in plots receiving P_2 + 150% F + M treatment, and 0.78 for N, 0.65 for P and 2.86 for K in plots receiving P_1 + 100% F treatment.

INTRODUCTION

The rice-wheat cropping system, accounting for 13.5×10^6 ha of arable land in South Asia, is mostly in the semi-arid region of northwest India and Pakistan. The system is associated with the bulk of food production and food security in the area. India's Punjab province alone contributes 60% of wheat and 42% of rice in the total national food grain procurement (Kumar, 1998). There is, however, evidence to suggest that growth in the production of South Asia's rice-wheat system is levelling off. Opportunities for expansion are limited due to finite and often overexploited natural resources. Therefore, to sustain yields of the rice–wheat system, agronomic management has to be improved for greater efficiency of utilization of applied inputs.

Both rice and wheat crops of the system are exhaustive consumers of nutrients. On average, rice crops remove about 300 kg ha^{-1} nitrogen (N), phosphorus (P) and potassium (K) as well as 0.2 kg ha^{-1} zinc (Zn), 0.75 kg ha^{-1} iron (Fe) and 3.4 kg ha^{-1} manganese (Mn) (Pillai and Kundu, 1993). Wheat crops remove about 390 kg ha^{-1} of N, P and K along with 0.5 kg ha^{-1} Zn, 1.8 kg ha^{-1} Fe, and 0.5 kg ha^{-1} Mn (Joseph and Prasad, 1992). Thus, when rice and wheat are grown in sequence, they account for the annual removal of more than 650 kg ha^{-1} N, P and K and micronutrients in the range of 0. 5–1.0 kg ha^{-1} Zn, 2–3 kg ha^{-1} Fe, and 3–3.5 kg ha^{-1} Mn (Narang *et al*, 1990). Considerable amounts of soil nutrient reserves are depleted, therefore, every year from the soils under the rice-wheat system. The depleted nutrients are replenished every year by fertilizing each crop of the rotation with 120 kg N, 60 kg P_2O_5 and 40 kg K_2O per ha, but diagnostic surveys conducted during the 1990s at selected sites in NW India indicated that in areas where the rice-wheat rotation had been practised for a considerable period, the use of compost and farm yard manure (M) has declined and that the farmers had adopted the practice of using greater than recommended doses of fertilizer N to maintain previously attained high yield levels (Chaudhary and Harrington, 1993). This is evident in the heartland of rice-wheat cropping, i.e. in the state of Haryana, India, where annual use of inorganic fertilizers for all crops has increased from 13 300 t of nutrients (NPK) in 1966–67 to 870 790 t in 1999–2000. During the same period, fertilizer-use rates (all crops) increased from 3 kg ha^{-1} to 143.4 kg ha^{-1} (FAI, 2000). The efficiency of applied fertilizers may, however, be increased by using organic manures (Yadav *et al*, 2000) and increasing plant population density. With these considerations in view, the present study was undertaken to (i) understand yield response to applied fertilizer NPK with and without farmyard manure under two planting densities, (ii) assess output:input ratios and apparent balances of NPK, and (iii) measure changes in soil organic C, total N, available P and K in a rice-wheat system.

MATERIALS AND METHODS

Site, soil and climate

A field experiment was conducted during 1995–96 and 1996–97 at the Project Directorate For Cropping Systems Research, Modipuram, India. Modipuram is located at 29.4°N, 77.46°E and at 237 m asl. Climatologically, Modipuram is categorized as a semi-arid sub-tropical climatic zone with very hot summers and cool winters. The average annual rainfall is 810 mm and potential evapotranspiration 1500 mm.

The soil of the experimental area was typic Ustochrept, sandy loam, deep and mildly alkaline (pH 8.2). Before commencement of the experiment, soil samples were drawn from the 0–150 mm soil layer by a core sampler, 80 mm diameter, at five places in the experimental field. These five samples were thoroughly mixed, bulked and a representative sample drawn for determination of organic C, (Walkley and Black method), total N (modified macro-Kjeldal method), 0.5M $NaHCO_3$ (pH 8.5)-extractable P and 1N NH_4OAC-extractable K, following

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Jackson (1973). The organic carbon content of the soil was 0.44%, total N 0.021%, 18 kg ha^{-1} available P and 168 kg ha^{-1} available K.

