Long-term Effects of Fertilizers and Organic Manures on Crop Yields, Nutrient Balance, and Soil Properties in Rice-Wheat Cropping System in Bihar

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Abstract

In a long-term fertilizer trial the conjuctive case use of 100% NPK with organic materials continuously for 8 years affected grain yields of rice and wheat in calcareous soil in the order of farmyard manure (FYM) + crop residues > FYM > crop residues > no FYM or crop residues. The FYM or FYM + crop residues could substitute 50% NPK for wheat production and their residual effect was equivalent to 50% of the recommended dose of NPK as chemical fertilizer on the yield of succeeding rice crop. Economic analysis indicated that recycling of crop residues is economical, profitable, and healthy for sustainable rice and wheat production. Recycling of crop residues can replenish 37% of the N removal by rice and wheat, 18% of the P removal by wheat, and 28% of the P removal by rice in calcareous soil. The K, Zn, Cu, Fe, and Mn requirement of rice and wheat could be met by the incorporation of crop residues. Available N, P, K, S, Zn, Fe, Cu, Mn, B, and Mo increased in soil when different levels of fertilizers were applied along with crop residues and organic manure. The efficiencies of applied nutrients by rice and wheat were higher in plots treated with crop residues than that of FYM-treated plots. The highest soil aggregation was recorded under balanced use of fertilizer with organic manure and crop residues. Improvement in soil aggregation with the application of crop residues and organic manure resulted in increase in porosity, hydraulic conductivity, infiltration rate, and water-storage capacity and decrease in bulk density and penetration resistance. Integrated nutrient management may lead to sustainable rice and wheat production in rice-wheat cropping system.

Introduction

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) is the most important cropping system of Bihar, India. The introduction of high-yielding varieties of rice and wheat with assured irrigation facilities fostered the adoption of rice-wheat cropping system, increased its productivity, and helped in generation of farmer's income. Growth in area and productivity of rice and wheat has decreased partly because resources of productivity and growth have been exhausted. The key constraints to sustainable rice and wheat production are emergence of multiple nutrient deficiencies, low fertilizer-use efficiencies, less use of organic manure and crop residues, and unbalanced use of fertilizers in this cropping system. Under these situations, the sustainability is getting adversely affected and there is a need to develop proper crop-soil management strategies. A long-term fertilizer trial established in Bihar provides some direction for better management of the rice-wheat cropping system. The most common soil-nutrient deficiencies observed even with adequate application of NPK (nitrogen, phosphorus, potassium) fertilizers

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Prasad, B. and **Sinha, S.K.** 2000. Long-term Effects of Fertilizers and Organic Manures on Crop Yields, Nutrient Balance, and Soil Properties in Rice-Wheat Cropping System in Bihar. Page 105-119 *in* Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems (Abrol, I.P., Bronson, K. F., Duxbury, J. M. and Gupta, R. K. eds.). Rice-Wheat Consortium Paper Series 6. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

under regular adoption of rice-wheat cropping system are those of micronutrients such as zinc (Zn), boron (B), and iron (Fe) and secondary nutrients such as sulfur (S). The continuous dressing of organic manure and crop residues could undoubtedly match the nutrient requirements of crop plants under low-medium cropping intensity where nutrient demands are comparatively smaller but it will be inadequate under rice-wheat cropping system. However, integrated use of organics, crop residues, biofertilizers, and chemical fertilizers has been found promising not only in maintaining and sustaining high productivity but also in providing stability to crop production (Prasad 1994).

Infiltration rate, bulk density, soil aggregation, and porosity are being affected by low organic carbon content, as the recycling of residues under such a situation is extremely low. Also, while low organic carbon will adversely affect soil physical characteristics, it would seem that puddling of soil for rice is the primary cause of soil physical problems in rice-wheat cropping system. Besides, neither the organic manure alone nor the chemical fertilizers can achieve the yield sustainability under the rice-wheat cropping system where the nutrient depletion and turnover in soil plant system is high. A cheap and efficient method of amelioration of multiple nutrient deficiencies should be accomplished in rice-wheat cropping system. The paper deals with results of long-term study on integrated use of chemical fertilizers with organic manure and crop residues in rice-wheat system in calcareous soil.

