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Research Paper

Influence of long-term integrated nutrient management on productivity and soil properties in rice (*Oryza sativa*)–rice cropping system in an acidic soil

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ABSTRACT

A permanent plot experiment on integrated nutrient supply system with 12 treatments replicated thrice in rice (*Oryza sativa* L.)–rice cropping system was conducted during 1983–84 to 2013–14 at Chiplima in a sandy loam soil. The soil had *p*H 5.4 and organic carbon 0.62%. Application of 50% recommended dose of nutrients through chemical fertilizers (RDF, i.e. N:P:K @ 100-22-41.3 kg/ha) coupled with 50% recommended N through green manuring of *Sesbania cannabina* to the rainy season (*kharif*) rice followed by supply of 100% RDF through chemical fertilizers to summer rice resulted in higher average (of 31 years) system yield of 9.32 t/ha/year. This treatment combination increased average system yield by 7, 25 and 122% over application of RDF, farmers' practice (N:P:K @ 50-11-20.7 kg/ha + 2 t FYM/ha for both crops) and control (without application of any fertilizer) respectively. This treatment also recorded the highest system gross returns (₹115,030/ha), net returns (₹59,284/ha) and benefit: cost ratio (2.06). Application of 50% RDF through fertilizers coupled with 50% recommended N through FYM to *kharif* rice followed by supply of 100% RDF through chemical fertilizers to summer rice was the second best treatment combination with system grain yield 9.21 t/ha/year, system gross returns (₹113,520) and net returns (₹54,874/ha). These were also most sustainable and improved soil physico-chemical properties with respect to bulk density, soil organic carbon, available NPK, microbial biomass carbon and soil nutrient balance.

***Key words* :** Cropping system, Long-term fertilizer experiment, Nutrient balance, Rice, Soil physico-chemical-microbial properties, Sustainable yield index, System yield

Rice in Odisha is synonymous to food and agriculture. It is the most widely cultivated crop in the state and covers 77% of total cropped area, 80% of total area under foodgrains and 95.7% of total area under cereals, contributing 78.3% to agricultural production, 93% of total foodgrain production and 97% of total cereal production (Government of Odisha, 2015). Out of several rice-based cropping patterns followed in the state, rice–rice is most important, especially in the irrigated areas. But productivity of rice in Odisha is one of the lowest in the country, mostly because of inadequate and imbalanced supply of plant nutrients. The poor economic condition of the rice farmers of the state is one of the major causes of low dose of fertilizers. The cropping intensity of the state is 167% and fertilizer consumption is as low as 58.74 kg/ha. With regard to rice cultivation, the farmers of Hirakud command areas apply 50 kg N and 11 kg each of P and 20.7 kg K along with 2 t FYM/ha.

Since rice is the staple food crop of the state, it is necessary to increase the productivity of rice–rice system to meet the food requirement of the burgeoning population. Not only the productivity has to be increased but it should be sustainable also over the years. It is widely recognized that the recommended dose of NPK fertilizers alone cannot sustain soil productivity under continuous intensive cropping (Yaduvanshi and Sharma, 2010). On the other hand, organic manures concurrently improve soil physical, chemical and biological properties, and as a result crop yields. Thus, increasing the productivity and sustainability of rice–rice system through judicious combination of organic and inorganic sources of plant nutrients is important to economize fertilizer use, besides maintaining productivity and soil health in a long run. Keeping these in view, a permanent plot experiment on integrated nutrient supply system in rice–rice crop sequence in Odisha was started in 1983–84 at Regional Research and Technology Transfer Station, Orissa University of Agriculture and Technology,

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Chiplima, Odisha, to find out sustainability of integrated nutrient management practices in rice–rice system.

MATERIALS AND METHODS

A long-term (31 years) field experiment was conducted from 1983–84 to 2013–14 at Regional Research and Technology Transfer Station, Orissa University of Agriculture and Technology, Chiplima, Odisha (21° 38' N, 83° 90' E, 144 m above mean sea-level) under irrigated ecosystem. The Chiplima soil belongs to *Typic Haplustalfs*. The soil was sandy loam (sand 62%, silt 18% and clay 20%), having *p*H 5.4, bulk density 1.51 g/cm^3, organic carbon 0.62%, available N, P and K of 295.4, 10.2 and 185.4 kg/ha respectively. Chiplima has a hot humid climate with mean annual rainfall of 1,496 mm, received mostly in the monsoon months from July to September. The mean maximum and minimum temperature was 33.8 and 22.0°C respectively. The experiment was conducted in a permanently laid out plot in randomized block design with 12 treatments replicated thrice (Table 1).