Treatments and crop culture

Eight treatment combinations comprising two levels of fertilizer NPK, 100% F = 100% of recommended applications of NPK (120 kg N, 26 kg P and 33 kg K ha^{-1}), and 150% F = 150% of the recommended fertilizer NPK (180 kg N, 39 kg P and 50 kg K ha^{-1}) with and without 5 t ha^{-1} manure (M) were evaluated at two planting densities, $P_1 = 200 \times 200$ mm spacing in rice and 230 mm row spacing in wheat, and $P_2 = 200 \times 100$ mm spacing in rice and 150 mm row spacing in wheat. The treatments were tested in a fixed layout for two years of a randomized block design having four replications. The plot size was 6 × 5 m. Fertilizers used were urea (46% N), superphosphate (6.8% P) and muriate of potash (46.2% K).

All P and K, and one-third of the N were applied as basal dressings and the remainder of the N top-dressed in two equal splits, at panicle initiation and flowering stages in rice, and at crown root initiation and maximum tillering stages in wheat. For the rice, M was applied before puddling, and for wheat, soon after the rice harvest.

Each year, rice (*Oryza sativa* var. Saket-4) was transplanted on 20 July using two seedlings per hill. After harvesting the rice on 20 October, wheat (*Triticum aestivum* var. HD 2329) was sown on 20 November. Wheat was harvested in the last week of April. The crops were harvested close to ground level, manually by sickle, and the entire above-ground biomass was removed from the field.

The crops were grown under irrigated conditions. At each irrigation, rice plots were flooded with 250 mm deep standing water. Subsequent irrigations were given when ponded water disappeared (i.e. no standing water). Wheat was irrigated five times, at the crown root initiation (21 days after sowing (DAS)), maximum tillering (50 DAS), jointing (70 DAS), ear emergence (95 DAS) and milking (125 DAS) stages.

Soil and plant analysis

After harvesting the rice and wheat, soil samples were drawn from 0–150 mm soil layer in each plot, and analysed for organic carbon (Walkley and Black method), total N (macro – Kjeldahl method), 0.5 M NaH CO_3 (pH-8.5)-extractable P and NH_4 OAC-extractable K, following Jackson (1973).

At harvest, representative grain and straw samples of rice and wheat were drawn from the bulk produce of the net plot harvest. These were oven dried at 70 °C for 48 h, ground in a stainless steel Wiley mill and wet digested in a di-acid mixture ($3HNO_3$:$1HC10_4$) for determination of P and K. Phosphorus was determined by vanadomolybdo-phosphoric yellow colour method, and the flame photometer was used for determining K. For N determination, plant material was digested separately and analysed by the modified micro-Kjeldahl method (Jackson, 1973).

Theoretical considerations

For sustainable yields in the intensive cropping systems, such as rice-wheat double crop rotation, it is important that nutrients that are removed by the crops are replenished continuously through fertilizers and manures. However, for computing the amount of nutrients that are to be applied, the nutrients present in the soil, and the efficiency with which these are taken up by the crops may also be considered. While the efficiency of nutrients may be judged by output:input ratios of the applied nutrients, the level of nutrients in the soil before sowing and after harvest of the crop, and the amount of nutrients added through fertilizers and removed by the crops may indicate apparent balances of nutrients. Although, for computing apparent balances using equation 2 (see below), the inputs of nutrient from external sources other than fertilizers and manures viz. rain, dry deposition, irrigation water, biological fixation and losses via leaching, volatilization and denitrification were not considered in the present study, therefore nutrient balances may be of limited value for calculating N, P and K cycles of the rice-wheat systems. Nonetheless these apparent balances may provide useful indications for making fertilizer recommendations for high and sustainable yields in the rice-wheat systems.

