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ON-FARM EXPERIMENTS ON INTEGRATED NUTRIENT MANAGEMENT IN RICE-WHEAT CROPPING SYSTEMS

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SUMMARY

On-farm experiments were conducted between 1990–91 and 1996–97 in the Indian districts of Jalandhar (Punjab) and Ghazipur (Uttar Pradesh), on rice-wheat cropping systems. The aim was to compare yields and net returns from three treatments: (i) farmers' nutrient management practices; (ii) integrated use of organic manures and fertilizer; and (iii) NPK fertilizer inputs alone. Productivity of the rice-wheat systems, in terms of grain yield per unit area, was greater in Jalandhar district than in Ghazipur district. In Jalandhar, a high productivity zone, greatest yields were achieved with integrated use of green manure and fertilizer NPK inputs, while in Ghazipur, a low productivity zone, yields were highest with inputs of fertilizer NPK alone. Increases in yield due to these improved practices, over farmers' practice, were 6.98% in Jalandhar and 46.6% in Ghazipur. At both locations, net returns were greater with the use of fertilizer NPK alone. However, benefits from NPK alone over farmers' practice were 6.96% in Jalandhar and 79.6% in Ghazipur. After 11 years of a long-term experiment, at Ludhiana (Punjab) and Faizabad (Uttar Pradesh) soil organic-C and available phosphorus contents have increased, and available potassium content decreased compared with the initial levels.

INTRODUCTION

Rice-wheat crop rotation, in the Indo-Gangetic plain region of four south Asian countries, India, Pakistan, Nepal and Bangladesh, is practised with different management regimes in different areas. Farmers in the trans- and upper-Gangetic plain regions of India (Punjab, Haryana and western Uttar Pradesh province) manage the system with relatively high use of inputs and irrigation compared with eastern India, Bangladesh and Nepal, where the system is practised by subsistence farmers whose resource base is small and whose physical access to supply markets is limited. They, therefore, are not able to take full advantage of technologies that depend on purchased inputs. In both regions, organic manures are important to enhance use-efficiency of purchased fertilizer inputs in the former and in the latter to serve as an alternative source of nutrients to mineral fertilizers. Evidence from on-station experiments shows that high and sustainable yields are possible with integrated use of fertilizers and manures (Mahapatra *et al.*, 1991; Bhandari *et al.*, 1992; Kumar and Yadav, 1995; Abrol *et al.*, 1997). In spite of these results however, integrated nutrient management practices have not become popular with the farmers. Probably farmers are concerned mostly with total profit and the

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marginal benefit:cost ratio from investment in labour and inputs, and might not be easily convinced by the economics of applying manures. Therefore, the present communication compares net returns and yields achieved by integrated use of organic manures and fertilizer NPK, application of inorganic fertilizer NPK alone, and farmers' fertilizer management practices in the rice-wheat systems. Changes in soil organic carbon content were also measured in on-station long-term experiments being conducted near the location of the on-farm experiments under the Network Research Programmes of the Project Directorate For Cropping Systems Research.

MATERIALS AND METHODS

Study area

The data analysed in this study were taken from the on-farm experiments conducted between 1990–91 to 1996–97 in Punjab and Uttar Pradesh provinces of India under the Experiments on Cultivators' Fields (ECF) programme of the Project Directorate for Cropping Systems Research.

The on-farm experiments were conducted in Jalandhar district in Punjab and Ghazipur district in Uttar Pradesh; for present purposes these districts will be referred to simply as Jalandhar and Ghazipur. In these districts, most farmers have been practising an annual rice-wheat double cropping system for the past 15–20 years. The cropping intensity in Punjab is 181% and in Uttar Pradesh, 149%, and the area under irrigation in Punjab is 94.9% and in Uttar Pradesh 62.6%. Average size of land holding in Punjab is 3.61 ha and in Uttar Pradesh 0.50 ha. During 1996–97, consumption of fertilizer NPK in Jalandhar was 37 048 t in the rice-growing season and 33 615 t in the wheat-growing season. In Ghazipur, 21 520 t fertilizer NPK were consumed during the rice-growing season and 32 650 t in the wheat-growing season (Anon, 1997).

Climatologically, Jalandhar is in the arid sub-tropical zone having cool winters in which temperatures occasionally drop below freezing point. In summer months (particularly May), temperatures may rise to 45°C. Average annual rainfall is 450 mm, and open-pan evaporation varies from less than 1.00 mm d^{-1} in winter to 16 mm d^{-1} in summer. The climate is suitable for the cultivation of rice, wheat, sugarcane, potatoes, mustard and sunflower.

