Long-term Effects of Organic Manuring and Crop Residues on the Productivity and Sustainability of Rice-Wheat Cropping System in Northwest India

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Abstract

A long-term field experiment was conducted during 1988–96 on a loamy sand soil to study the effect of fertilizer nitrogen (N), *Sesbania* green manure (GM), crop residues, and farmyard manure (FYM) on crop yield, nutrient uptake, and soil properties in a rice-wheat cropping system. *Sesbania* accumulated 60–130 kg N ha^{-1} in 52–55 days. In the treatment GM-N supplemented with urea to make up a total of 150 kg N ha^{-1}, grain yield of rice and N uptake were similar to that obtained with 150 kg urea N ha^{-1} treatment. Incorporation of wheat straw, compared with no straw, generally resulted in significantly reduced yield and N uptake of rice. Co-incorporation of crop residues and GM counteracted the adverse effect of crop residues on the rice yield. Nitrogen from FYM proved inferior to urea-N for yield and nutrient uptake of rice. Green manuring + FYM could meet the complete N requirement of rice. The grain yield of rice under different treatments showed a decreasing trend. Green manuring had small effects on organic carbon content of soil and availability of phosphorus (P) and potassium (K) in soil. Incorporation of crop residues increased the organic matter content of soil. Soil organic carbon and available P and K contents increased with the application of FYM. The DTPA-extractable zinc (Zn), iron (Fe), and manganese (Mn) increased with the incorporation of organic amendments. Green manuring and recycling of crop residues improved the physical properties of soil. The residual effect of green manure and crop residues was, however, not found significant in the succeeding wheat.

Introduction

In the coming decades, a major issue in designing sustainable agricultural systems will be the management of soil organic matter and the rational use of organic inputs such as animal manures, industrial wastes, green manure (GM), and crop residues (Powlson 1994). Maintaining or increasing soil organic matter content is of great benefit in terms of recycling plant nutrients, minimizing the need for inorganic fertilizers, and improving soil physical condition.

Farmyard manure is the most commonly used organic manure, but it is limited in supply and contains low and variable nutrient contents. Green manures offer considerable potential as a source of plant nutrients and organic matter. A considerable area under rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) in Punjab, India is now harvested by combine. The rice and wheat straw left in the field after combine harvesting are generally burnt by the farmers to facilitate seedbed preparation and seeding. Burning causes loss of organic matter and plant

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nutrients, and environmental pollution. Incorporation of cereal straw of wide C:N (carbon:nitrogen) ratio, however, immobilizes soil N and adversely affects yield of succeeding crop (Sidhu and Beri 1989). Recycling of crop residues without adversely affecting crop yield has been attracting the attention of soil scientists. A field experiment was started in 1988 to study the long-term effects of green manure (GM), farmyard manure (FYM), and crop residues on crop yields and soil productivity in rice-wheat cropping system.

Materials and Methods

A long-term field experiment with a rice-wheat rotation was initiated in summer 1988 at Ludhiana (30°56' N, 75°52' E), Punjab, India. Important characteristics of the 0–15 cm soil layer of the experimental field are presented in Table 1. Before 1988, the experimental field was under maize (*Zea mays* L.)-wheat rotation for more than 5 years. Rainfall distribution during rice-growing season was 0–52 mm (mean 26.6 mm) during 20–30 June, 78–553 mm (mean 243 mm) in July, 65–405 mm (mean 215 mm) in August, and 37–669 mm (mean 232 mm) in September. Mean daily air temperature was 30.8–33.5°C (mean 32.2°C), 29.2–31.4°C (mean 30.0°C), 28.3–31.2°C (mean 29.5°C) and 27.5–28.8°C (mean 28.1°C) during respective periods. The experiment with 30 m^2 (10 m × 3 m) plots was laid out in randomized complete block design with 3 replications. The treatments applied to rice were: (i) 0, 150, and 180 kg N ha^{-1} as urea on unamended plots; (ii) GM (51- to 55-day-old *Sesbania aculeata* Poir.); (iii) GM + wheat straw; (iv) GM + rice straw; (v) wheat straw + 150 kg N ha^{-1}; (vi) FYM (12 t fresh weight ha^{-1}); (vii) FYM + GM.

Dry biomass and N additions through GM, wheat straw, rice straw, and FYM during 1988–95 are given in Table 2. Nitrogen added through GM or FYM in different years was supplemented with urea-N to give a total of 150 kg ha^{-1} for comparison with 150 kg N ha^{-1} on unamended plot. In FYM + GM treatment, no fertilizer N was applied. The N added through wheat and rice straw was not accounted for in determining the urea dose.