$$\text{Nutrient output:input} = [\text{PN}] \div [\text{FN}] \quad (1)$$

$$\text{Apparent balance of nutrients N, P and K (ABN)} = [\text{IN-HN}] + [\text{FN-PN}] \quad (2)$$

Where, FN is the amount of nutrients (N, P and K) applied through fertilizers and manure, PN is the amount of nutrients (N, P and K) removed by the crop plants, IN is the amount of nutrients present in the soil before commencement of the experiment, and HN is the amount of nutrients present in the soil after the completion of two crop cycles of the rice-wheat rotation.

Statistical analysis

The data for each crop season were analysed separately. The homogeneity of error variance was then tested using Bartlett's X^2 test. As the error variance was homogenous, a pooled analysis was done as described by Cochran and Cox (1957). As the variation between the two crop seasons was not significant for most parameters, the mean data for the two crop cycles are presented here. The relationship between output:input ratios of N, P and K and grain yields of rice and wheat was also studied by simple correlation techniques.

RESULTS

Grain yield

Grain yield of both rice and wheat increased significantly with the increase in the rates of fertilizer NPK from 100% to 150% under P_2 planting density (Table 1). The differences in yields between the two levels of fertilizer NPK under P_1

Table 1. Grain yields (t ha^{-1}) of rice and wheat in rice-wheat rotation as influenced by planting density (P_1 and P_2) rates of fertilizer NPK (100% F and 150%F) and manure (M_0 and M_5) application.

Crops	P_1				Mean	P_2				Mean
	100% F		150% F			100% F		150% F		
	No M	M	No M	M		No M	M	No M	M	
					1995–1996					
Rice	7.35	6.87	7.19	7.78	7.30	8.14	7.74	8.34	8.50	8.18
Wheat	5.96	5.67	6.04	5.77	5.86	6.41	6.86	7.04	7.08	6.85
Total	13.31	12.54	13.23	13.55	13.16	14.55	14.60	15.38	15.58	15.03
LSD 5%, rice = 0.42, wheat = 0.36, total = 1.08										
					1996–1997					
Rice	7.00	6.67	6.46	7.40	6.89	6.87	7.28	7.41	7.64	7.30
Wheat	5.68	5.73	7.00	7.11	6.38	6.11	6.07	7.61	8.12	6.98
Total	12.68	12.40	13.46	14.51	13.27	12.98	13.35	15.02	15.76	14.28
LSD 5%, rice = 0.28, wheat = 0.60, total = 1.44										
					Mean of two crop cycles					
Rice	7.18	6.77	6.83	7.59	7.10	7.51	7.51	7.88	8.07	7.75
Wheat	5.82	5.70	6.52	6.34	6.10	6.26	6.47	7.33	7.60	6.92
Total	13.00	12.47	13.35	13.93	13.20	13.77	13.98	15.21	15.67	14.66
LSD 5%, rice = 0.88, wheat = 0.32, total = 1.64										

planting density, however, were not significant. It may, therefore, be inferred that the 100% recommended level of NPK was sufficient to sustain plant yields under P_1 planting density, whereas a higher dose of fertilizer NPK was found to be optimum to achieve potential yield in P_2 planting density. Total grain yield of the rice-wheat rotation was also significantly greater at P_2 density than at P_1 density during both years of experimentation. Manure application indicated a positive effect on the grain yield when applied along with 150% F. Greater response to M at 150% F might be due to the fact that the availability of micro-nutrients in the soil may have become limiting to sustain increased biomass at this level, and manure application may have supplied the needed micro-nutrients for higher crop productivity (Swarup, 1998).