Materials and Methods

A long-term fertilizer experiment was started during 1988/89 with wheat-rice at Pusa in Bihar. The soil was sandy loam having pH, 8.5; organic carbon, 0.51%; alkaline $KMnO_4$-N, 236 kg N ha^{-1}; Oslen's P, 19.3 kg P_2O_5 ha^{-1}; and 1N NH_4OAc-K, 100 kg K_2O ha^{-1} (Jackson 1973). DTPA-extractable Zn, copper (Cu), Fe, and mangenese (Mn) were 0.58, 1.4, 17.5, and 5 mg kg^{-1} soil respectively (Lindsay and Norvell 1969). Available S, B, and molybdenum (Mo) were 18.0 mg kg^{-1} (Williams and Steinbergs 1959), 0.89 mg kg^{-1} (Berger and Truog 1939), and 0.26 mg kg^{-1} (Johnson and Arkley 1954), respectively. Four levels of NPK [no NPK (F0), 50% NPK (F1), 100% NPK (F2), and 150% NPK (F3)] of recommended dose were applied as treatments in main plot. The 100% NPK level refers to recommended dose of NPK (100 : 60 : 40 kg ha^{-1} as N : P_2O_5 : K_2O for rice as well as wheat) based on soil-test values. These treatments were given to each crop every year. The treatments involving organic sources [no crop residues or farmyard manure (FYM) (F0), FYM (M1), crop residues (M2), and FYM + crop residues (M3)] were assigned plots to sub-plots. Farmyard manure @ 10 t ha^{-1} on dry-weight basis and crop residues harvested were added 1 month prior to transplanting of rice seedlings. Total N, P, and K contents of FYM were 1.12, 0.64, and 0.39% respectively. Rice and wheat straw were chopped (2 cm) and soaked in 2% urea solution in a big bucket, and then buried in the soil. For soaking each of rice and wheat straw in 2% urea solution, 40 kg N ha^{-1} was required. Chopped straw was also inoculated with cellulolytic culture *Aspergillus* sp to hasten the decomposition. The treatments were replicated thrice in split plot design. Plot size was 10 m^2 (4 m × 2.5 m). Nitrogen, P, and K were applied through urea, single superphosphate, and muriate of potash respectively. Half of N and whole P and K fertilizers were broadcast at the time of transplanting of rice and sowing of wheat and remaining N fertilizer was broadcast in equal proportion at tillering and panicle initiation stages. The crops were harvested at maturity and grain and straw yields of rice and wheat were recorded. After harvest of wheat and rice, roots and stubbles were taken from each plot by digging with a *khurpi* and washing on a sieve in succession with water, dilute HCl, and deionized water to avoid soil contamination. Straw sample was also washed in succession with water, dilute HCl and deionized water. Plant materials were dried and ground in a grinder with steel blades. The grain, straw, root, and stubble samples were digested in tri-acid mixture (HNO_3 : $HClO_4$: H_2SO_4 at 10:3:1). Zinc, Cu, Fe, and Mn in the extract were determined by atomic absorption spectrometer. Phosphorus and K in extract were estimated and N in grain, straw, root, and stubbles of wheat and rice was determined by Micro-Kjeldahl's method (Jackson 1973). Net profit and benefit:cost ratio were computed from response data and based on input and output prices the response in terms of kg grain kg^{-1} nutrient applied was calculated. The efficiency of applied nutrients was calculated as:

$$\text{Efficiency of applied nutrients} = \frac{\text{Nutrients uptake in treated plot (kg ha}^{-1}\text{)} - \text{Nutrients uptake in untreated plots (kg ha}^{-1}\text{)}}{\text{Nutrients applied (kg ha}^{-1}\text{)}} \times 100$$

Surface soil samples (0–15 cm) were taken from 4 places from each plot and mixed for analysis of physical and chemical properties of soils. Soil samples were taken after harvest of wheat crop during 1992. Analysis for soil aggregates was done by wet sieving with the help of Yoder wet sieving apparatus (Yoder 1936). Bulk density was measured by core method described by Blake (1965). Total porosity was estimated by method described by Vomocil (1965). Penetration resistance of the soil was measured at field capacity in situ with the help of cone penetrometer (Davidson 1965). Hydraulic conductivity was measured by constant head method (Richards 1954). Infiltration rate was determined by double-ring infiltrometer (Bertrand 1965).

Results and Discussion

Crop yield

The conjoint use of 100% NPK with organic materials affected grain yield of wheat and rice in calcareous soil in the order: FYM + crop residues > FYM > crop residues > no FYM or crop residues (Tables 1 and 2). The grain yields of wheat and rice in the treatments of 100% NPK + FYM + crop residues were greater than that of 100% NPK alone indicating that FYM + crop residue could substitute 50% recommended dose of NPK in wheat production and their residual effect equivalent to 50% NPK as chemical fertilizer on the yield of succeeding rice crop. These organic materials supply nutrients and complexing agents to soil, which maintains balanced supply of nutrients to plants. Insoluble nutrients present in soil are solubilized due to fulvic and humic acids liberated from these organic materials (Prasad and Sarangthem 1992). Incorporation of crop residues showed deleterious effect on the grain yields of rice and wheat during the first two years (1988–90) when no chemical fertilizers were applied but grain yields improved in subsequent years. The results indicated that there was N immobilization and in subsequent years, the mineralization of crop residues improved the crop yields. There was no adverse effect of crop residues when recommended levels of NPK were applied. Initially, there was no interaction effect between treatments on rice and wheat production but there was significant interaction effect on crop production in the last three years perhaps due to cumulative effect of crop residues over time. The grain yield of wheat and rice increased

Table 1. Long-term effect of farmyard manure (FYM) and crop residues on grain yield of wheat (t ha^{-1}) under rice-wheat cropping system in calcareous soil at Pusa, Bihar, India during 1988–96.