Table 1. Some important characteristics of the surface soil (0–15 cm) in the experimental field at Ludhiana, Punjab, India.

Description	Characteristics
Soil series	Fatehpur loamy sand
Soil subgroup	Typic Ustipsamment
Sand (%)	78.5
Clay (%)	12.6
pH (1:2)	7.6
Electrical conductivity (dS m^{-1})	0.16
Organic carbon (%)	0.36
Total nitrogen (mg kg^{-1})	445.0
Olsen phosphorus (mg kg^{-1})	9.8
Ammonium acetate extractable potassium (mg kg^{-1})	38.2
Cation exchange capacity [c mol (p+) kg^{-1}]	6.8
Moisture at field capacity (%)	16.5

Table 2. Addition of nutrients from organic amendments during 1998–95 at Ludhiana, Punjab, India.[1]

Organic amendment	1988	1989	1990	1991	1992	1993	1994	1995
Total N (kg ha^{-1})								
Green manure	122	101	130	90	90	100	60–111	73–124
Wheat straw	26	18	27	25	28	29	34	33
Rice straw	25	28	53	41	45	39	42	37
FYM	–	100	105	77	73	90	80	100
Total P (kg ha^{-1})								
Rice straw	7	6	5	5	5	6	6	6
FYM	–	67	78	21	22	63	23	50
Total K (kg ha^{-1})								
Rice straw	109	82	78	93	72	82	90	78
FYM	–	141	138	99	132	153	94	124

1. N=nitrogen; P=phosphorus; K=potassium; FYM=farmyard manure.

In unamended and GM alone plots, wheat was harvested close to the ground. In wheat straw treatment, wheat was harvested from the top leaving 40 to 45 cm high stubble to simulate combine harvesting. After threshing, the straw from the tops was returned to the same plots. The wheat straw was incorporated with a disc plow. The *S. aculeata* (GM) was sown in rows 20 cm apart in soil having good moisture. A seed rate of 50 kg ha^{-1} was used and no fertilizers were applied to *Sesbania.*

Incorporation of rice straw into the soil before sowing of wheat generally adversely affects the wheat yield. The short pre-wheat fallow period and low temperature conditions are not suitable for the growth of GM. Therefore, rice straw from the previous crop was stored and recycled in the rice season. In the rice straw treatment, 6 t ha^{-1} (dry weight) was placed between rows of *Sesbania* crop about 20 days after seeding. Farmyard manure was spread and incorporated into the soil at 15 cm depth at puddling. *Sesbania* of 50–55 days was incorporated into the soil by a tractor-drawn disc harrow 1–2 days before transplanting rice.

The soil was puddled and 35- to 40-day-old seedlings of rice cultivar PR 106 were transplanted in 20 cm × 15 cm spacing during 19–22 June in different years. In the GM treatments total N of GM was kept uniform in all years except during 1994 and 1995. In the unamended and FYM plots, urea was applied in 3 equal splits, at transplanting, and 21 and 42 days after rice transplanting. In the GM plots, urea was applied in 2 equal doses at 21 and 42 days after transplanting. The FYM + GM treatment received no application of urea. No phosphorus (P) and potassium (K) fertilizers were applied to rice. A basal dose of 50 kg zinc sulfate ha^{-1} was applied to rice in alternate years. The rice crop was harvested in the first week of October. Grain yield (rough rice) was corrected to 14% moisture content and straw yield was calculated on an oven-dry weight basis. Grain and straw samples were oven dried and analyzed for total N content (Table 2). Surface soil samples (0–15 cm) from each plot were collected after the harvest of each rice crop, air dried, and processed for the analysis of organic C by wet digestion method, 0.5 M $NaHCO_3$ extractable P (Olsen's P), and available K (1 M neutral ammonium acetate extractable). Soil samples collected after rice in 1995 were analyzed for DTPA-extractable zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn). Grain and straw samples of rice were analyzed for N, P, and K content to calculate total nutrient uptake by rice.

After rice harvest, wheat cultivar HD 2329 (PBW 343 during 1995/96), was sown in 20 cm wide rows in the first week of November. A basal dose of 90 kg N through urea + 26 kg P through superphosphate + 50 kg K through muriate of potash ha^{-1} was applied to wheat. Half of the N and all the P and K were drilled at sowing, and the remaining N was top-dressed at the first irrigation (21–25 days after sowing). The wheat was harvested in the second week of April, and grain and straw yields were recorded.