Uptake of N, P and K

N uptake in rice was significantly greater under P_2 than under P_1 planting density (Figure 1). At 100% F under P_1, N uptake increased by 99% due to M over no M but, under P_2, N uptake decreased due to M application. At 150% F, M resulted in greater uptake of N over no M by 5% under P_1 and 0.7% under P_2. In wheat also, N uptake was significantly greater under P_2 than under P_1. At 100% F, N uptake increased due to M over no M by 1% under P_1 but decreased by 11% under P_2. At 150% F, N uptake increased due to M over no M by 28% under P_1 and 2% under P_2.

Phosphorus uptake, in general, increased with increasing levels of fertilizer

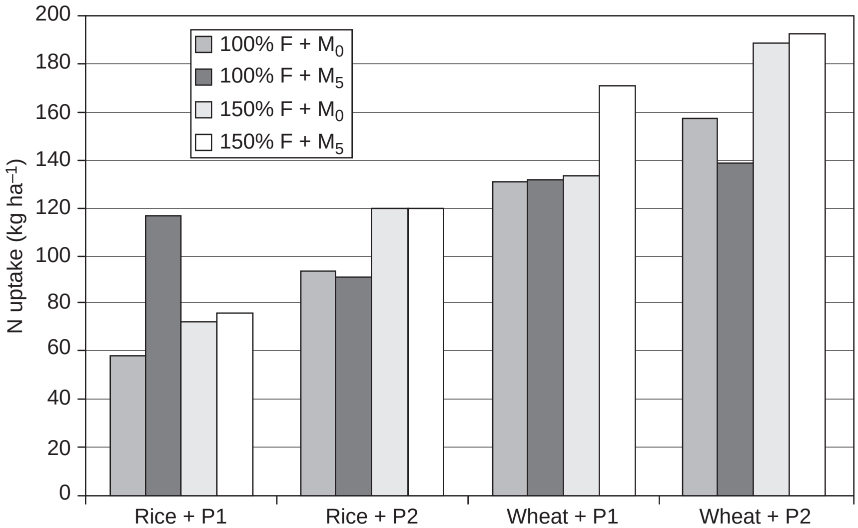

Figure 1. Nitrogen uptake (kg ha^{-1}) in rice and wheat as influenced by rates of fertilizer N and manure (M) application, and planting density (based on mean data of two crop cycles).

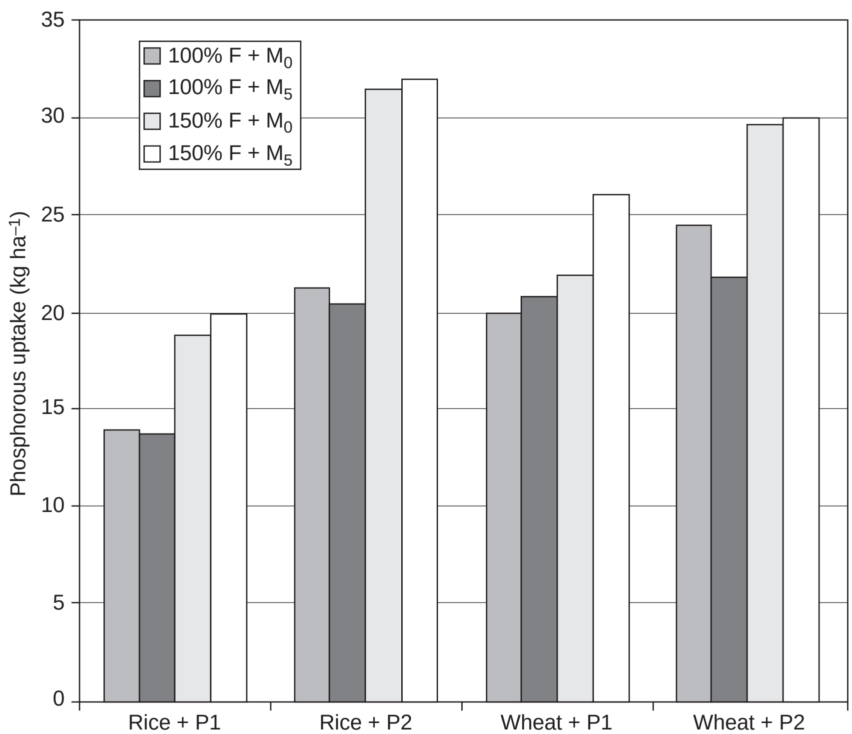

Figure 2. Phosphorus uptake (kg ha^{-1}) in rice and wheat as influenced by rates of fertilizer N and manure (M) application, and planting density (based on the mean data of two crop cycles).