The organic sources of nutrients used in the experiment such as farm yard manure (FYM), paddy straw and green manuring of *Sesbania cannabina* were analysed for nitrogen content and their quantities, required to substitute a specified amount of N (75, 50 or 25%) as per the treatments were calculated. The N, P, K contents of FYM, paddy straw and of *Sesbania cannabina* on air-dry weight basis were 0.58, 0.29, 0.66%, 0.46, 0.12, 1.70%, and 2.86, 0.59, 1.21%, respectively. The inorganic sources were N, P and K containing fertilizers such as urea, single superphosphate and muriate of potash respectively. In case of organic nutrient management, all manures were applied before final land preparation and thoroughly incorporated in the soil. In case of inorganic nutrient management, whole quantity of P and K were applied basal and N was applied in split doses, 25% of N was applied basal, 50% of N was top-dressed at tillering and remaining 25% of N at panicle-initiation stage. The plot size was 10 m × 8 m. The test varieties were 'Meher', 'Swarna' and 'Pratiksha' for rainy season (135–145 days duration) and 'Lalat', 'Khandagiri' and 'Naveen' for summer (120–130 days duration). Standard agronomic management practices were followed to raise the crop.

Soil samples were drawn at initial (in 1983) and at the end of each cropping cycle (up to 31 cropping cycle) from a depth of 0–15 cm from each treatment and soil organic carbon (SOC), N, P and K content were analysed using standard procedures (Jackson, 1973). A portion of fresh soil samples were passed through a 2 mm sieve and stored at 4°C for determination of microbial population (Clark, 1965) and soil microbial biomass carbon (MBC) (Anderson and Domsch, 1978).

Grain and straw yields of rice were recorded in each season and system yields were calculated for each cycle. System yield trends were analysed on 5-yearly average basis (1983–88, 1988–93, 1993–98, 1998–2003, 2003–08) except for 2008–14 which was on 6-years average basis. Average yields for each treatment were also calculated over 31 cropping system cycles at the end of experiment. The treatment with recommended dose of inorganic nutrients was taken as reference treatment and increase or decrease in system yield was calculated for each treatment on 5-yearly average basis over this treatment for comparison. For economic analysis (cost of cultivation and net return) cost of inputs and price of outputs were used from 31 cycle (2013–14) for all the years. Sustainable yield index (SYI) (i.e., the ratio of minimum assured grain yield to maximum observed yield) for each treatment was also calculated using standard procedure. Statistical analyses

Table 1. Treatment details

Treatment	Rainy season	Summer season
T_1	No manure and fertilizers (control)	No manure and fertilizers (control)
T_2	50% recommended dose of fertilizers (RDF) through fertilizers	50% RDF through fertilizers
T_3	50% RDF through fertilizers	100% RDF through fertilizers
T_4	75% RDF through fertilizers	75% RDF through fertilizers
T_5	100% RDF through fertilizers	100% RDF through fertilizers
T_6	50% RDF through fertilizers + 50% N through farmyard manure (FYM)	100% RDF through fertilizers
T_7	75% RDF through fertilizers + 25% N through FYM	75% RDF through fertilizers
T_8	50% RDF through fertilizers + 50% N through paddy straw	100% RDF through fertilizers
T_9	75% RDF through fertilizers + 25% N through paddy straw	75% RDF through fertilizers
T_{10}	50% RDF through fertilizers + 50% N as green manuring of *Sesbania cannabina*	100% RDF through fertilizers
T_{11}	75% RDF of NPK through fertilizer + 25% N as green manuring of *Sesbania cannabina*	75% RDF through fertilizers
T_{12}	Farmers' practice	Farmers' practice

Recommended dose of fertilizers, N:P:K @ 100-22-41.3 kg/ha for both rainy (*kharif*) and summer season crops; farmers' practice, N:P:K @ 50-11-20.7 kg/ha + 2 t FYM/ha for both crops were carried out using standard methodology of randomized block design.