Ghazipur is in the sub-humid sub-tropical zone where temperatures during winter (December–January) fall as low as 5–7°C, and during summer (May–June) rise to 40°C. Average annual rainfall is 1200 mm. The climate is suitable for growing rice, wheat, maize, millets and pulses.

Jalandhar soils, of alluvial origin derived mostly from the Sutlej and Beas rivers, are Entisols and Inceptisols, mostly young, deep, coarse textured, well drained but low in organic matter content. The soils of Ghazipur are also alluvial Entisols and Inceptisols. They are deep, but moderately to poorly drained, neutral to slightly alkaline in reaction with calcareousness in pockets, coarse- to fine-textured and low in organic matter content (Sehgal *et al.*, 1990).

On-farm experiments

The on-farm experiments were conducted every year on the fields of 28 farmers in 7 villages in Jalandhar and on the fields of 30 farmers in 6 villages in Ghazipur. Thus, every year 58 farmers' fields were used in this study. Each year, fields selected for on-farm experiments belonged to different farmers, i.e. farmers' fields were moving fields. The source of irrigation in both the districts was tube-wells. However, in Ghazipur, rice was grown as a rainfed crop.

Farmers grow transplanted rice with only 120 kg N ha^{-1} in Jalandhar and 60 kg N ha^{-1} in Ghazipur. Succeeding wheat is grown with irrigation and 120 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1} in Jalandhar and 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1} in Ghazipur. The average grain yields of rice in Jalandhar are 3132 kg ha^{-1} and in Ghazipur 1867 kg ha^{-1}. Average wheat grain yields are 3877 kg ha^{-1} in Jalandhar and 2458 kg ha^{-1} in Ghazipur.

Within each farmer's field, four 10 × 15 m plots were established, and each plot was allotted one treatment. The treatments in Jalandhar were:

T_1 = Farmers' practice as described above;
T_2 rice = 100% NPK i.e. 120 kg N, 30 kg each of P_2O_5 and K_2O;
T_2 wheat = 120 kg N, 60 kg each of P_2O_5 and K_2O ha^{-1};
T_3 rice = 10 t ha^{-1} farmyard manure (FYM) + 50% NPK;
T_3 wheat = 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1};
T_4 rice = Green manuring (GM) before rice transplanting + 50% level of fertilizer NPK;
T_4 wheat = Green manuring (GM) before rice transplanting + 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1}.

The treatments in Ghazipur were:

T_1 = Farmers' practice as described above;
T_2 = 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1} to both rice and wheat;
T_3 = as for Jalandhar;
T_4 = as for Jalandhar.

Urea (46.4% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O) were used to supply N, P and K respectively. Farmers were responsible for all other crop management operations. Researchers, however, recorded the energy and inputs used and labour employed in each treatment to calculate cost of cultivation. Grain yields were measured from a sample area of 4 × 8 m in each plot.

Economic analysis

Economic evaluation of different treatments was made through marginal analysis. For this, the cost of cultivation (CC) of rice and wheat was calculated on the basis of following operations performed and materials used for growing the crops. For rice, the operations and materials used were: seed (35 ± 5 kg ha^{-1}), growing rice seedlings and their maintenance (Rs 100 ± 20), transplanting of rice seedlings in field (35 ± 5 labourers ha^{-1}), puddlings for rice (2 ± 1 harrowing, and 1 irrigation), irrigation (20 ± 2 at Jalandhar, and nil at Ghazipur), fertilizer use (as per treatment), harvesting (manual with 30 ± 5 labourers ha^{-1}) and threshing (manual with 25 ± 5 labourers). For wheat, the operations and materials used were: seed (100 ± 20 kg ha^{-1}), seedbed preparation (1 ploughing, 4 ± 3 harrowings), sowing operation (1 tilling), irrigation (4 ± 2), weedicide application (Rs. 400 ± 100 ha^{-1}), harvesting (manual with 30 ± 5 labourers ha^{-1}) threshing (on thresher with 2 ± 1 labourers). The prices of different materials used and operations performed are presented in Table 1, and cost of cultivation derived therefrom in Table 2. The cost of rice and wheat seed was double the prices of their grains. For growing a green manure crop, the operations and materials used were: seed (30 ± 5 kg ha^{-1}); sowing (1 harrowing); irrigation (2 ± 1, one pre-sowing and one or two during crop growth); and turning and mixing into the soil (1 harrowing).