Physical properties of the soil were recorded after the harvest of rice in 1993. Water intake measurements were made using double ring infiltrometers of 35–45 cm diameter of inner rings and 28 cm height. Initially water intake was recorded at short intervals and then at 1- and 2-h intervals. A wet sieving method using Yoder's apparatus was used to determine water stable aggregates of the surface 15 cm soil layer. The data on aggregate size distribution were corrected for soil particles.

Results and Discussion

Crop yield

Grain yield of rice increased significantly with 150 kg N ha^{-1} relative to unamended no-N control every year (Table 3). The yield increase with 150 kg N ha^{-1} compared with the no-N control ranged from 1.2 t ha^{-1} to 2.6 t ha^{-1} (mean 2.08 t ha^{-1}). The results confirm the findings of Singh et al. (1987) in soils low in organic C. GM-N supplemented with fertilizer N to provide a total of 150 kg N ha^{-1} gave grain yields of rice similar to those obtained from 150 kg N ha^{-1} as urea. The data indicate that GM-N was almost as efficient as fertilizer N in rice. Ghai et al. (1988) and Singh et al. (1990)

Table 3. Effect of application of nitrogen (N), green manure (GM), farmyard manure (FYM), and crop residue on grain yield of rice (t ha^{-1}) during 1988–95 at Ludhiana, Punjab, India.

Treatment	1988	1989	1990	1991	1992	1993	1994	1995
No N (control)	4.0	4.6	3.7	4.3	4.1	3.4	2.8	2.6
150 kg N ha^{-1}	6.3	6.6	6.2	6.5	5.7	5.6	4.0	5.2
GM	6.6	6.5	6.2	6.3	5.8	5.5	3.8	5.5
Wheat straw + GM	6.9	6.9	6.4	6.8	5.6	5.5	3.9	5.3
Rice straw + GM	6.9	6.9	6.7	7.0	5.9	5.3	3.8	6.4
Wheat straw + 150 kg N ha^{-1}	–	6.8	5.8	6.1	5.2	4.8	3.9	4.6
FYM	–	6.3	4.6	5.7	6.0	4.8	3.9	4.6
FYM + GM	–	7.7	6.1	6.9	6.5	6.1	4.0	4.9
LSD (P=0.05)	0.53	0.59	0.46	0.45	0.32	0.37	0.51	0.54

reported equal or higher efficiency of GM-N compared with fertilizer N on rice. This is explicable from a laboratory incubation study showing rapid mineralization of GM-N under waterlogged conditions, representing the rice ecosystem (Singh 1993).

The wheat straw + 150 kg urea-N ha^{-1} treatment, compared with 150 kg urea-N ha^{-1} alone, resulted in reduced rice grain yield in 6 out of 7 years (Table 3). Straw application did not adversely affect the grain yield in 1989. Singh et al. (1988) and Singh (1993) showed distinct evidence of N immobilization in straw amended soil. Sidhu and Beri (1989) also reported reduction in rice yield with incorporation of wheat straw into the soil. The adverse effect of wheat straw incorporation on rice grain yield was not observed when *Sesbania* was grown and incorporated before transplanting rice (Table 3). Similar yields were also obtained with the rice straw + GM treatment. Singh (1993) observed that wheat straw + GM-N treatment maintained higher levels of ammoniacal-N in the soil than wheat straw + urea-N treatment during 2–8 weeks of incubation. These data indicate that combined use of GM and crop residues ensured sustained N supply during rice growth season resulting in higher grain yield than the wheat straw treatment.

Application of FYM @ 12 t ha^{-1} along with 45–77 kg N ha^{-1} (to make up to 150 kg N ha^{-1}) resulted in significantly lower yield than 150 kg urea-N ha^{-1}. This indicates a lower availability of N from FYM than urea to rice. Singh et al. (1995) reported that efficiency of N from FYM was 45–50% when compared with urea-N applied in 3 equal splits to rice. Total N added with FYM + GM ranged from 167 kg ha^{-1} to 240 kg ha^{-1}. The application of FYM plus GM gave rice yields equal to or higher than those obtained with 150 kg urea-N ha^{-1}. It could be due to additional N and/or increased supply of other nutrients through FYM (Table 2). The results indicate that a combination of two organic sources can completely replace the use of N fertilizers for high-yielding cultivars of rice. Singh et al. (1988) showed in a laboratory incubation study that net release of mineral N from FYM generally occurs after 3–4 weeks. The initial N requirement of rice was therefore met from the rapid release of mineral N from GM.