RESULTS AND DISCUSSION

Grain and straw yields

Application of 50% recommended dose of nutrients through chemical fertilizers (RDF, i.e. N:P:K @ 100-22-41.3 kg/ha) coupled with 50% recommended N through green manuring of *Sesbania cannabina* to *kharif* rice followed by supply of 100% RDF (i.e., N:P:K @ 100-22-41.3 kg/ha) through chemical fertilizers to summer rice resulted in higher average (of 31 years) system yield of 9.32 t/ha/year (Table 2). This treatment combination increased the average system yield by 7, 25 and 122% over application of RDF, farmers' practice (N:P:K @ 50-11-20.7 kg/ha + 2 t FYM/ha for both crops) and control (without application of any fertilizer) respectively. Application of 50 % RDF through fertilizers coupled with 50% recommended N through FYM to *kharif* rice followed by supply of 100% RDF through chemical fertilizers to summer rice was the second best treatment combination with system grain yield 9.21 t/ha/year. Banerjee and Pal (2009) also observed higher system productivity in rice–rice system by reducing 50% RDF and supplementing 50% recommended N through green manuring to *kharif* rice followed by 100% RDF through chemical fertilizers to summer rice in a long-term fertility experiment. Presence of organic matter might have improved the physico-chemical properties of soil that resulted in increased productivity by increasing availability of plant nutrients (Surekha *et al.*, 2008). Further, organic matter also maintained regular supply of macro- and micronutrients in soil resulting in higher yields. Application of 50% RDF through fertilizers coupled with 50% recommended N through green manuring or FYM to *kharif* rice followed by supply of 100% RDF through fertilizers to summer rice also recorded significantly higher system straw yield compared to supply of 100% RDF through fertilizers to both the crops (Table 2), which corroborates the earlier findings of Sharma and Subehia (2014) in rice–wheat cropping system. However, supplementation of paddy straw as organic manure had no significant beneficial effect on 31-year average system grain or straw yields. Application of 50% RDF coupled with 50% recommended N through paddy straw to *kharif* season rice followed by supply of 100% RDF through chemical fertilizers to summer rice reduced the average system grain yield marginally compared to application of RDF to both season crops.

Reduction in RDF without supplementing any organic manure significantly reduced the system grain and straw yields compared to application of RDF. Application of 50% RDF to both the crops through fertilizers, 50% RDF

Table 2. Effect of integrated nutrient supply systems on system grain and straw yield (t/ha) of rice–rice cropping system over years (5 years average)

Treatment	Mean 1983–84 to 1987–88		Mean 1988–89 to 1992–93		Mean 1993–94 to 1997–98		Mean 1998–99 to 2002–03		Mean 2003–04 to 2007–08		Mean* 2008–09 to 2013–14		Mean+ 1983–84 to 2013–14		Sustainable yield index
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	
T_1	3.65	4.76	5.03	5.61	3.33	4.75	3.15	3.83	5.19	7.48	4.63	7.48	4.19	5.71	0.21
T_2	5.16	6.39	7.73	9.35	6.61	10.30	6.28	7.88	9.19	12.14	7.60	10.85	7.11	9.53	0.41
T_3	5.41	6.93	8.15	10.21	7.55	10.56	7.37	8.97	9.84	13.14	8.47	11.82	7.82	10.32	0.46
T_4	5.92	7.42	8.47	10.02	7.35	10.80	8.20	9.91	9.67	12.74	8.38	11.83	8.00	10.50	0.48
T_5	6.28	8.26	9.55	11.61	7.96	12.19	8.89	11.41	10.45	14.18	9.12	12.37	8.72	11.69	0.53
T_6	5.77	7.83	9.88	12.67	8.88	12.32	9.84	12.50	11.36	15.17	9.49	12.66	9.21	12.21	0.55
T_7	5.81	8.82	9.40	11.92	8.04	11.37	9.24	12.04	11.32	14.50	9.31	12.49	8.90	11.88	0.53
T_8	5.65	7.14	9.02	10.91	8.09	11.17	8.95	11.33	10.11	13.40	9.59	12.33	8.60	11.09	0.51
T_9	6.06	7.60	9.12	10.61	7.72	10.77	8.82	11.30	10.67	13.86	9.40	12.38	8.72	11.13	0.52
T_{10}	5.80	8.08	9.58	12.22	8.57	12.63	9.74	12.60	11.58	15.41	10.34	13.84	9.32	12.51	0.54
T_{11}	6.04	7.52	9.43	11.08	7.91	11.72	9.10	10.89	10.35	13.84	9.42	12.61	8.73	11.32	0.53
T_{12}	5.81	6.63	8.18	8.84	6.48	8.83	7.65	9.59	9.28	12.52	7.27	9.97	7.44	9.42	0.46
SEm±	0.05	0.23	0.03	0.34	0.03	0.62	0.04	0.44	0.05	0.46	0.04	0.55	0.07	0.28	
CD (P=0.05)	0.15	0.66	0.10	1.03	0.08	1.83	0.13	1.31	0.15	1.37	0.15	1.66	0.21	0.81	

Details of treatments are given in Table 1; *mean of 6 years data; +mean of 31 years data to *kharif* and 100% RDF to summer crop, and 75% RDF to both the crops reduced average system yield by 18, 10 and 8% compared to RDF. Upadhyay and Vishwakarma (2014) also observed declined system yield with the treatments receiving sub-optimal dose of nutrients, i.e. 50 and 75% RDF, without organic manures in rice–wheat system.