Treatment[1]	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	Mean
F0 + M0	1.25	1.45	1.42	1.70	1.44	1.61	1.60	1.43	1.45
F0 + M1	1.85	1.75	2.00	2.33	1.69	1.87	1.37	1.63	1.85
F0 + M2	1.18	1.13	1.87	1.93	2.03	1.57	1.57	1.83	1.64
F0 + M3	2.33	1.80	2.50	2.44	2.25	1.77	1.53	2.03	2.08
F1 + M0	2.27	2.17	2.75	3.03	2.65	2.30	2.07	2.55	2.47
F1 + M1	3.18	3.08	3.10	3.83	2.96	3.07	2.87	2.87	2.99
F1 + M2	2.55	2.35	3.00	3.53	3.34	3.50	2.20	2.93	2.93
F1 + M3	3.29	3.18	3.30	4.00	3.47	3.87	3.07	3.03	3.40
F2 + M0	3.22	3.12	2.95	3.57	3.21	3.60	3.03	2.83	3.19
F2 + M1	3.67	3.47	3.15	4.05	3.43	3.43	3.22	3.03	3.46
F2 + M2	3.43	3.23	3.30	3.75	3.62	3.70	3.20	3.27	3.44
F2 + M3	3.87	3.67	3.55	4.43	3.88	3.93	3.50	3.43	3.78
F3 + M0	3.42	2.92	2.80	3.40	3.04	3.17	3.10	3.20	3.16
F3 + M1	3.70	3.50	3.39	4.17	3.51	3.83	3.30	3.47	3.61
F3 + M2	3.45	3.25	3.38	3.93	3.67	4.07	3.07	3.72	3.57
F3 + M3	4.03	3.55	3.60	4.56	3.93	4.13	3.47	4.00	3.91
Mean	2.92	2.71	2.88	3.42	3.01	3.09	2.65	2.83	
CD (P=0.05)									
Fertilizer (F)	0.21	0.31	0.18	0.29	0.20	0.33	0.15	0.12	
Manure (M)	0.19	0.16	0.20	0.24	0.24	0.17	0.11	0.84	
F × M	NS[2]	NS	NS	NS	NS	0.34	0.23	0.13	

1. F0, no NPK (nitrogen, phosphorus, potassium); F1, 50% NPK; F2, 100% NPK; F3, 150% NPK (100% NPK is 100 kg N ha^{-1}, 60 kg P_2O_5 N ha^{-1} and 40 kg K_2O ha^{-1}); M0, no organic manure; M1, FYM; M2, crop residue; M3, FYM + crop residue.
2. NS=not significant.

significantly up to recommended levels of NPK and beyond this level, the yields did not increase significantly. The crop residue incorporation with recommended dose of NPK showed higher yields of wheat than that of FYM + 100% NPK. It was further observed that an early application of FYM @ 10 t ha^{-1} or crop residues harvested and mixed together with recommended dose of NPK improved and sustained crop productivity.

In another long-term experiment on calcareous soil at the Rajendra Agricultural University, Pusa, integrated use of fertilizers with 10 t ha^{-1} of FYM and blue green algae substituted 25% of recommended dose of NPK (25 kg N ha^{-1}, 15 kg P_2O_5 ha^{-1}, and 10 kg of K_2O ha^{-1}) in rice and their residual effect equivalent to 25% recommended dose of NPK on succeeding wheat crop in rice-wheat system.

Table 2. Long-term effects of farmyard manure and crop residues on grain yield of rough rice (t ha^{-1}) under rice-wheat cropping system in calcareous soil at Pusa, Bihar, India during 1988–95.

Treatment[1]	1988	1989	1990	1991	1992	1993	1994	1995	Mean
F0 + M0	1.80	1.60	1.40	1.78	2.23	1.67	1.97	1.93	1.80
F0 + M1	2.12	2.45	2.47	2.42	2.70	1.97	1.47	2.53	2.27
F0 + M2	1.72	1.45	1.35	2.13	2.63	2.20	1.30	2.53	1.91
F0 + M3	2.52	2.65	2.60	2.65	3.50	2.57	1.77	3.13	2.67
F1 + M0	2.60	2.05	2.67	2.12	3.00	2.93	2.83	3.02	2.65
F1 + M1	2.79	2.88	3.13	3.05	3.50	2.43	3.20	3.36	3.04
F1 + M2	2.23	2.29	2.73	2.35	3.30	3.37	3.00	3.27	2.82
F1 + M3	2.90	3.02	3.30	3.17	4.03	3.90	3.53	3.63	3.44
F2 + M0	2.45	2.20	3.17	2.57	3.12	3.20	3.07	3.63	2.93
F2 + M1	3.20	3.09	2.87	3.40	3.70	3.87	3.43	3.67	3.53
F2 + M2	3.66	2.69	3.30	2.83	3.47	3.92	3.27	4.23	3.42
F2 + M3	4.00	3.25	4.00	3.60	4.40	4.10	3.90	4.40	3.96
F3 + M0	3.05	2.46	3.09	2.51	3.02	3.40	3.03	3.97	3.06
F3 + M1	3.23	3.35	3.86	3.44	3.72	3.97	4.00	4.27	3.34
F3 + M2	3.69	2.85	3.29	2.84	3.48	4.17	3.43	4.63	3.55
F3 + M3	4.01	3.40	4.02	3.64	4.44	4.27	4.43	4.90	4.14
Mean	2.87	2.61	2.95	2.78	3.39	3.25	2.98	3.57	
CD (P=0.05)									
Fertilizer (F)	0.22	0.15	0.28	0.25	0.21	0.19	0.19	0.24	
Manure (M)	0.43	0.18	0.19	0.27	0.17	0.15	0.18	0.20	
F × M	NS[2]	NS	NS	NS	0.34	0.32	0.36	NS	

