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Long-term effect of integrated nutrient management on yield sustainability and soil fertility of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A long-term experiment was conducted on integrated nutrient management in rice (Oryza sativa)–wheat (*Triticum aestivum* L. emend. Fiori & Paol.) system at Jabalpur (Madhya Pradesh) since rainy (*kharif*) season 1987–88 to maintain the sustainable and high grain yields of this system without degradation of soil health under irrigated production system. The present paper deals with the studies conducted during the 2002–03 and 2003–04. Substituion of 50% N by green leaf manuring with sunnhemp (*Crotalaria juncea* L.) attained highest system productivity (33.12 kg grain/ha/day). While determining the sustainability yield index (SYI), the value was also maximum with 50% NPK + 50% N through green manuring with sunnhemp to rice, followed by 100% NPK to wheat. Maximum soil available nitrogen, phosphorus, potassium, sulphur and zinc, and minimum bulk density were noticed with substitution of 50% N by green manure. However, the pH value and EC were almost constant in all the treatments. Integrated use of 50% NPK and 50% N through green manuring of sunnhemp to rice followed by 100% NPK to wheat also fetched the maximum net monetary returns (Rs 34,403/ha/year) with the benefit: cost ratio 2.40.

Key words: Integrated nutrient management, Green leaf manure, FYM, Wheat straw, Rice–wheat cropping system, SYI

Rice–wheat cropping system is predominant under irrigated agroecosystem as well as lowlands of high rainfall areas in south-eastern and central parts of Madhya Pradesh. This system contributes more than one-fourth to total foodgrain production (Singh *et al.*, 2003) and is the backbone of food security in India. Both rice and wheat crops grown in a sequence require high quantity of nutrients to harness their potential yields (Hegde and Pandey, 1989). However, it is unaffordable to poor and subsistence farmers of the state. Application of inadequate and unbalanced quantity of fertilizers to these crops not only results low crop yields, but also deteriorates the soil properties also (Sharma *et al.*, 2003). Therefore, a long-term experiment is in progress on integrated nutrient management in rice–wheat system at Jabalpur (Madhya Pradesh) since rainy (*kharif*) season of 1987–88 for obtaining the effect of sustainability of crop yields and soil health and to identify the best integrated nutrient management (INM) practice in rice–wheat production system.

MATERIALS AND METHODS

The soil was neutral (soil pH 7.7) and normal in EC (0.38 dS/m) with medium organic carbon (OC) 6.9 g/kg, available N (260 kg/ha), available P (16 kg/ha) and high available K (448 kg/ha) contents. Total 12 treatments comprising 4 treatments of different levels of recommended fertilizers, 6 of integration of inorganic and organic sources of nutrient like green leaf manure (GLM) of sunnhemp, farmyard manure (FYM) and wheat straw, along with no-application of nutrients (control) and farmers' practice of manuring (40 kg N + 20 kg P_2O_5 + 3 tonnes FYM/ha to rice followed by 40 kg N + 20 kg P_2O_5 to wheat) were imposed. Different organic manures, viz. FYM (1.22, 0.55, 0.90% and 1.18, 0.48, 1.02% N, P, K in 2002–03 and 2003–04 respectively) and GLM of sunnhemp (2.21, 0.48, 1.77% and 2.30, 0.51, 1.79% N, P, K in 2002–03 and 2003–04 respectively) were analysed and their quantities, required to substitute a specified amount of N as per the treatments, were calculated. Recommended NPK for both the crops were 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha. These were applied as per the treatment through urea, single superphosphate and muriate of potash respectively. The data were recorded for 2002–03 and 2003–04 on different parameters and were pooled as differences between the years were not significant.

During both the years, rice (cv. 'Kranti') was grown by using 40 kg seeds/ha under transplanting with 20 cm x 15 cm planting geometry and the succeeding wheat (cv. 'Lok 1') was grown by using 100 kg seeds/ha in rows 20 cm apart. The crops were grown under assured irrigation as per need of crops. Other cultural practices, viz. weed management and plant-protection measures, were followed as per local recommendation. Data on grain yields of individual crops were recorded and than combined yield of entire cropping system was determined as wheat-equivalent yield and system productivity with the help of existing market price of rice and wheat grains.