Gross returns (GR) were calculated by multiplying grain yield by grain price. Net returns (NR) were calculated as:

$$NR = [GR] - [CC] \tag{1}$$

Marginal returns (MR) from the given fertilizer management practice over the farmers' practice were calculated as:

$$MR = [(NR_t - NR_f) \div (CC_t - CC_f)] \times [100] \tag{2}$$

where NR_t is net returns from given fertilizer treatment, t; NR_f is net returns from farmers' practice, CC_t is cost of cultivation of given fertilizer treatment, t; and CC_f is cost of cultivation in farmers' practice.

In the marginal analysis, any treatment with a lower net return and higher cost of cultivation than farmers' practice was termed 'dominated' (D).

Changes in soil organic C

Every year, before commencement of the on-farm experiments, soil samples were taken at soil depths between 0–15 cm at 5 sites in each farmer's field. The samples

Table 1. Prices (Rs kg^{-1}) of rice and wheat grains and plant nutrients, supplied through fertilizers and farmyard manure (FYM), and cost (Rs. $unit^{-1}$) of ploughing/harrowing, irrigation and labour wages during different years.

Year	Rice grain	Wheat grain	*Sesbania* seed	N	P_2O_5	K_2O	FYM	Labour wage	Ploughing/ harrowing	Irrigation charges
1990–91	2.05	2.25	5.50	7.17	8.38	3.03	0.10	20.0	100	60
1991–92	2.30	2.50	5.50	6.65	7.75	2.83	0.11	30.4	115	60
1992–93	2.70	3.30	6.00	6.00	7.75	2.83	0.13	35.9	115	80
1993–94	3.10	3.50	6.50	6.00	7.75	2.83	0.15	48.6	120	80
1994–95	3.40	3.60	6.50	7.22	12.18	5.94	0.15	57.5	120	90
1995–96	3.60	3.80	7.50	7.22	16.26	6.03	0.15	58.1	120	90
1996–97	3.80	4.15	8.00	7.96	14.92	6.19	0.16	64.6	120	90

Table 2 Cost of cultivation (Rs. ha^{-1}) for rice and wheat under different treatments in Jalandhar and Ghazipur districts during different years.

	Rice				Wheat			
Year	Farmers' practice	NPK only	FYM + 50% NPK	GM + 50% NPK	Farmers' practice	NPK only	FYM + 50% NPK	GM + 50% NPK
				Jalandhar				
1990–91	4573	4915	5314	4799	3935	3935	3935	3935
1991–92	5466	5783	6326	5741	4295	4295	4295	4295
1992–93	6482	6799	7581	6815	4659	4659	4659	4659
1993–94	7786	8103	9085	8181	5155	5155	5155	5155
1994–95	9050	9593	10 389	9505	6142	6142	6142	6142
				Ghazipur				
1990–91	2943	3996	4255	3739	3874	3874	3874	3874
1991–92	3867	4843	5256	4669	4238	4238	4238	4238
1992–93	4522	5459	6111	5381	4602	4602	4602	4602
1993–94	5826	6763	7815	6710	5098	5098	5098	5098
1994–95	6817	8218	8801	7916	6015	6015	6015	6015
1995–96	6889	8579	9018	8163	6364	6364	6364	6364
1996–97	7596	9217	9768	8787	6615	6615	6615	6615

from each field were pooled, mixed thoroughly and a representative homogeneous sample drawn for the analysis of organic carbon, and available N, P and K, following Jackson (1973). The data from 25 farmers' fields are reported here.

The long-term consequences of integrated nutrient management practices on soil organic carbon content were also studied through on-station long-term experiments conducted at Ludhiana in Punjab (30.56°N, 75.52°E, 247 m asl) and Faizabad in Uttar Pradesh (24.26°N, 80.12°E, 113 m asl). The climate at Ludhiana is arid sub-tropical with hot, dry summers and cool winters. Annual precipitation is 500 mm and potential evapotranspiration 1500 mm. The soils are typic Ustochrepts, alluvial sandy loams. Faizabad has a semi-arid sub-tropical climate with severe hot summers and fairly cool winters. The annual rainfall is 1100 mm and the soils are silty loam alluvial Inceptisols.

Before commencement of the long-term experiments at Ludhiana (1983–84) and at Faizabad (1984–85), soil from the 0–15 cm layer of the experimental fields were analysed for organic C, available P and K, as per Jackson (1973). The experiment, which is still continuing, has 12 treatments in a randomized block design with four replications. For the present study, however, data from only 4 treatments were considered. These treatments were: (i) control (unfertilized); (ii) recommended level of fertilizer NPK, i.e., 120 kg N, 60 kg P_2O_5 and 40 kg K_2O per ha to both the crops; (iii) 10 t ha^{-1} FYM to rice with 50% levels of recommended dose of NPK + recommended dose of fertilizer NPK to succeeding wheat; and (iv) *Sesbania aculeata* green manuring before rice transplanting with 50% doses of fertilizer NPK to rice + recommended dose of fertilizer NPK to succeeding wheat. The fertilizers used were urea, single super phosphate and muriate of potash. After 11 years, soil samples were drawn again from the 0–15 cm soil layer in each plot and analysed for organic C, available P and K, following Jackson (1973).