1. Details of treatments are given in Table 1.
2. NS=not significant.

Integrated nutrient supply system increased fertilizer-use efficiency from 22.8% to 39.4% for N; 9.3% to 15.6% for P, and 80% to 94% for K (Prasad 1994). Integrated use of chemical fertilizers with biogas slurry, water hyacinth compost, and FYM @ 10 t ha^{-1} in combination with 30 kg P_2O_5 ha^{-1} gave higher yield than that of 60 kg P_2O_5 ha^{-1} as chemical fertilizer. These results indicate that the application of these organic manures can substitute 30 kg P_2O_5 ha^{-1} in rice production and their residual effect equivalent to 30 kg P_2O_5 ha^{-1} on succeeding wheat crop (Prasad 1994). The use of these organic manures not only helped in supplementing a part of phosphatic fertilizer but also improved physical properties and the overall soil productivity by augmenting soil organic carbon and nutrient status of soil.

The response of fertilizer to wheat in terms of kg grain kg^{-1} nutrients generally decreased during 1994–96 compared with 1988–89, whereas it increased in rice. The response of rice and wheat to crop residue incorporation is greater than the response to FYM application. The response of these crops to chemical fertilizers decreased with increasing levels of fertilizers (Table 3).

Root and stubble remains

When wheat and rice crops were harvested by the conventional method, about 7.1–12.4% and 6.4–7.2% of total dry matter production, respectively remained as root and stubbles in the

Table 3. Response of wheat and rice to applied nutrients through chemical fertilizers, organic manure, and crop residues in calcareous soil at Pusa, Bihar, India during 1988–93.

Treatment	Response (kg grain kg^{-1} nutrient)				
	1988/89	1989/90	1990/91	1991/92	1992/93
Wheat					
F1 + M0	10.2	10.2	6.9	4.7	11.2
F1 + M1	6.1	6.1	4.6	4.0	4.6
F1 + M2	6.5	6.0	9.5	3.0	7.5
F1 + M3	4.6	4.6	5.1	3.3	3.5
F2 + M0	9.9	9.9	10.0	7.2	7.0
F2 + M1	5.8	5.6	4.8	3.9	3.9
F2 + M2	6.9	6.6	6.6	5.1	5.8
F2 + M3	4.9	4.8	4.4	3.6	3.8
F3 + M0	7.2	5.9	5.2	5.0	5.9
F3 + M1	4.8	4.6	4.3	3.3	4.0
F3 + M2	5.2	5.0	5.8	3.5	5.4
F3 + M3	4.3	3.7	3.9	2.9	4.0
Mean	6.4	6.1	5.9	4.1	5.6
Rice					
F1 + M0	8.0	4.5	12.6	8.6	10.9
F1 + M1	3.1	4.1	2.4	3.9	4.6
F1 + M2	3.8	2.9	7.4	4.3	5.6
F1 + M3	2.9	2.9	4.6	3.2	3.5
F2 + M0	3.3	3.0	7.7	5.5	8.5
F2 + M1	3.4	3.6	5.3	3.5	4.2
F2 + M2	5.0	2.9	6.0	3.5	6.2
F2 + M3	3.9	2.9	4.3	3.4	4.0
F3 + M1	2.8	3.9	4.5	3.9	5.0
F3 + M2	3.9	2.6	5.2	3.0	7.0
F3 + M3	3.0	2.5	3.6	3.4	5.0
Mean	3.6	3.0	5.3	3.9	5.4

1. Details of treatments are given in Table 1.

field (Table 4). These values were less than those reported by Yoshida (1981) because of difference in climatic condition, soil types, methodology used for collection of data, and levels of crop and soil management. Root and stubble remains increased from 0.61 t ha^{-1} to 0.75 t ha^{-1} in wheat with increasing levels of fertilizers. Organic manure and crop residue incorporation influenced wheat and rice stubble remains in the order of FYM + crop residues > FYM > crop residues > no FYM or crop residues. The results confirm the findings of John et al. (1989).

Nutrients absorption and efficiencies of applied nutrients

The primary indicator of utilization of nutrients applied to the soil is their absorption by the crop as reflected in their uptake. The N, P, and K absorption by wheat and rice increased with increasing levels of fertilizers; micronutrients (Zn, Fe, Cu, and Mn) absorption increased up to 100% NPK and beyond this level, their absorption slightly declined (Table 5). The mean absorption of macro- and micronutrients by wheat and rice in plots treated with organic manure and crop residues were in the order: FYM + crop residues > FYM > crop residues > no organic manure or crop residues (Table 5). The utilization of P and micronutrients by wheat and rice enhanced with incorporation of crop residues and FYM. Numerous compounds such as humic and fulvic acids and a variety of biochemical substances (organic acids, polyphenols, aminoacids, and polysaccharides) released from organic manures form stable

Table 4. Effect of farmyard manure and crop residue on root and stubble remains of wheat and rice under rice-wheat cropping system in calcareous soil at Pusa, Bihar, India during 1989–92.[1]