For computation of sustainable yield index (SYI), the mean WEY for the years 1987–80 to 2003–04 were determined. The SYI was compuated by using the formula as suggested by Wanjari *et al.* (2004).

Bulk density, pH, EC, organic carbon, available N, P and K were estimated as per standard procedures. The changes in soil parameters over their initial status after completion of 17-crop cycles under each treatment were determined.

RESULTS AND DISCUSSION

Rice yield attributes

After 15 years of study, based on 2-years mean data (Table 1), the control treatment had the lowest ear-bearing tillers/m^2 and grains/panicle. The control treatment was followed by farmers' practice for these parameters. With increasing rates of fertilizer doses, these yield attributes increased correspondingly, but values recorded with the applications of 50% NPK to both the crops were at par with 50% NPK to rice crop followed by 100% NPK to wheat crop. Substitution of 50% N through green manuring with sunnhemp or FYM or wheat straw + 50% N to rice followed by 100% NPK to wheat crop or substitution of 25% N through green manuring with sunnhemp or FYM or wheat straw + 75% N to rice followed by 75% NPK to wheat crop was comparable to 100% NPK application to both crops. However, substitution of 50% N through green manure with sunnehmp resulted significantly higher number of effective tillers/m^2 (237) and grains/panicle (89.6) over all other treatments, except treatment of 50% N substitution by FYM. Different treatments in both years did not show significant variations in test weight of rice grains.

Wheat yield attributes

Similar to rice, minimum effective tillers/m^2 and grains/ear (Table 1) were recorded under the control treatment, followed by farmers' practice; increased with increasing rates of fertilizer alone or in combination with different organic manures. As in case of rice, substitution of 50% N

Table 1. Mean data of different yield attributes, grain yield, system productivity and sustainable yield index (SYI) of rice–wheat cropping system under different integrated nutrient management

Treatment		Yield attributes of rice			Yield attributes of wheat			Grain yield (q/ha)		System productivity (kg grain/ha/day)	SYI
Rice	Wheat	Effective tillers/m^2	Grains/ panicle	Test weight (g)	Effective tillers/m^2	Grains/ ear/pod	Test weight (g)	Rice	Wheat		
Control	Control	180	61.6	29.4	112	25.6	49.2	32.7	8.4	14.0	0.27
50% NPK	50% NPK	205	72.1	29.4	154	30.0	49.4	46.0	25.0	24.5	0.48
50% NPK	100% NPK	203	72.9	29.5	199	36.1	49.4	44.9	31.5	26.5	0.56
75% NPK	75% NPK	213	80.1	29.5	168	36.5	49.5	51.8	28.0	27.5	0.60
100% NPK	100% NPK	224	84.5	29.2	218	37.1	49.3	55.5	33.7	30.8	0.71
50% NPK + 50% N through FYM	100% NPK	235	86.4	29.1	222	39.0	49.5	58.5	34.2	32.0	0.69
75% NPK + 25% N through FYM	75% NPK	223	85.8	29.6	202	36.1	49.5	55.5	32.8	30.6	0.69
50% NPK + 50% N through WS	100% NPK	227	83.0	29.1	211	37.0	49.4	56.2	33.0	30.9	0.64
75% NPK + 25% N through WS	75% NPK	218	82.7	29.1	191	36.1	49.6	52.2	31.0	28.8	0.61
50% NPK + 50% N through GLM	100% NPK	237	89.6	29.6	224	39.0	49.3	61.3	34.7	33.1	0.73
75% NPK + 25% N through GLM	75% NPK	229	84.1	29.9	203	36.9	49.3	56.8	33.7	31.2	0.68
N:P (40:20 kg/ha) + 3 tonnes FYM/ha	N:P (40:20 kg/ha)	196	74.9	29.4	126	30.8	49.3	43.2	19.4	21.6	0.42
CD (P=0.05)		7	5.8	NS	13	2.1	NS	2.8	0.8	1.0	