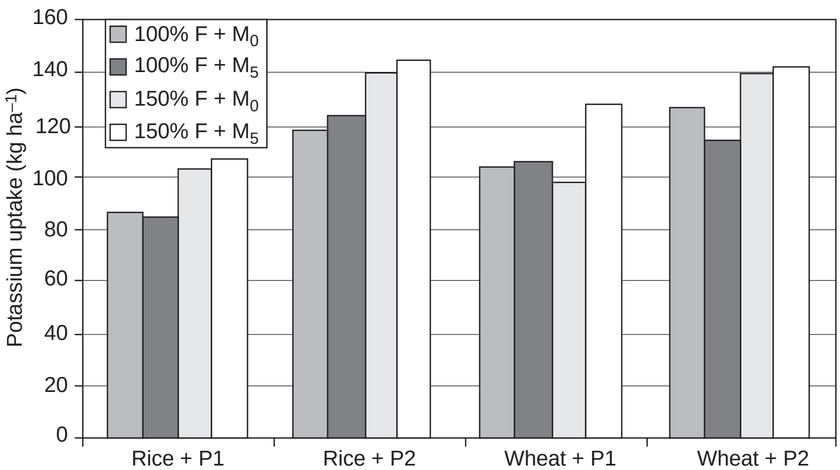

Figure 3. Potassium uptake (kg ha^{-1}) in rice and wheat as influenced by rates of fertilizer N and manure (M) application, and planting density (based on mean data of two crop cycles).

NPK from 100% to 150% and plant population from P_1 to P_2 planting density both in rice and wheat (Figure 2). The effects of M application on enhancing P uptake, however, were significant only at 150% F with P_1 planting density compared to that in other treatments in both the crops.

K uptake increased significantly with increasing levels of fertilizer NPK from 100% to 150% (Figure 3). The effect of applied M over no M for enhancing K uptake, however, was not significant compared with that under all other treatments except in wheat at P_1 planting density.

Output:input ratios of N, P and K

The output:input ratios of N, P and K in both the crops were greater in plots having P_2 planting density compared with that with P_1 planting density (Table 2). In general, the ratios decreased with the increase in the fertilizer dose from 100% F to 150% F. For N and P, however, they did not differ significantly due to different treatment combinations tested in the present study.

The output:input ratios for K in rice and wheat, however, differed significantly due to different treatments. They increased with increasing planting density, and decreased significantly with increasing levels of fertilizer NPK inputs, either alone or with M (Table 2).

Soil organic C, N, P and K

Soil organic C, after two cycles of rice-wheat rotation, declined over initial status in all treatments (Table 3). The magnitude of decrease, however, was greater in plots of P_2 planting density having 100% F with and without M, and 150% F without M, compared with that in other plots. Total N content, on the

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Table 2. Output:input ratios of N, P and K in rice and wheat in the rice-wheat rotation as influenced by planting density (P_1 and P_2), rates of fertilizer NPK (100% F and 150% F) and manure (no M and M) application (mean of two crop cycles of rice-wheat rotation).