Treatment[2]	Wheat root and stubbles (t ha^{-1})					Rice root and stubbles (t ha^{-1})				
	M0	M1	M2	M3	Mean	M0	M1	M2	M3	Mean
F0	0.57	0.64	0.59	0.65	0.61	0.41	0.47	0.42	0.52	0.46
	(14.7)	(11.5)	(12.7)	(10.6)	(12.4)	(8.4)	(6.9)	(7.1)	(6.5)	(7.2)
F1	0.60	0.68	0.66	0.69	0.66	0.52	0.52	0.51	0.55	0.53
	(10.8)	(7.3)	(8.0)	(7.7)	(7.7)	(7.4)	(5.7)	(6.5)	(5.8)	(6.4)
F2	0.66	0.73	0.70	0.78	0.72	0.55	0.61	0.60	0.66	0.61
	(7.2)	(7.0)	(7.1)	(7.1)	(7.1)	(6.8)	(6.0)	(6.7)	(6.7)	(6.4)
F3	0.69	0.77	0.74	0.80	0.75	0.57	0.64	0.62	0.68	0.63
	(7.7)	(7.6)	(7.7)	(7.4)	(7.6)	(7.3)	(6.6)	(7.2)	(6.5)	(6.9)
Mean	0.63	0.71	0.67	0.73	0.69	0.51	0.56	0.54	0.60	0.55
	(9.3)	(8.9)	(8.9)	(8.2)	(8.7)	(7.5)	(6.3)	(6.9)	(6.2)	(6.7)
			CD (P=0.5)					CD (P=0.5)		
Fertilizer (F)			0.08					0.05		
Manure (M)			0.06					0.04		
F × M			NS[3]					NS		

1. Values are pooled data of 3 years from 1989–92; figures in parentheses indicate percentage of total dry matter.
2. Details of F and M treatments are given in Table 1.
3. NS=not significant.

Table 5. Effect of organic manure, crop residues, and chemical fertilizers on average nutrient absorption by crops in calcareous soil at Pusa, Bihar, India during 1989–92.[1]

Treatment[2]	Nutrient uptake by wheat							Nutrient uptake by rice						
	N	P	K	Zn	Fe	Cu	Mn	N	P	K	Zn	Fe	Cu	Mn
	(kg ha^{-1})			(g ha^{-1})				(kg ha^{-1})			(g ha^{-1})			
F0 + M0	34.1	6.7	43.5	139	268	34	95	43.4	6.2	74.1	131	510	63	250
F0 + M1	44.5	10.2	65.7	124	504	62	149	60.2	10.2	96.0	243	788	114	484
F0 + M2	35.8	8.6	54.5	179	423	48	124	51.7	8.9	79.4	199	618	96	400
F0 + M3	49.1	12.6	69.9	250	558	71	170	64.9	12.8	128.0	307	960	137	556
F1 + M0	55.1	10.4	74.8	267	567	70	211	69.4	8.8	116.1	207	754	99	384
F1 + M1	71.4	15.1	102.7	394	1110	123	201	86.1	14.2	145.8	336	1368	178	621
F1 + M2	64.1	12.8	91.6	333	985	105	263	75.6	10.6	130.9	283	1187	155	531
F1 + M3	81.9	17.1	104.2	455	1141	140	331	93.5	15.5	155.2	263	1450	187	658
F2 + M0	69.5	14.9	93.9	351	690	94	279	85.6	13.0	132.3	260	910	121	454
F2 + M1	84.6	18.9	121.3	495	1432	181	392	104.8	15.5	161.9	400	1801	240	732
F2 + M2	74.6	15.6	107.6	436	1422	169	367	92.0	14.4	154.5	348	1552	260	647
F2 + M3	88.9	17.8	123.7	526	1489	215	415	107.8	20.3	170.9	440	1964	258	837
F3 + M0	73.3	16.4	98.0	340	670	89	267	87.8	13.5	141.0	247	870	112	433
F3 + M1	90.2	22.3	124.1	504	1440	190	409	108.5	16.8	177.2	411	1811	246	746
F3 + M2	80.4	17.5	112.2	441	1430	173	370	102.0	14.8	164.2	359	1537	266	647
F3 + M3	93.7	24.8	112.0	541	1499	224	431	112.4	18.4	190.7	451	1969	268	862
Mean	68.2	15.0	94.4	367	977	124	286	84.1	13.4	138.6	312	1253	175	578
CD (P=0.05)														
Fertilizer (F)	4.4	1.5	7.4	29.0	59.0	15	22	5.6	1.5	11.8	239	99	15	57
Manure (M)	4.3	1.2	7.5	26.3	51.6	8	21	4.4	1.1	10.5	161	59	9	36
F × M	NS[3]	NS	NS	NS	170.2	21	NS	NS	NS	NS	NS	143	22	80

1. Values are pooled data of 3 year from 1989–92.

2. Details of treatments are given in Table 1.

3. NS=not significant.

complexes with native miocronutrients (Prasad and Sinha 1980). Phosphorus and K-use efficiencies by rice were greater than that by wheat. Phosphate-use efficiency by wheat was higher than that by rice in calcareous soil. In such soils, volatilization loss of ammoniacal-N in wheat field is higher than that in rice field (Singh and Prasad 1992). The efficiency of applied P in wheat field was higher than that in rice field. Nitrogen and P-use efficiencies by crops in crop residue-treated plots at different levels of chemical fertilizers were greater than that of FYM-treated plots. These results can be substantiated with organic carbon built up in crop residue-treated plots being higher than that of FYM-treated plots. On the other hand K-use efficiency of applied K by rice through chemical fertilizers, organic manure, and crop residues was higher than that by wheat crop, indicating utilization of K by rice had been greater than that by wheat in calcareous soil. Efficiency of applied K of >100% indicated high utilization of K from native sources (Table 6).