Yield trend analysis

Trend analysis of grain yield averaged over 5 years indicates that application of sub-optimal doses of chemical fertilizers reduced the system yield throughout the 31 years of experimentation compared to supply of 100% RDF. Reduction in yield due to supplementation of 25 and 50% N through organic sources was to the tune of 10% during initial five years, and the yield gap between 100% RDF and integrated nutrient management practices narrowed down with passage of time. Yield advantage owing to supplementation of N through green manuring and farmyard manure was noticed from 5th year onwards. However, the yield advantage owing to integration of paddy straw to supplement 50% N was observed only after 20 years. Green manuring of *Sesbania cannabina* having narrow C:N ratio (13:1) might have facilitated early release of nutrient like inorganic fertilizers as compared to paddy straw having wide C:N ratio (40:1), which in turn might have resulted in immobilization of applied fertilizer N resulting in slow and gradual release (Surekha *et al*., 2008).

Sustainable yield index

Application of 50% RDF coupled with 50% recommended N through green manuring of *Sesbania cannabina* to *kharif* rice followed by supply of 100% RDF to summer rice resulted in the highest sustainable yield index 0.55. The control treatment without application of any manures and fertilizers reduced the system yield of rice–rice sequence by 52% as compared to 100% RDF and was the most unsustainable practice with the lowest sustainable yield index (SYI) of 0.21, followed by the treatment with only 50% RDF to both season crops with yield reduction of 18% and SYI of 0.41. Upadhyay and Vishwakarma (2014) also reported similar results. The treatments with organic supplementation were more sustainable than those supplied with sub-optimal dose of inorganic fertilizers alone. Organic manure alone or in combination with inorganic fertilizers besides improving the physico-chemical and biological properties of soil might have prevented leaching and volatilization losses and its slow-release pattern might have supplied nutrients in optimal congruence with crop demand improving synthesis and translocation of metabolites to various reproductive structures resulting in improvement in its yield and yield attributes (Kumari *et al*., 2010).

Economics

Application of 50% RDF through fertilizers coupled with 50% recommended N through green manuring of *Sesbania cannabina* to *kharif* rice followed by supply of 100% RDF through fertilizers to summer rice recorded highest system gross returns ₹115,030 and net returns ₹59,284 with highest benefit: cost ratio 2.06 (Table 3). This treatment increased system net return by 59.3% over farmers' practice. Application of 50% RDF through fertilizers coupled with 50% recommended N through FYM to *kharif* rice followed by supply of 100% RDF through chemical fertilizers to summer rice was the second best treatment combination with system gross returns ₹113,520 and net returns ₹54,874.

Table 3. Economics of rice–rice cropping system as influenced by integrated nutrient management (mean of 31 years data)

Treatment	Cost of cultivation ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Benefit: cost ratio
T_1	48.7	3.1	1.06
T_2	50.9	36.8	1.72
T_3	52.2	44.1	1.84
T_4	52.1	46.4	1.89
T_5	53.3	54.3	2.02
T_6	58.6	54.9	1.94
T_7	55.3	54.5	1.98
T_8	58.5	47.2	1.81
T_9	55.2	51.8	1.94
T_{10}	55.7	59.3	2.06
T_{11}	55.0	52.3	1.95
T_{12}	52.1	39.1	1.75
SEm±		0.36	
CD (P=0.05)		1.06	

Details of treatments are given in Table 1; sale price (₹/t): rice grain, 11,000; rice straw, 1,000

Bulk density

The highest bulk density (1.54 mg/cm^3) of the soil at the end of 31 years of rice–rice cropping system was recorded with control plot where no manure or fertilizer was applied (Table 4). The lowest bulk density was 1.47 mg/cm^3 with the treatment that received 50% RDF and 50% N through green manuring of *Sesbania cannabina*. Addition of organic nutrient sources (farmyard manure, paddy straw, green manure) with inorganic fertilizers over the years reduced the bulk density of the soils compared to the soils treated with only inorganic fertilizers. The reduction of bulk density is related to the increase in organic carbon, which results in more pore space and good soil aggregation (Yaduvanshi and Sharma, 2010). The marginal decrease in bulk density under 100% RDF (1.51 mg/cm^3) over the control could be attributed to the increased biomass production with consequent increase in organic matter content of the soils.