Crops	P_1				Mean	P_2				Mean
	100% F		150% F			100% F		150% F		
	M_0	M_5	M_0	M_5		M_0	M_5	M_0	M_5	
					Nitrogen					
Rice	0.48	0.39	0.40	0.36	0.41	0.77	0.61	0.66	0.58	0.66
Wheat	1.08	0.88	0.74	0.81	0.88	1.29	0.93	0.95	0.91	1.02
Total	0.78	0.63	0.57	0.58	0.64	1.03	0.77	0.84	0.74	0.84
LSD 5%, rice = 0.444 (NS), wheat = 0.796 (NS), total = 0.732										
					Phosphorus					
Rice	0.53	0.37	0.48	0.37	0.44	0.81	0.49	0.80	0.59	0.68
Wheat	0.77	0.50	0.55	0.48	0.58	0.93	0.52	0.75	0.55	0.69
Total	0.65	0.43	0.51	0.42	0.51	0.87	0.51	0.77	0.57	0.68
LSD 5%, rice = 0.472 (NS), wheat = 0.652 (NS), total = 0.548 (NS)										
					Potassium					
Rice	2.61	1.33	2.09	1.34	1.85	3.57	1.95	2.83	1.82	2.55
Wheat	2.42	1.66	1.99	1.60	2.17	3.81	1.79	2.82	1.78	2.56
Total	2.86	1.50	2.04	1.47	1.97	3.69	1.87	2.82	1.80	2.55
LSD 5%, rice = 0.124, wheat = 0.088, total = 0.116										

NS = not significant

Table 3. Soil organic C, total N, available P and K contents after two crop cycles of the rice-wheat rotation and changes over initial content as influenced by planting densities (P_1 and P_2), rates of fertilizer NPK (100% F and 150% F) and manure (no M and M) application.

Treatment	Organic C (%)		Total N (%)		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	Final	% change over initial (i.e. 0.44%)	Final	% change over initial (i.e. 0.021%)	Final	% change over initial (i.e. 18 kg ha^{-1})	Final	% change over initial (i.e. 168 kg ha^{-1})
P_1, 100% F, M_0	0.41	−6.8	0.023	9.5	10.0	−44.4	161.0	−4.2
P_1, 100% F, M_5	0.37	−15.9	0.024	14.3	14.0	−22.2	163.0	−1.8
P_1, 150% F, M_0	0.41	−6.8	0.026	23.8	18.0	0.0	169.0	0.6
P_1, 150% F, M_5	0.41	−6.8	0.028	33.3	18.0	0.0	168.5	0.3
P_2, 100% F, M_0	0.30	−31.8	0.024	14.3	11.0	−38.9	163.0	3.0
P_2, 100% F, M_5	0.30	−31.8	0.026	23.8	16.0	−11.1	165.5	−1.5
P_2, 150% F, M_0	0.30	−31.8	0.027	28.6	18.0	0.0	169.0	0.6
P_2, 150% F, M_5	0.37	−15.9	0.0290	38.1	18.0	0.0	168.0	0.0
LSD 5%	0.004		0.0068		1.88		1.92	

other hand, increased over initial status under all the treatments. The magnitude of increase, however, was the largest in plots of P_2 planting density with 150% F + M treatment. Available P and K contents either remained unchanged or decreased. The rate of decrease was the largest in plots of P_1 planting density and 100% F without M treatments.

Nutrient balances

After two years of continuous rice-wheat cropping at a fixed site, a negative N balance of 54 kg ha^{-1} was observed in plots of P_1 planting density, and 87 kg ha^{-1} in plots of P_2 planting density. In the plots of P_2 planting density (Figure 4), the extent of negative balance of N, however, was reduced by the addition of M.

Available P content showed a positive balance in all plots except P_1 planting density with 100% F treatment (Figure 5). The positive balance was significantly greater in plots treated with 150% F than that with 100% F. The balance increased further by addition of manure.

The balance of available K was negative in all treatments (Figure 6). The negative balance, however, was smaller in plots of P_1 planting density than that in P_2 planting density.