through green manuring (sunnhemp) or FYM or wheat straw + 50% N to rice followed by 100% NPK to wheat crop or substitution of 25% N through green manuring with sunnhemp or FYM or wheat straw + 75% N to rice followed by 75% NPK to wheat crop was comparable to 100% NPK application to both crops for these yield attributes. Substitution of 50% N with green manure was found to be the best among all the treatments. Test weight of grains in wheat did not show marked variations due to different treatments in both years.

System productivity

The productivity of rice–wheat system as a whole, increased significantly with the increasing rate of NPK application as 50, 75 and 100% of recommended dose of fertilizers (NPK) to both crops (Table 1). Application of 50% NPK to rice followed by 100% NPK to wheat (T_3) resulted in significantly lesser system productivity (26.45 grain/ha/day) than the same quantity of NPK (75% NPK to both crops) applied for entire cropping sytem under T_4 treatment (27.56 kg grain/ha/day). It indicates that application of fertilizers to rice was more conducive to enhance the productivity of entire cropping system than its application to wheat, particularly with low rate of fertilizer application.

The farmers' practice of plant nutrient management (T_{12}) also showed significantly higher system productivity than control. Although T_{12} and T_2 treatments supply nearly same quantity of nutrients to crops, but former had lesser system productivity than later. Integrated use of 50% N through FYM or wheat straw or green leaf manuring with sunnhemp + 50% NPK to rice followed by 100% NPK to wheat or 25% N through FYM or wheat straw or green manuring + 75% NPK to rice followed by 75% NPK to wheat were comparabale to application of 100% NPK to both crops in terms of system productivity of entire cropping system.

Among the organic manures, substitution of 50% N by green manuring with sunnhemp (33.12 kg grain/ha/day) and FYM (32.01 kg grain/ha/day) attained significantly higher system productivity by 6.88% and 3.62% over 100% recommended dose of fertilizers to both crops. While 50% N substitution by wheat straw in rice crop was at par with 100% NPK application to both crops (Table 1). As a whole, 50% NPK fertilizers may be substituted with integrated use of FYM or green manure or wheat straw in rice under rice–wheat system without sacrificing the productivity. Sharma and Medhi (2001) also reported similar results.

Sustainability in crop yields

For sustainability yield index (SYI), the value was maximum (0.73) with 50% NPK + 50% N through green manuring with sunnhemp to rice followed by 100% NPK to wheat (Table 1). Green manuring with sunnhemp might have helped release N, P, K, Zn and S speedily and as per the need of crop growth throughout the crop cycle. The INM treatments comprising FYM or green manuring had identical SYI values to application of 100% NPK in both the crops. The SYI was slightly lesser (0.61 to 0.64) under integration of wheat straw as a source of nutrient than 100% NPK to both crops (0.71) because of poor grain yields of crops during the initial 5 years of experimentation. The SYI values were quite lesser where no manures and fertilizers were applied (0.27) or 50 to 75% NPK were applied (0.48 to 0.60). The farmers' practiace of nutrient management (T_{12}) had quite lesser SYI (0.42) than all above-mentioned treatments, but it was markedly higher than the SYI of the control treatment. Sinha *et al.* (2002) also reported similar results in rice–wheat cropping system.