In this long-term experiment on the rice-wheat system, each year rice was transplanted in July using two seedlings per hill at 20 × 10 cm spacing. After harvesting the rice, wheat was sown in November using 100 kg seed ha^{-1} in rows 23 cm apart. The plot size was 6 × 5 m. Grain yield, however, was recorded from a net plot size of 5 × 4 m. Other crop management practices have already been described by Yadav *et al*. (2000).

Statistical analysis

The data were analysed using standard procedures for randomized block designs (Cochran and Cox, 1957) to compare treatment means each year at a given location. The number of farmers' fields were considered replications for the purpose of statistical analysis. The analysis thus was based on 112 observations (4 treatments × 4 farmers × 7 villages) in Jalandhar and 120 observations (4 treatments × 5 farmers × 6 villages) in Ghazipur. In the analysis of variance (ANOVA), the degrees of freedom (*d.f.*) were partitioned as: replications = 27, treatments = 3, error = 81 at Jalandhar, and replications = 29, treatments = 3 and error = 87 at Ghazipur. For comparison, least significant differences (LSD) between two means were calculated.

RESULTS

Grain yield

The data presented in Table 3 indicate that yields in the rice-wheat systems were greater in Jalandhar than in Ghazipur. With farmers' nutrient management practices, the yields were 74.9% higher in Jalandhar than in Ghazipur for rice, and 54.6% higher for wheat.

In Jalandhar, which may be considered a high-productivity zone, rice yielded most when fertilized with green manure + 50% of the recommended NPK doses in 3 out of 5 years of the experiment. In the remaining 2 years, however, yields were greatest with sole fertilizer NPK inputs compared with other treatments. The differences in yield between green-manured plots and NPK-treated plots, however, were significant only during 1994–95. The advantages in yield due to green manuring and fertilizer NPK application compared with farmers' practice, were 6.98% and 6.31% respectively.

In Ghazipur, which may be considered a low-productivity zone, rice yielded significantly more when fertilized solely with fertilizer NPK inputs compared with other treatments. The yield advantage due to sole NPK application over farmers' practice, however, was 46.6%.

At both the locations, wheat yielded significantly more when the preceding rice crop received complete doses of NPK, either through fertilizers alone or with integrated use of manures and fertilizers, compared with farmers' practice.

Table 3. Grain yields (kg ha^{-1}) of rice and wheat when grown in sequence with different integrated nutrient management practices in on-farm experiments conducted in Jalandhar and Ghazipur districts, India, during different years.

	Rice					Wheat				
Year	Farmers' practice	NPK only	FYM + 50% NPK	GM + 50% NPK	LSD 5%	Farmers' practice	NPK only	FYM + 50% NPK	GM + 50% NPK	LSD 5%
				Jalandhar						
1990–91	4173	4876	4698	4821	205.2	3291	4179	4394	4246	81.3
1991–92	5566	5858	5895	6044	124.4	4836	4745	4795	4822	49.8
1992–93	5874	5982	5860	6277	94.7	4676	4682	4935	4736	27.2
1993–94	6551	6654	6558	6918	46.9	4894	4850	5025	4916	23.6
1994–95	4273	4672	4088	4153	52.3	5393	5890	5468	5424	36.4
Mean	5275	5608	5420	5643	165.6	4608	4873	4915	4829	216.2
				Ghazipur						
1990–91	3524	4491	4350	4481	111.3	3231	4426	4241	4311	105.3
1991–92	3060	4437	4174	4261	105.5	3091	4321	4105	4149	83.7
1992–93	2728	4137	3853	3918	83.4	2702	3956	3118	3737	132.2
1993–94	3314	4180	3764	3879	131.2	2884	3751	3841	3763	94.5
1994–95	2927	4612	3952	4107	204.1	3027	4117	4563	4243	243.1
1995–96	2650	4082	3973	3902	88.7	2767	4044	4059	3993	100.3
1996–97	3112	5001	4478	4644	131.2	3157	3951	4236	4019	178.5
Mean	3015	4420	4078	4170	108.4	2980	4079	4023	4037	288.2