DISCUSSION

Soil organic C content decreased and total N content increased due to continuous cultivation of the rice-wheat rotation at a fixed site for two years, resulting in the lowering of the C:N ratio. As a consequence, soil nutrients might have become more readily available to crop plants. This may be seen by greater uptake of nutrients by the crops. Total uptake of N, P and K varied between 411 kg ha^{-1} at the smallest yield levels in plots receiving $P_1 + 100\%$ F treatment to 659 kg ha^{-1} under largest yields obtained in the plots of $P_2 + 150\%$ F + M treatment. The nutrient use efficiencies, as indicated by the output:input ratios of N, P, and K, were 74% for N, 57.5% for P and 180% for K in plots of $P_2 + 150\%$ F + M treatment, and 78% for N, 65% for P and 286% for K in plots of $P_1 + 100\%$ F treatment. From the greater than 100% efficiency of K, and the greater than earlier reported efficiencies of N and P in rice and wheat (Saha *et al.*, 2000; Prasad and Sinha, 2000), it may be inferred that the crops might have also utilized native soil nutrients in the present study. As far as K is concerned, it might have been made available from the non-exchangeable pool and from additions through irrigation water. Since the non-exchangeable fraction is a potential source of available K and contributes more than 50% to the total K

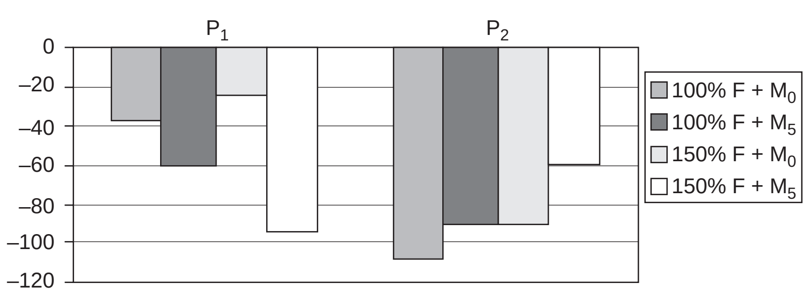

Figure 4. Apparant balance of N (kg ha^{-1}) after two cycles of rice-wheat rotation at a fixed site as influenced by rates of fertilizer N and manure (M) application, and P_1 and P_2 planting densities.

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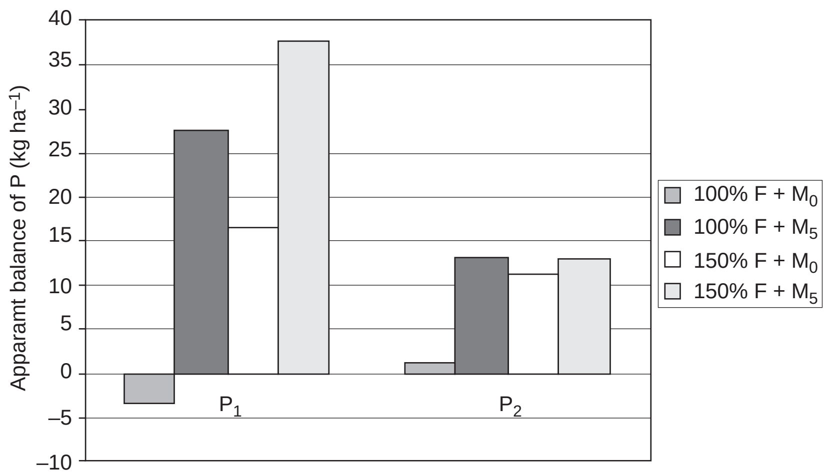

Figure 5. Apparant balance of phosphorus (kg ha^{-1}) after two cycles of rice-wheat rotation at a fixed site as influenced by rates of fertilizer N and manure (M) application, and planting densities.