Soil fertility

Application of NPK through fertilizers up to 75% of recommended levels in both the crops markedly reduced P, K, S and Zn contents of soil from their initial status up to completion of 17 crop-cycle of the rice-wheat sequence (Table 2). However, OC, N, K, S and Zn contents of soil showed rising trend with maintaining stability of P contents under all INM treatments. The farmers' practice of plant nutrient management (T_{12}) had soil OC and N comparable to all INM treatments as well as 100% NPK application to both crops, but soil S and Zn status was found stable to its initial level. There was no any remarkable change over parental status in soil pH and EC due to different treatments , but bulk density of soil reduced markedly due to different combinations of organic and inorganic fertilizer sources of nutrients compared to application of only inorganic fertilizers. Maximum increase in OC, N, K, S and Zn contents of soil and minimum bulk density were found in green-manured plot with 50% N substitution. All these beneficial effects on soil properties owing to integration of inorganic and organic sources of nutrients resulted in the sustainable productivity of rice–wheat cropping system on long-term basis. These results are in close conformity to the findings of Yaduvanshi (2001).

Nutrient uptake by rice–wheat system

Nitrogen: Total N uptake by rice–wheat system (Table 3) was the minimum under control treatment, but increased by applying fertilizers with different levels alone and in combination with different organic manures such as FYM (T_6 and T_7), wheat straw (T_8 and T_9) and green ma-

Table 2. Changes in soil properties over their initial status due to continuous rice–wheat cropping up to end of 2003–04 under different integrated nutrient management

Treatment		Soil pH	EC	BD	OC	N	P	K	S	Zn
Rice	Wheat		(dS/m)	(g/cm^3)	(g/kg)		(kg/ha)			(g/kg)
Initial**		7.7	0.39	NA	6.9	260	16	448	7.8*	0.35*
Control	Control	7.64	0.53	1.36	6.40	246	8.9	296	6.8	0.28
50% NPK	50% NPK	7.63	0.52	1.35	6.5	251	9.0	322	7.3	0.29
50% NPK	100% NPK	7.58	0.54	1.35	6.71	254	9.1	342	7.2	0.31
75% NPK	75% NPK	7.67	0.54	1.34	7.07	270	13.1	435	7.2	0.34
100% NPK	100% NPK	7.67	0.53	1.34	6.81	257	10.7	384	1.2	0.30
50% NPK + 50% N through FYM	100% NPK	7.48	0.56	1.28	7.40	269	16.0	453	8.2	0.40
75% NPK + 25% N through FYM	75% NPK	7.68	0.57	1.29	7.35	269	15.7	472	8.1	0.39
50% NPK + 50% N through WS	100% NPK	7.57	0.56	1.32	7.59	272	15.3	492	8.1	0.38
75% NPK + 25% N through WS	75% NPK	7.57	0.54	1.33	7.52	270	16.6	455	8.0	0.35
50% NPK + 50% N through GLM	100% NPK	7.56	0.57	1.26	7.74	276	16.9	486	8.3	0.43
75% NPK + 25% N through GLM	75% NPK	7.70	0.58	1.28	7.42	270	15.9	470	8.2	0.41
N:P (40:20 kg/ha) + 3 tonnes FYM/ha	N:P (40:20 kg/ha)	7.60	0.55	1.33	7.11	265	14.8	444	7.8	0.35
CD (P=0.05)		NS	NS	0.04	0.64	13	1.9	43.2	0.5	0.03

*Initial status during the year 1993–94, **initial status during the year 1987–88

Table 3. Mean nutrient uptake and economics of rice–wheat cropping system under different integrated nutrient management