In the long-term experiment at Ludhiana, rice yielded significantly more in plots receiving sole NPK or GM + NPK in the first cycle of the rice-wheat system compared with those receiving FYM + NPK and no fertilizer or manure, i.e. control (Table 4). In the eleventh cycle, however, yields were significantly greater in plots receiving complete doses of NPK through fertilizers, compared with other treatments. The yields, in the eleventh cycle, were greater than those in the first cycle by 22% in NPK-treated plots, 28% in FYM + NPK plots and 16% in GM + NPK-treated plots (Table 4). In both the cycles, wheat yielded significantly more when the preceding rice crop received FYM + NPK, compared with other treatments. However, wheat yields in the eleventh cycle were greater than those of the first cycle by 13.6% in NPK-treated plots, 23.7% in FYM + NPK-treated plots and 7% in GM + NPK-treated plots.

At Faizabad, rice yields in the first cycle were significantly greatest when the crop was fertilized solely with fertilizer NPK. In the eleventh cycle, however, they were greatest in plots treated with FYM + NPK. Wheat yields, however, were significantly highest in plots treated with GM + NPK in the first cycle, and in the plots treated with FYM + NPK in the eleventh cycle. The wheat yields in the eleventh cycle, however, were lower than those of the first cycle by 9.1% in sole NPK-treated plots, 8.2% in FYM + NPK-treated plots and 14.4% in GM + NPK-treated plots.

Table 4. Grain yields (kg ha^{-1}) of rice and wheat in the first and the final cycles of an 11 year rice-wheat system under different treatments of applied fertilizer and manure at Ludhiana and Faizabad.

	Ludhiana			*Faizabad*		
Treatment	First 1983–84	Final 1993–94	% change	First 1984–85	Final 1994–95	% change
			Rice			
Control	2145	1775	−17.2	2004	1403	−30.0
NPK	4570	5569	21.9	4594	4541	−1.2
FYM + NPK	4102	5272	28.5	3258	5107	56.8
GM + NPK	4585	5333	16.3	3285	4554	38.6
SE	210.3	196.1		82.7	122.5	
			Wheat			
Control	971	1358	39.9	1848	681	−63.1
NPK	3646	4142	13.6	4512	4102	−9.1
FYM + NPK	3918	4856	23.7	4688	4304	−8.2
GM + NPK	3858	4134	7.2	4887	4184	−14.4
SE	15.6	103.2		93.4	70.8	

Economic analysis

At both the on-farm experiment locations, mean data over the years indicated that application of complete doses of NPK through fertilizer alone resulted in significantly greater net returns compared with other nutrient management practices (Table 5). Compared with farmers' practice, the net returns from NPK application were higher by 6.96% in Jalandhar and by 79.6% in Ghazipur.

The data for individual years, however, indicated that in Jalandhar, GM + 50% NPK inputs gave greater net returns than the other treatments in 4 out of 5 cycles, and in Ghazipur, fertilizer NPK inputs alone gave the greatest net returns in all the 7 cycles.

Marginal analysis of different treatments, presented in Table 6, indicated that in Jalandhar the FYM treatment 'dominated' in 4 cycles, and green manuring and fertilizer NPK treatments 'dominated' in one cycle each out of 5 cycles of the rice-wheat systems. Such analysis performed on mean data of 5 cycles, for cost of cultivation and net returns, however, indicated that for every extra rupee invested on sole NPK application, farmers earned Rs. 3.25, and for every extra rupee spent on green manuring they earned Rs. 3.09. In Ghazipur, marginal returns were greater with green manuring than with the application of fertilizer NPK alone, in 6 out of 7 cycles of the experiment. On the basis of mean data of all the 7 years, it was found that farmers earned Rs. 5.97 for every extra rupee spent on green manuring, and Rs. 5.23 for every extra rupee spent on sole fertilizer NPK application.

Changes in soil organic carbon and available P and K

At Ludhiana, organic C content measured after 11 years of the long-term rice-wheat system was found to have increased over the initial content (Table 7). The

Table 5. Total cost of cultivation (Rs ha^{-1}) and net returns (Rs ha^{-1}) from rice-wheat system under different treatments of fertilizer management practices in Jalandhar and Ghazipur districts during different years of the on-farm experiment.