The residual effects of inorganic fertilizer, GM, wheat straw, and wheat straw or rice straw + GM application to preceding rice was not generally reflected in grain yield of wheat which received uniform dose of 90 kg N ha^{-1} + 26 kg P ha^{-1} + 50 kg K ha^{-1} (Table 4). Wheat yield, however, increased in plots receiving combined application of GM and crop residues in the preceding rice crop. The beneficial effect of GM + crop residues was possibly due to more supply of plant nutrients and improvement in soil structure. The legume GM with narrow C:N ratio decomposed fast during the rice-growing season and did not increase organic C content of the soil, thereby showing no significant residual effect on wheat yield. Wheat or rice straw with wide C:N ratios applied alone or in combination with GM increased the organic C content of soil, but did not release enough N to increase wheat yield. Meelu et al. (1994) reported low or no residual effect of GM applied to rice on the succeeding wheat. Application of FYM to rice increased the grain yield of wheat by 0.1–0.4 t ha^{-1} (mean 0.27 t ha^{-1}) compared with 150 kg N ha^{-1} treatment in different years; the differences were, however, not significant. A similar trend in grain yield was obtained with FYM + GM treatment, and the yield increase was significant during 2 out of 7 years of the study. The higher

Table 4. Effect of nitrogen (N), green manure (GM), farmyard manure (FYM), and crop residue application to preceding rice crop on wheat grain yield (t ha^{-1}) during 1988–96 at Ludhiana, Punjab, India.

Treatment to rice[1]	1988/ 89	1989/ 90	1990/ 91	1991/ 92	1992/ 93	1993/ 94	1994/ 95	1995/ 96
No N (control)	4.3	4.2	4.6	4.3	3.7	3.8	4.7	4.7
150 kg N ha^{-1}	4.1	4.0	4.8	4.4	4.0	3.9	4.5	4.3
GM	4.1	4.2	4.8	4.5	4.1	3.9	4.6	4.2
Wheat straw + GM	4.5	4.4	5.0	4.5	4.1	3.9	4.4	4.2
Rice straw + GM	4.4	4.3	4.9	4.7	4.3	3.9	4.6	4.5
Wheat straw + 150 kg N ha^{-1}	–	4.2	4.7	4.0	4.2	3.9	4.2	4.3
FYM	–	4.4	4.9	4.7	4.3	4.2	4.7	4.6
FYM + GM	–	4.5	5.1	4.9	4.4	3.9	4.3	4.4
LSD(P=0.05)	NS[2]	NS	NS	0.37	0.34	NS	NS	NS

1. A uniform dose of 90 kg N ha^{-1} + 26 kg phosphorus ha^{-1} + 50 kg potassium ha^{-1} was applied to wheat in all the treatments.
2. NS=not significant.

residual effect of FYM on wheat yield was possibly owing to increase in soil organic C and total N content of the soil.

Yield trend

The grain yield of rice under all the treatments decreased with the period of the study (Table 3; Fig. 1). The rate of decline was maximum under FYM + GM treatment (Table 5). The rate of yield decline was almost similar in plots amended with 150 kg N ha^{-1}, GM, and GM + rice straw. The trend is similar to rice yield decline in rice-wheat system in the heavier textured soils of Pantnagar, India and Bhairawaha, Nepal. The

Table 5. Trends in rice yields during 1988–95 in different treatments in rice-wheat cropping system at Ludhiana, India.[1]

Treatment	Rate of yield decline (t ha^{-1} yr^{-1})	r^2
No N (control)	0.213	0.61
150 kg N ha^{-1}	0.190	0.77
Green manure (GM)	0.180	0.89
Wheat straw + GM	0.267	0.82
Rice straw + GM	0.159	0.37
Wheat straw + 150 kg N ha^{-1}	0.360	0.86
Farmyard manure (FYM)	0.194	0.31
FYM + GM	0.371	0.74

1. Data for 1994 not included in the regressions.

rate of yield decline was lower in FYM-amended plots than that under all other treatments. The rate of yield decline under different treatments seems to be indirectly related to the yield levels achieved during the initial years of the study. The application of FYM, GM, and crop residues increased the organic matter content and physical properties of soil compared to the plots treated with chemical fertilizer. Factors other than soil fertility and physical conditions, therefore, appear to be limiting the rice yields. The notable yield reduction in 1994 was associated with the heavy incidence of stem borer in rice crop.