Nutrients recycling through crop residues

Surplus crop residues can be recycled to agricultural land safely and will meet a part of nutrient needs of the crop and augment physical, chemical, and biological properties of soil environment. Incorporation of rice and wheat straw in soil under rice-wheat cropping system will replenish 37%, 19%, and 81% depletion of N, P, and K by wheat and 37%, 28%, and 85% removal of N, P, and K respectively by rice in calcareous soil (Table 7). Similarly, rice straw incorporation in soil recycled on an average 52%, 79%, 70%, and 69% removal of Zn, Fe, Cu, and Mn by wheat and wheat straw

Table 6. Efficiencies of applied nutrients (%) by rice and wheat through chemical fertilizer, organic manure, and crop residues in calcareous soil at Pusa, Bihar, India.

Treatment[1]	Wheat			Rice		
	N	P	K	N	P	K
F1 + M0	42	12	157	52	7	210
F1 + M1	23	9	100	26	9	122
F1 + M2	42	19	50	43	13	66
F1 + M3	23	11	40	26	10	42
F2 + M0	35	14	126	42	11	146
F2 + M1	24	10	99	29	8	111
F2 + M2	32	14	51	36	13	214
F2 + M3	22	9	45	26	11	43
F3 + M0	26	11	91	30	11	112
F3 + M1	21	10	81	25	7	104
F3 + M2	26	12	46	32	9	44
F3 + M3	20	11	34	23	8	44
Mean	28	12	77	33	10	105

1. Details of treatments are given in Table 1.

Table 7. **Nutrients recycling (percentage of total nutrient removal) through crop residue under rice-wheat cropping system in calcareous soil at Pusa, Bihar, India during 1989–92.**

Nutrient	Straw						Roots and stubble			
	Wheat			Rice			Wheat		Rice	
	1989/90	1990/91	1991/92	1989/90	1990/91	1991/92	1990/91	1991/92	1990/91	1991/92
N	39	34	37	36	38	37	5	5	4	4
P	19	17	19	27	28	28	3	3	2	2
K	83	79	81	84	86	85	27	23	15	14
Zn	52	48	52	60	62	61	29	26	31	29
Fe	80	77	79	81	82	82	44	39	98	96
Cu	71	69	70	73	73	73	29	26	20	19
Mn	70	67	69	82	83	83	42	38	81	77

incorporation also replenished 61%, 82%, 73%, and 83% depletion of Zn, Fe, Cu, and Mn respectively by rice under rice-wheat cropping system. Nutrients recycling is more or less the same in each year in rice-wheat system. Root and stubble remains of wheat and rice recycled considerable amount of Zn, Fe, Cu, and Mn. These results indicated that the requirement of micronutrients by rice and wheat could be met by recycling of crop residues (roots, stubbles, and straw). Of K removal by total harvest, about 78–87% is present in rice and wheat straw. About 80% K in straw is water soluble. The utilization rate of K in straw could be as high as 50–60% — almost the same as that with inorganic fertilizers. Similar results were also recorded by Yoshida (1981) in Japan. Potassium, Zn, Fe, Cu, and Mn can be recycled by incorporation of rice and wheat straw and soil can be protected from K and micronutrients depletion under intensive cropping systems.

Economics of crop residue recycling

Economics of crop residue recycling revealed that FYM, crop residues and FYM + crop residue incorporation in soil resulted in a profit of Rs 1,787, Rs 1,059, and Rs 2,425 respectively for wheat production, and Rs 1,750, Rs 700, and Rs 2,690 for rice production under rice-wheat cropping system. Similarly, benefit:cost ratio varied from 3.2 to 4.2 for wheat and from 3.2 to 3.6 for rice. These results indicated that organic and crop residue recycling in the cropping system in calcareous soil is profitable and economical.

Constraints in adoption of crop residue recycling

With the adoption of mechanical harvester in many parts of the country, rice and wheat straw is generally burnt in the field, due to ignorance of farmers, for quick composting of these materials by microbial inoculation. Proper technology either for composting or in situ incorporation of crop residue was not available among farmers in the villages. The farmers do not adopt scientific methods of composting such as proper moisture (50–60%), and turning of organic mass during composting of crop residues (2–3 turns) resulting in nutrient losses and poor quality of organic manure. They are not making serious efforts for preparation and conservation of organic manure and recycling of crop residue and animal residues.

The bulk of crop residues are used as cattle feed, being rich in silica and oxalic acid, or used as fuel. Straw is used as packing materials and for making paper and building board. Rice straw is also used as thatching materials for huts and temporary dwellings in villages. Rice and wheat straws are used as cattle feed or as fuel.