Year	Cost of cultivation					Net returns				
	Farmers' practice	NPK only	FYM + 50% NPK	GM + 50% NPK	LSD 5%	Farmers' practice	NPK only	FYM + 50% NPK	GM + 50% NPK	LSD 5%
					Jalandhar					
1990–91	8508	8850	9249	8734	105.5	7325	10 549	10 167	10 702	203.4
1991–92	9761	10 078	10 621	10 036	227.4	15 130	15 257	14 924	15 920	155.6
1992–93	11 141	11 458	12 240	11 510	405.3	20 129	20 143	19 867	21 062	147.5
1993–94	12 941	13 258	14 240	13 336	203.8	24 338	24 344	23 676	25 304	266.3
1994–95	15 192	15 735	16 531	15 647	118.2	18 750	21 350	17 052	17 999	208.6
Mean	11 509	11 876	12 576	11 853	136.5	17 134	18 329	17 137	18 167	109.2
					Ghazipur					
1990–91	6817	7870	8129	7613	159.1	7676	11 294	10 230	11 272	243.2
1991–92	8105	9081	9494	8907	118.5	6660	11 926	10 368	11 370	215.4
1992–93	9124	10 061	10 713	9983	166.8	7157	14 162	9969	12 927	297.1
1993–94	10924	11 861	12 713	11 808	103.3	9443	13 390	12 398	13 386	148.3
1994–95	12 832	14 233	14 816	13 931	145.4	8186	16 268	15 046	15 306	199.6
1995–96	13 252	14 943	15 382	14 527	112.2	6801	15 119	14 344	14 693	187.2
1996–97	14 211	15 832	16 383	15 402	202.1	10 715	19 567	18 212	18 923	169.4
Mean	10 752	11 983	12 519	11 739	128.5	8091	14 532	12 940	13 982	142.3

magnitude of increase, however, was greater (55.9% over initial 0.311%) in plots treated with FYM + NPK compared with other treatments. At Faizabad, soil organic C content in unfertilized plots decreased by 45.9% over an initial 0.37% but increased by 8.1% in NPK-treated plots to 35.1% in FYM + NPK- and GM + NPK-treated plots.

At both the locations, within 11 years of continuous rice-wheat systems, available phosphorus content decreased in unfertilized control plots but increased in plots receiving manures plus 50% doses of fertilizer NPK. Available potassium content, however, decreased in all the plots.

On farmers' fields, during the period of experimentation, soil organic C content ranged between 0.51% and 0.68% in Jalandhar and between 0.47% and 0.71% in Ghazipur (Table 8). At both the locations, soil organic C tended to increase under rice-wheat cropping. Available N content (measured only in Jalandhar) also exhibited an increasing trend (Table 8). Available K content remained almost stable in Jalandhar but decreased markedly in Ghazipur (Table 9).

DISCUSSION

The yields of rice-wheat systems were greater in Jalandhar (Punjab) than in Ghazipur (eastern Uttar Pradesh) primarily because of differences in climate, farmers' socio-economic conditions and infrastructure development. In Jalandhar

Table 6. Marginal analysis (%) of improved fertilizer management method versus farmers' practices in rice-wheat systems during different years of on-farm field experiments in Jalandhar and Ghazipur, India.

	Fertilizer management practices		
Year	NPK only	FYM + 50% NPK	GM + 50% NPK
		Jalandhar	
1990–91	942.6	383.5	14.94
1991–92	40.0	D	287.2
1992–93	4.4	D	252.8
1993–94	D	D	244.5
1994–95	478.8	D	D
Mean	325.6	0.3	309.0
		Ghazipur	
1990–91	343.5	194.6	451.7
1991–92	539.5	266.9	587.3
1992–93	747.5	177.6	671.7
1993–94	421.2	165.2	446.0
1994–95	576.9	345.8	647.9
1995–96	491.9	354.1	619.0
1996–97	546.1	354.2	689.2
Mean	523.2	274.4	596.9

D = 'dominated' where net returns were low and cost of cultivation was higher than for farmers' practice.

environmental conditions are suited to wheat cultivation, the irrigation infrastructure is good for cultivating rice, and marketing facilities are available. The low yields recorded in Ghazipur were associated with a partially irrigated and rainfed situation, and a shorter growing period for wheat (Aggarwal and Kalra, 1994). The skewed distribution of land and the higher incidence of crop-sharing tenancy arrangements may also be responsible for low yields in eastern Uttar Pradesh (Ladha *et al.*, 2000).

In the high-yield zone of Jalandhar, green manuring was the superior practice for enhancing grain yields of the system, compared with other nutrient management practices, in 3 out of 5 years of the experiment. That yields were the greatest with FYM application in the remaining 2 years may have been because the efficiency of fertilizer NPK increases when it is used in conjunction with organic manures, particularly the green manures (Yadav *et al.*, 2000). Green manuring also has other beneficial effects such as: (i) green manure N is as efficient as fertilizer N (urea) in rice (Ladha and Kundu, 1997); and (ii) higher root density of wheat due to improved physical conditions of the soil enhances nutrient absorption by the crop and thereby improves biological yield at a given level of fertilizer application (Mahapatra and Sharma, 1989; Boparai *et al.*, 1992).