The grain yield of wheat showed no trend with respect to time during the 8 years of the study (Table 4). The lack of yield trend in wheat may be due to more than 15 years of wheat cropping on the experimental field and low level of N (90 kg N ha^{-1}) applied compared with the recommended rate of 120 kg N ha^{-1}. The maximum yield, therefore, could not be achieved in wheat particularly during the initial years of the study. Besides, wheat crop is less prone to the incidence of pest and disease attack.

Nutrient balance

Total N uptake by rice increased significantly under 150 kg N ha^{-1} compared with no-N control. Total N uptake under GM, rice straw + GM, and wheat straw + GM treatments was equal to or higher than that from the 150 kg fertilizer N ha^{-1} treatment (Table 6). Immobilization of fertilizer N in wheat straw + 150 kg N ha^{-1} treatment was clearly reflected in reduced N uptake in all the years. Total N uptake by rice in FYM-amended plots was significantly lower than that in 150 kg fertilizer N ha^{-1} treated plots in all the years except during 1993. The data provide evidence of lower efficiency of FYM-N than urea-N in supplying N to the rice crop. The average N uptake under FYM + GM treatment was generally equal to that under 150 kg N ha^{-1} treatment. Total N uptake by wheat was generally similar under different treatments except that it was somewhat higher in rice straw + GM plots. Apparent urea-N recovery by rice was 30.7–56.0% with a mean

Table 6. Nitrogen (N) inputs, removal, and balance in different treatments during 8 years (1988–96) in rice-wheat cropping system at Ludhiana, Punjab, India.

Treatment	N inputs[1] (kg ha^{-1})			N removal (kg ha^{-1})			N balance
(to rice)	F	O	Total	Rice	Wheat	Total	(kg ha^{-1})
No N(control)	720	–	720	473	858	1331	–611
150 kg N ha^{-1}	1920	–	1920	995	845	1840	+80
GM	1099	657	1756	1028	860	1888	+132
Wheat straw + GM	1154	613	1767	1060	664	1724	+43
Rice straw + GM	1122	948	2070	1063	914	1977	+93
Wheat straw + 150 kg N ha^{-1}	1680	–	1680	799[2]	530[2]	1329	+351
FYM	1055	625	1680	688[2]	810[2]	1498	+182
FYM + GM	630	1319	1949	895[2]	817[2]	1712	+237

1. F=Fertilizer; O=Organic amendments [rice straw, green manure (GM), and farmyard manure (FYM)]. About 80% of the total N added through *Sesbania* GM was considered to be derived through biological N_2-fixation.
2. Data pertains to 1989–96.

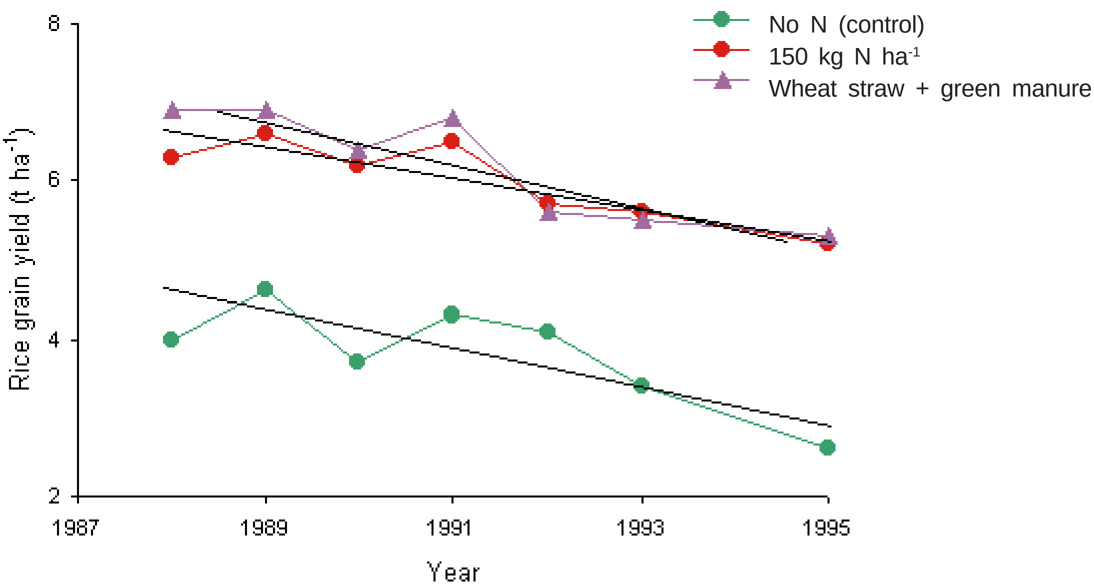

Figure 1. Rice grain yield trend in the long-term rice-wheat cropping system experiment conducted at the research farm, Punjab Agricultural University, Ludhiana, India during 1987–95.

value of 43.5%.