Changes in soil fertility status

Addition of total nutrients was more than their removal by the crops (Table 8). Available P, K, S, Zn, Fe, Cu, Mn, B, and Mo were increased significantly in soil when different levels of fertilizers were applied along with crop residues and organic manure (Table 9). Initial soil available N was not changed significantly with the addition of fertilizer and organic manure. Initial available K declined in soil when fertilizers, organic manure, and crop residues were applied alone. Initial available P, K, Zn, Fe, Cu, Mn, B, and Mo decreased when no fertilizers, organic manure, and crop residues were applied (Table 9). Addition of crop residues and organic manure along with chemical fertilizers helped to maintain sufficient levels of macro- and micronutrients and protect soil health from deterioration. Small and non-significant changes in available N in soil were found. Available N remained deficient in spite of integrated use of fertilizers with organic manure and crop residue. Addition of organic manure and crop residues increased available P and Zn from deficient to sufficient level. With the application of organic manure and crop residues

Table 8. Nutrient balance in rice-wheat cropping system in calcareous soil at Pusa, Bihar, India during 1989–92.[1]

Treatment[2]	Nitrogen (kg ha^{-1})			Phosphorus (kg P_2O_5 ha^{-1})			Potassium (kg K_2O ha^{-1})		
	Added	Removed	Balance	Added	Removed	Balance[2]	Added	Removed[2]	Balance
F0 + M0	–	50	–50	–	11	–11	–	22	–22
F0 + M1	132	68	+64	64	16	+48	80	41	+39
F0 + M2	33	55	–22	4	14	–10	108	26	+82
F0 + M3	174	72	+102	71	20	+51	243	35	+208
F1 + M0	100	84	+16	60	15	+45	40	28	+12
F1 + M1	232	110	+122	124	23	+101	120	41	+79
F1 + M2	148	92	+56	65	18	+47	228	39	+189
F1 + M3	297	110	+187	132	25	+107	347	32	+315
F2 + M0	200	100	+100	120	22	+98	80	35	+45
F2 + M1	332	119	+213	184	27	+157	160	45	+115
F2 + M2	263	104	+159	127	23	+104	299	43	+256
F2 + M3	408	121	+287	192	28	+164	406	59	+347
F3 + M0	300	100	+200	180	24	+156	120	40	+80
F3 + M1	432	132	+300	244	30	+214	200	60	+140
F3 + M2	367	115	+252	188	30	+158	352	44	+308
F3 + M3	514	124	+390	255	33	+222	467	56	+411
Mean	246	97	+149	126	23	+103	204	40	+164

1. Data is average of 3 years from 1989–92; nutrients added and removed by rice and wheat.

2. Details of treatments are given in Table 1.

Table 9. Changes in available nutrients in calcareous soil as influenced by recycling of crop residues and organic manure after five cycles of rice-wheat crop rotation at Pusa, Bihar, India.

Treatment[1]	Available nutrients[2]									
	N	P_2O_5	K_2O	S	Zn	Fe	Mn	Cu	B	Mo
	(kg ha^{-1})			(mg kg^{-1})						
F0 + M0	231	18	91	17.6	0.58	17.2	5.0	1.42	0.87	0.24
F0 + M1	237	42	94	19.5	0.70	21.5	5.5	1.38	0.95	0.28
F0 + M2	235	27	92	18.2	0.69	19.3	5.4	1.39	0.82	0.27
F0 + M3	240	46	94	21.5	0.71	21.9	5.1	1.43	1.02	0.30
F1 + M0	236	30	94	23.1	0.60	17.8	5.1	1.49	1.03	0.29
F1 + M1	240	63	105	24.2	0.72	22.5	6.0	1.62	1.11	0.31
F1 + M2	238	33	102	23.1	0.71	20.9	5.4	1.52	1.08	0.30
F1 + M3	240	70	107	25.6	0.74	22.6	6.4	1.67	1.18	0.33
F2 + M0	238	39	99	27.5	0.61	18.7	5.1	2.01	1.11	0.31
F2 + M1	240	71	109	28.5	0.76	21.8	6.2	2.65	1.19	0.23
F2 + M2	239	44	110	27.6	0.75	21.9	5.6	2.63	1.16	0.32
F2 + M3	243	74	112	30.4	0.78	23.5	6.3	2.73	1.26	0.35
F3 + M0	240	46	104	32.1	0.62	19.1	5.2	2.17	1.33	0.30
F3 + M1	242	74	111	33.3	0.79	23.5	6.3	2.69	1.43	0.34
F3 + M2	241	48	108	32.2	0.78	22.7	5.8	2.66	1.38	0.33
F3 + M3	244	74	117	35.4	0.81	24.6	6.4	2.75	1.48	0.36
Mean	239	50	103	26.2	0.71	21.2	5.7	2.01	0.30	
CD (P=0.05)										
Fertilizer (F)	NS[3]	8.0	5.3		0.03	NS	NS	0.14		
Manure (M)	NS	6.5	NS		0.02	1.3	0.51	0.11		
F × M	NS	NS	NS		NS	NS	NS	0.24		