Moreover, because of high yields in Jalandhar, rice-wheat cropping might be depleting soil micro-nutrients continuously without being replenished adequately every year (Hegde and Sarkar, 1992). In such situations, by increasing water-

Table 7. Changes in soil organic carbon and available phosphorus and potassium from initial to final years of an 11-year continous rice-wheat cropping system under different treatments of fertilizer and manure application at Ludhiana and Faizabad.

	Ludhiana			*Faizabad*		
Treatment	Initial	Final	% change	Initial	Final	% change
			Organic carbon %			
Control	0.311	0.340	7.7	0.370	0.200	−45.9
NPK	0.311	0.425	36.7	0.370	0.400	8.1
FYM + NPK	0.311	0.485	55.9	0.370	0.500	35.1
GM + NPK	0.311	0.434	39.5	0.370	0.500	35.1
SE		0.011			0.028	
			Available phosphorus (mg kg^{-1})			
Control	5.09	4.00	−21.4	6.27	3.45	−44.9
NPK	5.09	10.09	98.2	6.27	9.27	47.8
FYM + NPK	5.09	13.72	169.5	6.27	9.82	56.6
GM + NPK	5.09	12.32	142.0	6.27	10.41	66.0
SE		0.93			1.07	
			Available potassium (mg kg^{-1})			
Control	46	38	−17.4	161	126	−21.7
NPK	46	42	−8.7	161	133	−17.4
FYM + NPK	46	42	−8.7	161	139	−13.7
GM + NPK	46	46	0.0	161	135	−16.1
SE		6.2			7.3	

Table 8. Organic carbon (%) and available N (kg ha^{-1}) contents in soil in Jalandhar and Ghazipur before commencement of on-farm experiment in different years.

	Organic C					Available N				
Year	No. of farmers	Max.	Min.	Mean	SD	No. of farmers	Max.	Min.	Mean	SD
					Jalandhar					
1991	18	0.72	0.36	0.56	0.134	18	188	63	129	33.0
1992	25	0.96	0.39	0.68	0.192	25	179	45	89	30.3
1993	25	0.74	0.20	0.51	0.143	25	226	54	111	49.9
1994	25	0.89	0.22	0.64	0.175	25	170	81	130	25.0
1995	26	1.34	0.37	0.59	0.201	25	206	18	124	33.3
					Ghazipur					
1991	25	0.70	0.38	0.55	0.092					
1992	25	0.61	0.37	0.47	0.074					
1993	25	0.65	0.41	0.53	0.076					
1994	25	0.90	0.37	0.66	0.152					
1995	25	0.87	0.61	0.71	0.074					
1996	25	0.80	0.55	0.65	0.063					
1997	25	0.81	0.56	0.63	0.066					

Table 9. Available P and available K contents (kg ha^{-1}) in soils in Jalandhar and Ghazipur before commencement of on-farm experiments in different years.

	Available P					Available K				
Year of analysis	No. of farmers	Max.	Min.	Mean	SD	No. of farmers	Max.	Min.	Mean	SD
					Jalandhar					
1991	18	26	5	16	6.0	17	349	97	195	82.7
1992	25	40	7	20	10.7	25	744	83	276	201.1
1993	25	26	1	14	6.5	25	276	59	118	55.8
1994	25	49	2	19	12.1	24	415	84	197	100.1
1995	25	53	7	25	12.6	25	349	55	188	77.1
					Ghazipur					
1991	25	7	4	6	0.9	25	214	114	165	25.7
1992	25	7	3	5	1.2	25	238	131	183	27.4
1993	25	8	3	6	1.4	25	168	86	130	20.6
1994	25	10	4	7	1.4	23	65	45	55	5.5
1995	25	10	4	7	1.5	24	40	34	36	2.2
1996	25	9	5	7	1.1	25	115	68	91	12.2
1997	25	10	5	7	1.3	24	74	45	58	9.1

soluble Ca and Mg (Khind *et al.*, 1987) and available K in soil solution due to release of Fe^{++} and Mn^{++} under highly reduced conditions of flooded soils (Nagarajah *et al.*, 1989), green manuring might be making these nutrients more easily available to the crop plants. Similarly, in a 2-year field experiment at Ludhiana, Takkar and Nayyar (1986) found effective correction of Fe deficiency by manuring with *Sesbania*.