The N balance for 8 years of rice-wheat cropping was positive for all the treatments receiving fertilizer, GM, and FYM (Table 6). In this study no data were collected for inputs of N from external sources other than fertilizers, viz., rain, dry deposition, and biological N_2-fixation. Similarly, losses of N via leaching, ammonia volatilization, and denitrification were not considered. Therefore, long-term N balance shown in Table 6 may be of limited value for calculating N cycle of the rice-wheat cropping system.

The P balance (total P applied minus P recovered in crops over the period) was negative in all the treatments except those receiving FYM (Table 7). Total P uptake by rice under different treatments followed a trend similar to that for grain yield. In a given treatment, the P balance depended on the total P inputs. The data indicate that following the P fertilizer recommendations for rice and wheat on a long-term basis may adversely affect the sustainability of rice-wheat cropping system.

Total K uptake by rice in 8 years averaged 127 kg ha^{-1} under no-N control treatment. Application of 150 kg N ha^{-1} increased the K uptake by rice compared with the control and the mean K uptake was 207 kg K ha^{-1}. Total K uptake under the treated plots was generally similar, except that it was high (mean 225 kg K ha^{-1}) in FYM + GM treatment and low in FYM treatment (mean 177 kg K ha^{-1}). Different treatments caused small changes in P and K concentration in rice grain and straw. The P and K uptake under different treatments was therefore mainly related to grain and straw yields. Potassium concentration in rice plant showed increasing trend with FYM. Total K uptake by wheat was almost similar under different treatments except when wheat straw was recycled in situ. The total K removed by the rice and wheat crops was much higher than that added through fertilizer, GM, and crop residues. Therefore, the K balance was notably negative in all the treatments (Table 8). The K balance in FYM-treated plots was less negative due to large additions of K through the manure.

Table 7. Phosphorus (P) inputs, removal, and balance in different treatments during 8 years (1988–96) in rice-wheat cropping system at Ludhiana, Punjab, India.

Treatment	P inputs[1] (kg ha^{-1})			P removal (kg ha^{-1})			P balance
(to rice)	F	O	Total	Rice	Wheat	Total	(kg ha^{-1})
No N(control)	211	–	211	114	139	253	–42
150 kg N ha^{-1}	211	–	211	183	136	319	–108
Green manure	211	–	211	180	139	319	–108
Wheat straw + GM	211	–	211	187	1112	298	–87
Rice straw + GM	211	47	258	190	144	334	–76
Wheat straw + 150 kg N ha^{-1}	185	–	185	154[3]	94[2,3]	198	–13
FYM	185	324	509	155[3]	130[3]	285	+224
FYM + GM	185	324	509	187[3]	133[3]	320	+189

1. F=Fertilizer; O=Organic amendments [rice straw and farmyard manure (FYM)].
2. Data is P removal by wheat grain only as wheat straw was incorporated.
3. Data pertains to 1989–96.

Soil nutrient status

Soil organic carbon. Green manuring, compared with fertilizer N, did not significantly increase organic C content of soil (Table 9). Leguminous GM decomposed fast on incorporation into the soil under the experimental conditions characterized by high temperature and alternate aerobic-anaerobic conditions (Singh et al. 1992). Therefore, only a small fraction of GM-C was converted into stable soil humus (Meelu et al. 1994). Incorporation of crop residues and FYM alone or in combination with GM significantly

Table 8. Potassium (K) inputs, removal, and balance in different treatments during 8 years (1988–96) in rice-wheat cropping system at Ludhiana, Punjab, India.

Treatment	K inputs[1] (kg ha^{-1})			K removal (kg ha^{-1})			K balance
(to rice)	F	O	Total	Rice	Wheat	Total	(kg ha^{-1})
No N (control)	400	–	400	1002	804	1806	–1406
150 kg N ha^{-1}	400	–	400	1623	785	2408	–2008
Green manure (GM)	400	–	400	1641	777	2418	–2018
Wheat straw + GM	400	–	400	1644	299[2]	1943	–1543
Rice straw + GM	400	684	1084	1781	843	2624	–1540
Wheat straw + 150 kg N ha^{-1}	350	–	350	1506[3]	242[2,3]	1748	–1398
FYM	350	881	1231	1241[3]	762[3]	2003	–772
FYM + GM	350	881	1231	1575[3]	749[3]	2324	–1093

1. F=Fertilizer; O=Organic amendments [rice straw and farmyard manure (FYM)].
2. Data is K removal by wheat grain only as wheat straw was incorporated.
3. Data pertains to 1989–96.