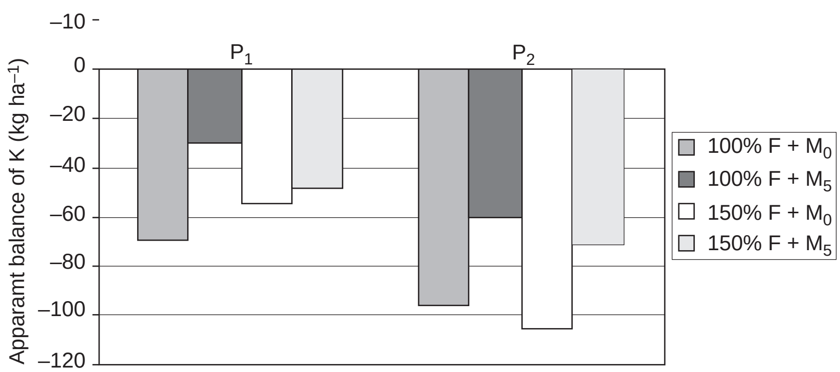

Figure 6. Apparant balance of K (kg ha^{-1}) after two cycles of rice-wheat rotation at a fixed site as influenced by rates of fertilizer N and manure (M) application, and planting densities.

uptake in rice-wheat systems (Tiwari *et al.*, 1992), significant K release from this pool can mask the dynamics of the initial pool of available K. This is particularly true in alluvial soils, such as those of the Indo-Gangetic plains, with high K-fixing capacity owing to the presence of illite as the dominant clay mineral (Tandan and Sekhon, 1988).

The apparent negative balances of N as observed in the present study, may be explained on the basis of the study of Shrestha and Ladha (1998) who found that due to alternate soil wetting (anaerobic conditions in rice season) and drying (aerobic condition in wheat season) in the rice-wheat system, soil N mineralized and nitrified at the onset of monsoon rains in June, is lost by leaching and by denitrification when the soil becomes submerged for rice. In the study of Tripathi

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Table 4. Correlation coefficients (r-values) between output:input ratios of N, P and K, and grain yields of rice and wheat under P_1 and P_2 planting densities.

Crop	P_1 planting density			P_2 planting density		
	N	P	K	N	P	K
Rice	0.593*	0.469*	0.159	0.643*	0.531*	0.133
Wheat	0.617*	0.513*	0.182	0.686*	0.561*	0.155

* Significant at 0.05 probability.

et al. (1997), N losses in farmer's fields ranged from 240 kg ha^{-1} with a dry season tobacco crop to 575 kg ha^{-1} with a sweet-pepper crop. Much of this N leached into groundwater in the sweet-pepper area.

The highest productivity of the rice-wheat system, i.e. 15.8 t ha^{-1} in plots receiving $P_2 + 150\%$ F + M treatment, was almost equal to the potential yield of the region as simulated by Aggarwal *et al.*, (2000). This level of yield was also significantly greater than that obtained in plots having $P_1 + 150\%$ F + M treatment. Greater yields under closer planting may be due to the closer configuration of plants (200×100 mm) that resulted in increased plant population density (50 hills m^{-2}) compared with 25 hills m^{-2} under P_1 density (i.e. 200×200 mm). Increased plant populations may have utilized solar radiation more efficiently for absorption of nutrients under the higher planting density (Rathi *et al.*, 1984; Raghuvanshi, *et al.*, 1986; Narang and Gill, 2000). Inadequate plant populations with P_1 density may also have not been able to utilize soil nutrients fully (Chauadhary and Harrington, 1993). The output:input ratios of N and P have correlated positively with grain yields in rice and wheat (Table 4). The values of correlation coefficients, however, were greater under P_2 than under P_1 planting density.

The grain yield data presented in Table 1 indicated that, at P_1 planting density, increasing levels of N, P and K from 100% to 150% increased the yields by only 2.7%, but at P_2 planting density, the corresponding increase in the yield was 10.5%. Manure application with 150% F under P_1 density increased the yields by 7.2% over those obtained with 100% F + M treatment, but under P_2, 150% F + M treatment increased the yields by 20.5% over those obtained with $P_1 + 100\%$ F + M treatment. From these data, it was inferred that the response to manure application increases with increasing levels of mineral fertilizers and planting densities.

From the above discussion, it was concluded that to obtain greater responses to higher doses of mineral fertilizers in the rice-wheat system, application of manures is essential, and to realize the potential yields of the system, planting densities may also have to be increased along with increasing levels of mineral fertilizers and manures.

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