As far as the economics of the green manuring is concerned, it was observed that whenever total yields of the system (rice + wheat) fell below 10 t ha^{-1}, e.g. during 1990–91 and 1994–95, the marginal benefits increased with the application of fertilizer NPK alone. However, when total yields of the system were greater than 10 t ha^{-1} as during 1991–92, 1992–93 and 1993–94, the marginal benefits increased with the green manuring. This suggests that, under high-yield situations of the system, green manuring was a profitable practice.

In the low-productivity zone of Ghazipur, fertilizer NPK alone significantly increased the yields of rice-wheat systems compared with other fertilizer management practices, but the marginal benefits were the highest with green manuring in 6 out of the 7 years of the experiment. The mean data of 7 cycles of the rice-wheat systems showed that from every extra rupee invested in NPK application farmers gained Rs. 5.23, while from every extra rupee spent on green manuring they gained Rs 5.97. It may be inferred, therefore, that the chances of getting higher marginal benefits from integrated use of green manure and fertilizer NPK inputs are greater than from the application of fertilizer NPK alone. Thus the reasons for non-adoption of green manuring may be other than economic.

In Ghazipur, where a rainfed situation prevails, the risk involved in cultivating a green manure crop and its incorporation into the soil may be more than the gains due to monetary benefits. Moreover, most farms in the region are marginal, with a mean land-holding size of about 0.5 ha. For these farmers, therefore, household food security is more important than profiting from farming. Also, as grain yields were greater with fertilizer NPK application alone compared with green manuring, they may have preferred the former practice. In Jalandhar, the extra effort required to raise a green manure crop, such as arranging irrigation, ploughing and harrowing during summer months might not justify additional benefits earned from green manuring.

Organic C and available P contents of soil increased gradually due to application of complete doses of fertilizer NPK alone or with organic manures both in the long-term experiment and also on farmers' fields. The available potassium content, however, was depleted significantly in both the long-term experiment and on farmers' fields in Ghazipur. Continuous rice-wheat cropping may also lead to the depletion of sulphur (Hegde and Sarkar, 1992). Thus the deficiencies of potassium and sulphur may become limiting factors leading to yield reductions in the long term, as observed in wheat at Faizabad. On farmers' fields, such yield reductions were not very common, however, despite heavy K removal resulting in a decline in available K (Yadav *et al.*, 1998). This may have been due to replenishment of available K from the non-exchangeable pool and added K through irrigation water. Since the non-exchangeable fraction is a potential source of available K and contributes more than 50% to the total K 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 (Tandon and Sekhon, 1988). Potassium, thus, always remained readily available to meet requirement of crop plants, but the soil was eventually depleted of available K under rice-wheat cropping.

The gradual increase in soil organic C on farmers' fields may be explained on the basis of Hobbs and Morris (1996) who found that, although farmers may follow a rice-wheat system, the system itself can vary tremendously. Temporal and spatial relationships between the two crops often differ; rice and wheat may be grown in the same plot in the same year, in the same plot in different years, or in different plots in the same year. Though rice and wheat may be the only crops grown in a given plot, frequently other crops are also present, either associated with rice or wheat (grown at the same time) or rotated with either or both (grown before or after). Crops commonly included in rice-wheat systems are: oilseeds (mustard (*Brassica juncea*), rapeseed (*Brassica campestris*) and sunflower (*Helianthus annuus*)); pulses (pea *(Pisum sativum*), mung bean (*Phaseolus aureus*), blackgram (*Vigna mungo*) and lentil (*Lens esculenta*)); fodder crops, for example berseem (*Trifolium alexandrinum*), fodder sorghum (*Sorghum vulgare*) and pearl millet

(*Pennisetum typhoideum*); vegetables, e.g. potato (*Solanum tuberosum*); sugarcane (*Saccharum officinarum*); and jute (*Corchorus olitorius*).

Thus, it may be seen that on farmers' fields, crops differing in growth habit, and rooting pattern and density are grown or rotated in the same field with a rice-wheat system. In such situations, nutrients from deeper soil layers are continuously recycled and made available to the rice and wheat. Further, the decomposition of root and stubble residues of these crops is accelerated by the nitrogenous fertilizers applied to the rice-wheat system, thereby making other macro- and micro-nutrients quickly available to the crops (Glendining *et al*., 1996). The root residues and stubbles on decomposition also enhance the organic matter content of the soil. This may indicate that the benefits which might have occurred by green manuring increasing soil organic carbon content are already being achieved by the practice of rotating crops on farmers fields.

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