Table 9. Effect of application of nitrogen (N), green manure (GM), farmyard manure (FYM), and crop residue on organic carbon content after rice harvest in rice-wheat cropping system at Ludhiana, Punjab, India.

Treatment	Soil organic carbon (%)			
	1989	1991	1993	1995
No N (control)	0.31	0.37	0.35	0.34
150 kg N ha^{-1}	0.32	0.37	0.38	0.38
GM	0.35	0.39	0.41	0.42
Wheat straw + GM	0.42	0.52	0.47	0.44
Rice straw + GM	0.45	0.49	0.50	0.44
Wheat straw + 150 kg N ha^{-1}	0.38	0.47	0.49	0.47
FYM	0.36	0.49	0.47	0.45
FYM + GM	0.38	0.53	0.52	0.47
LSD (P=0.05)	0.061	0.047	0.050	0.051

increased the soil organic C content (Table 9). Cereal crop residues with wider C:N ratio and higher humification coefficient than GM possibly leave more C in soil for conversion to soil organic matter. Sharma et al. (1987) and Beri et al. (1992) reported that crop residue incorporation, as compared with its removal, greatly increased organic C and total N contents in soils under rice-wheat cropping system. Similarly, Maskina et al. (1988) reported significant increase in the organic C content of soil with the application of FYM. The data indicate little increase in soil organic C content of soil even with the application of crop residues and FYM over the years. For example, organic C content after 4 years (i.e., in 1991) of application of crop residues ranged from 0.47% to 0.53% and after 8 years it was 0.44–0.47% . Therefore, it seems that organic C values of the new equilibrium were established under the experimental conditions.

Available P. Available P content in soil decreased with 150 kg N ha^{-1} and GM when compared with no-N control (Table 10). Total P removal by rice was 8.2 kg ha^{-1} yr^{-1} higher in these treatments than in the control. Also, total P input in the rice-wheat cropping system was much lower than that removed by the crops resulting in negative P balance. Therefore, the effect of GM on available P content of soil was perhaps not reflected over long-term period. However, green manuring may have increased the availability of P in soil over short-term basis during the rice growth as reported in a laboratory incubation study by Singh et al. (1988). Available P content of soil slightly increased with the recycling of crop residues when compared with 150 kg N ha^{-1} treatment (Table 10). Phosphorus balance was positive under FYM and FYM + GM treatments. Therefore, FYM application significantly increased the available P content of soil as also observed by Maskina et al. (1988).

Available K. Application of N @ 150 kg ha^{-1}, GM, and crop residues did not significantly affect available K content compared with control (Table 10). Rice crop removed more K from the soil in these treatments than no-N control treatment and total K input in the cropping system was much lower (50 kg K ha^{-1}) than its

Table 10. Effect of application of nitrogen (N), green manure, farmyard manure (FYM), and crop residue on available nutrients (mg kg^{-1}) in soil after rice harvest in rice-wheat cropping system at Ludhiana, Punjab, India.

Treatment	Available P		Available K		Available micronutrient (1995)			
	1991	1995	1991	1995	Zn	Fe	Mn	Cu
No N (control)	8.5	8.5	33	34	1.67	19.4	6.08	1.02
150 kg N ha^{-1}	6.9	6.7	29	33	0.92	10.6	2.75	0.56
GM	6.7	7.1	30	30	2.21	20.7	6.61	1.35
Wheat straw + GM	7.1	8.9	34	36	1.05	20.8	4.29	0.72
Rice straw + GM	6.7	8.5	34	36	1.75	22.4	6.49	1.42
Wheat straw + 150 kg N ha^{-1}	7.1	9.4	33	34	1.95	25.1	6.88	1.27
FYM	13.4	13.4	42	43	2.16	17.8	6.42	1.06
FYM + GM	15.6	13.0	49	45	1.68	12.7	6.15	0.92
LSD (P=0.05)	2.8	3.9	7.8	9.2	–	–	–	–

removal by the crops. Therefore, large depletion of non-exchangeable K fraction from the soil might have occurred due to continuous cropping, as also reported previously by Meelu et al. (1995). Although significant quantities of total K were added through crop residues, small effect on available K content of soil was observed. This may be due to the negative K balance under these treatments and fixation of K released from crop residues into non-exchangeable forms and also leaching of water soluble K in the highly percolating coarse-textured soil in the experimental field. As previously reported by Maskina et al. (1988), application of FYM significantly increased the available K content of the soil (Table 10).