Treatments		NPK uptake by rice (kg/ha)			NPK uptake by wheat (kg/ha)			NPK uptake by system (kg/ha)			NMR (Rs/ha)	B:C ratio
Rice	Wheat	N	P	K	N	P	K	N	P	K		
Control	Control	75.4	12.4	84.2	20.3	4.8	15.9	95.6	17.1	100.1	6,744	1.38
50% NPK	50% NPK	105.4	16.6	117.4	55.3	13.0	46.6	160.6	29.6	164.0	22,844	2.10
50% NPK	100% NPK	99.8	16.4	110.3	72.6	16.0	58.4	172.5	32.4	168.7	24,989	2.13
75% NPK	75% NPK	116.1	19.1	131.2	62.6	14.6	51.1	178.7	33.7	182.3	26,776	2.21
100% NPK	100% NPK	128.9	23.4	139.1	85.2	19.6	63.7	214.1	43.0	202.8	31,407	2.33
50% NPK + 50% N through FYM	100% NPK	129.4	20.3	145.0	75.2	17.1	63.4	204.5	37.3	208.4	33,115	2.38
75% NPK + 25% N through FYM	75% NPK	125.9	21.7	135.7	75.9	17.3	58.5	201.8	39.0	194.2	31,326	2.36
50% NPK + 50% N through WS	100% NPK	132.4	22.5	142.8	78.4	17.2	59.6	210.8	39.6	602.4	29,246	2.13
75% NPK + 25% N through WS	75% NPK	120.1	19.3	129.6	74.3	15.9	53.1	194.4	35.3	182.7	27,248	2.14
50% NPK + 50% N through GLM	100% NPK	134.5	21.2	147.9	76.7	17.4	58.8	211.2	38.6	206.7	34,403	2.4
75% NPK + 25% N through GLM	75% NPK	128.8	21.2	140.3	77.4	17.7	55.7	206.2	38.9	196.0	32,315	2.38
N:P (40:20 kg/ha) + 3 tonnes FYM/ha	N:P (40:20 kg/ha)	96.0	17.0	105.6	46.0	10.6	36.5	142.0	27.6	142.1	18,100	1.91
CD (P=0.05)		8.2	3.8	8.6	10.0	2.4	6.8	12.3	5.1	15.9	1,667	0.08

nure (T_{10} and T_{11}). Application of nutrients in rice–wheat system as per farmers' practice also showed significantly more N uptake than the control (Table 3). The N uptake was maximum with 100% NPK application to both crops (214.1 kg/ha), followed by integrated use of 50% N through green leaf manuring with sunnhemp or FYM or wheat straw + 50% NPK to rice, followed by 100% NPK to wheat or 25% N through green manuring or FYM + 75% NPK to rice, followed by 75% NPK to wheat.

Phosphorus: Like N uptake the mean total uptake of P by rice–wheat system was also significantly minimum with the control among all treatments (Table 3). Increasing rates of fertilizer doses to both crops as T_2, T_3, T_4 and T_5 under rice–wheat system resulted in corresponding increase in P uptake, but differences among T_2, T_3 and T_4 were not much. Integration of FYM under T_6, T_7 or wheat straw under T_8 or green manuring under T_{10} and T_{11} along with fertilizers removed almost similar quantity of P as under T_5. Though application of fertilizers with wheat straw under T_9 removed numerically higher quanity of P than application of fertilizers alone with different fertilizer levels except to T_5, differences were not significant.

Potassium: The mean total K uptake (Table 3) by rice–wheat system was significantly increased with the use of fertilizers under different doses either alone (T_2, T_3, T_4 and T_5) or in combination with organic manures like FYM (T_6, T_7), wheat straw (T_8, T_9) or green manures (T_{10}, T_{11}). Treatment of farmers' practice of plant nutrition (T_{12}) also re-

moved significantly greater quantity of K than the control treatment. The K uptake was the maximum with the treatment T_6 (208.4 kg/ha), followed by T_{10}, T_5, T_{11} and T_7.

Economics

The application of every increasing rate of balanced nutrients as 50, 75 and 100% NPK to both crops significantly increased the NMR and benefit : cost (B:C) ratio. These parameters were either comparable or slightly high under different INM treatments compared to application of 100% NPK to both crops. Application of 50% NPK + 50% N through green manure to rice followed by 100% NPK to wheat fetched maximum NMR (Rs 34,403/ha/year) with the highest B:C ratio (2.40). The integration of FYM in place of green manure was equally good for NMR and B:C ratio. Other INM treatments, viz. integration of green manure or FYM with low level (equivalent to 25% N), under T_{11} and T_7 or wheat straw with high level (equivalent to 50% N) under T_8 also led to register comparable NMR and B:C ratio to T_5 (application of 100% NPK to both crops).

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