1. Details of treatments are given in Table 1.
2. Initial soil available N, 236 kg ha^{-1}; available P_2O_5, 19 kg ha^{-1}; available K_2O, 100 kg ha^{-1}; available S, 18 mg kg^{-1}; available B, 0.8 mg kg^{-1}; available Mo, 0.26 mg kg^{-1} soil.
3. NS=not significant.

in calcareous soil, available S, Fe, Cu, Mn, B, and Mo increased from sufficient level to excess but not to toxic levels. The build-up of available macro- and micronutrients increased with increasing levels of fertilizers alone and along with crop residues and organic manure. The increase in available nutrients in soils was due to addition of these nutrients through fertilizers, organic manure, and crop residues and total nutrients added was more than that of the amount removed by crops (Table 8). The nutrient-complexing agents such as humic and fulvic acids produced during decomposition of organic manure and crop residues augmented solubility, mobility, and availability of insoluble micronutrients in calcareous soil. Organic carbon level in soils increased from 0.57% to 0.84% in 8 years in the treatment of 100% NPK + FYM + crop residues. The build-up of carbon was found in the order of 100% NPK + FYM + crop residues (0.84%) $\geq$ 100% NPK+ crop residues (0.84%)> 100% NPK+ FYM (0.75%)> 100% NPK (0.68%). Amelioration of multiple micronutrient deficiencies in the cropping system is possible by integrated nutrient management and nutrient recycling through crop residue management.

Changes in soil physical properties

Organic matter is important to augment physical environment of soils. The application of crop residues and organic manures compared with the control improved soil aggregation, porosity, hydraulic conductivity, infiltration rate, and available water-storage capacity (Table 10). Biswas et al. (1971) reported that the application of crop residues improved soil structure and tilth. A good soil structure provides better environment for root development and aeration. The water-holding capacity of the soil increases

Table 10. Effect of crop residues, organic manures, and chemical fertilizer application on some physical properties of soil at Pusa, Bihar, India.

Treatment[1]	Soil aggregates >0.25 mm (%)	Bulk density (g cm^{-3})	Total porosity (%)	Hydraulic conductivity ($\times 10^4$ cm h^{-1})	Infiltration rate (cm h^{-1})	Penetration resistance (MPa)	Available water (v/v)
F0 + M0	36.0	1.51	40.2	205	0.35	1.29	30.0
F0 + M1	38.5	1.43	42.4	246	0.55	1.25	31.5
F0 + M2	43.9	1.40	45.1	307	0.45	1.19	33.6
F0 + M3	47.1	1.35	46.9	335	0.45	1.04	34.2
F1 + M0	39.3	1.45	41.0	234	0.50	1.28	32.9
F1 + M1	40.2	1.43	43.7	255	0.45	1.23	32.2
F1 + M2	42.2	1.39	44.7	306	0.35	1.20	33.4
F1 + M3	40.5	1.38	46.7	283	0.55	1.10	33.5
F2 + M0	37.2	1.44	43.0	242	0.35	1.26	32.7
F2 + M1	40.1	1.41	43.1	279	0.40	1.20	33.6
F2 + M2	40.8	1.38	45.0	302	0.45	1.24	32.1
F2 + M3	44.4	1.36	46.7	337	0.35	1.07	34.0
F3 + M0	36.4	1.47	41.1	219	0.40	1.07	30.7
F3 + M1	38.9	1.46	41.7	231	0.45	1.27	30.7
F3 + M2	37.1	1.45	42.6	254	0.40	1.26	31.3
F3 + M3	38.2	1.42	43.5	270	0.60	1.21	31.5
Mean	40.1	1.42	43.6	270	0.44	1.70	32.4
CD (P = 0.05)							
Fertilizer (F)	1.48	NS[2]	NS	16		NS	1.52
Manure (M)	1.58	NS	3.15	5		0.04	1.16
F × M	2.96	NS	NS	32		NS	NS

1. Details of treatments are given in Table 1.

2. NS=not significant.

significantly compared with soil receiving no crop residues which gives protection to the crops against drought. Improvement in soil aggregation is attributed to the action of polysaccharides and fulvic acid component of organic matter. The organic manure incorporation decreased bulk density (1.51 to 1.42 g cm^{-3}), and penetration resistance (1.25 to 1.21 MPa) (Prasad 1995).

The effects of fertilizer, and organic manure and their interaction were statistically significant on soil aggregation and hydraulic conductivity. The treatment effect on bulk density was not significant. The application of organic manure affected porosity, penetration resistance, and available water-storage capacity significantly.

Long-term fertilizer experiments conducted in Bihar indicated generally a declining trend in productivity even with application of N, P, and K under rice-wheat cropping system. The deterioration in the productivity was found associated with multiple nutrient deficiencies. Neither organic manure or crop residues alone nor chemical fertilizers can achieve the yield sustainability under this cropping system where nutrients turnover in soil plant system has been much higher. However, integrated nutrient management and nutrient recycling through organic manure and crop residue management hold great promise in achieving not only a high level of soil fertility and crop productivity, but also against emergence of multiple nutrient deficiencies from deterioration of soil health. Integrated nutrient management leads to sustainable rice and wheat production in rice-wheat cropping system.

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