DTPA-extractable micronutrients. The DTPA-extractable micronutrients [zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu)] decreased greatly with 150 kg N ha^{-1} over no-N control (Table 10). This was perhaps due to higher removal of micronutrients by the rice crop. Green manuring either maintained or increased the concentration of micronutrients in the soil (Singh et al. 1992). Recycling of crop residues increased the availability of micronutrients in the soil generally similar to that with green manuring. While availability of Zn in soil under FYM treatment was higher than or on par with that of other organic-amended plots, DTPA-extractable Fe content was low in FYM amended soil (Table 10).

Soil physical properties

Incorporation of GM, wheat straw, and wheat straw + GM for 4 years increased the formation of water stable aggregates, particularly >2 mm size when compared with fertilizer N treatment (Table 11). Mean weight diameter of water stable aggregates was maximum in the treatment receiving combined application of GM and wheat straw. Green manuring and incorporation of crop residues possibly improved the soil physical conditions through increased organic C content of soil. Decomposition products of organic residues act as binding agents for stable aggregate formation. Boparai et al. (1992) and Liu and Shen (1992) also reported improvement in soil structure in terms of aggregation due to green manuring and wheat straw incorporation.

Table 11. Effect of nitrogen (N) application, green manure, and crop residue management on soil aggregation after rice harvest in rice-wheat system during 1993 at Ludhiana, Punjab, India.[1]

Treatment	Water stable aggregates (%)					Mean weight diameter (mm)
	>2 mm	1–2 mm	0.5–1 mm	0.25–0.5 mm	0.1–0.25 mm	
150 kg N ha^{-1}	9.8a	10.0a	5.6a	6.3b	5.0ab	1.42a
Green manure	11.1b	15.5c	6.1ab	6.5b	5.5b	1.58b
Wheat straw + 150 kg N ha^{-1}	11.7b	15.0c	5.5a	6.6b	4.7a	1.56b
Wheat straw + green manure	17.1c	11.1b	6.9b	4.5a	4.6a	1.68c

1. Figures with the same letter in a column do not differ significantly at P=0.05.

The intake rate of water under GM and wheat straw treatments was greater than that under the fertilizer N alone treatment (Fig. 2). Combined application of GM and straw caused greater increase in the water intake rate than their separate application. This may be due to improvement in soil structure and formation of channels after the decay of root of the GM crop (Biswas et al. 1970; Sharma et al. 1987).

Conclusion

Green manuring is an attractive practice for meeting the fertilizer N needs of irrigated rice and for improving soil productivity. The adverse effects of wheat or rice straw can be effectively counteracted by combined incorporation of GM and crop residues into the soil before transplanting rice. Apart from increasing soil organic matter content, crop residues add

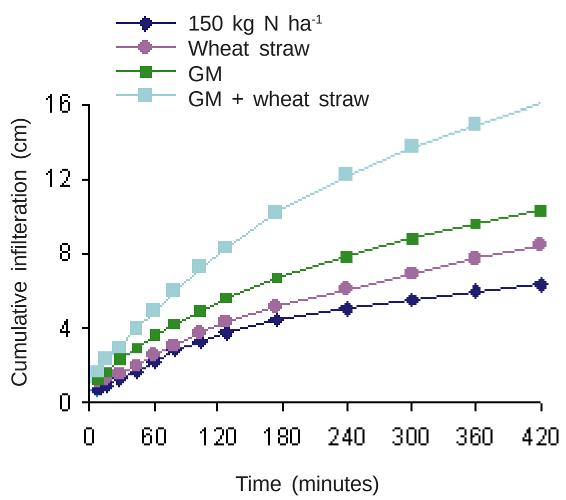

Figure 2. Effect of green manure (GM) and crop residue recycling on infiltration characteristics of soil after harvest of rice in rice-wheat system during 1993 at Ludhiana, Punjab, India.

significant quantities of plant nutrients in soil. Green manuring results in small effects on organic matter content of soil in rice-wheat rotation under subtropical conditions of India. Farmyard manure plays an important role in supplying plant nutrients and enhancing soil productivity. Yield decline in rice occurs with continuous irrigation in rice-wheat cropping system.

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