Soil p*H*

The soil *p*H decreased from the initial level of 5.4 to 5.1 with the application of 100% RDF through inorganic fertilizers (Table 4). Sharma and Subehia (2014) also reported reduction of *p*H by continuous use of fertilizers over the years. The marginal increase in soil *p*H in treatments under integrated nutrient management might be due to moderating effect of organics like farm yard manure, paddy straw or green manuring of *Sesbania cannabina* over the years as it decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelating effect of organic molecules.

Soil organic carbon

Application of organic nutrient sources with inorganic fertilizers over 31 years resulted in increase in soil organic carbon (SOC) contents over the initial status of 0.62% and the increase was in the tune of 20 to 43%. The maximum build-up of SOC was observed in treatment applied with 50% RDF through fertilizers + 50% N as green manuring (Table 4). The increase in SOC owing to integrated use of inorganic and organics could be attributed to higher contribution of biomass to the soil in the form of better root growth, crop residues and the added organic nutrient sources (Upadhyay and Vishwakarma, 2014). The increase in SOC owing to use of inorganic fertilizers could also be attributed to higher contribution of biomass to the soil in the form of roots, stubbles and residues.

Microbial population

Practice of rice–rice cropping system for 31 years in succession, enhanced the microbial densities of the soils including control (Table 4). The maximum population of bacteria, fungi and actinomycetes was recorded from the soils receiving 50% RDF + 50% N as green mauring in *kharif* and 100% RDF in summer. Addition of organic nutrient sources with inorganic fertilizers showed a profound increase in the microbial population in comparison to chemical fertilizers used alone. The farmyard manure, paddy straw or green manure act as source of nutrients to the microbes and also as a substrate for decomposition and mineralization of nutrients, thereby creating a favourable condition for the proliferation of microbes in the soil (Bahadur *et al*., 2012).

Microbial biomass carbon

Although soil microbial biomass (MBC) represents only a small portion of overall soil organic matter, it is more dynamic than total soil organic matter and a better indicator of soil health and productivity. The MBC of soils at Chiplima varied from 129.4 µg C/g in control to the highest level of 279.6 µg C/g in soils treated with 50% RDF + 50% N through green manuring (Table 4). Addition of organics with inorganics for 31 years led to a substantial increase in MBC over application of inorganic fertilizers alone. The supply and availability of additional mineralizable and readily hydrolysable carbon due to or-

Table 4. Effect of integrated nutrient management practices in rice–rice system on physico-chemical and microbial properties of soils

Treatment	Bulk density (g/cm^3)	*p*H	Soil organic carbon (%)	Microbial population (cfu/g)			MBC (µg C/g)
				Bacteria (× 10^7)	Fungi (× 10^4)	Actinomycetes (× 10^6)	
T_1	1.54	5.34	0.61	20.3	12.3	12.9	129.4
T_2	1.51	5.30	0.71	26.7	15.1	16.2	191.4
T_3	1.52	5.18	0.67	24.3	14.1	15.2	172.5
T_4	1.52	5.23	0.69	25.1	14.6	15.7	181.6
T_5	1.51	5.10	0.70	25.5	15.3	16.8	186.3
T_6	1.48	5.86	0.85	31.6	17.1	18.3	257.7
T_7	1.50	5.49	0.74	29.3	15.5	17.2	217.4
T_8	1.49	6.12	0.81	30.1	16.6	17.9	235.8
T_9	1.50	5.67	0.77	30.1	15.7	17.4	226.3
T_{10}	1.47	6.15	0.88	33.3	17.8	18.9	279.6
T_{11}	1.49	5.81	0.77	30.4	16.1	17.7	231.4
T_{12}	1.52	5.40	0.64	23.3	12.8	14.1	157.7
SEm±				0.67	0.59	0.59	5.32
CD (P=0.05)				2.04	1.75	1.78	15.86
Initial	1.51	5.40	0.62	16.7	10.1	10.4	105.3

Details of treatments are given in Table 1; MBC, microbial biomass carbon in soil; cfu, colony-forming units ganics might be responsible for higher microbial activity and MBC in treatments applied with organics (Sharma and Subehia, 2014).

Available N, P and K

The soils under integrated nutrient management exhibited no increase in N content over initial (295.4 kg/ha) except the treatment under 50% RDF + 50% N through green manuring (329.5 kg/ha). The soils under control and imbalanced nutrient management exhibited a reduction in available N contents over the initial (Table 5).

The available P content of the soils varied from 7.2 kg/ha in the control to 14.1 kg/ha in treatments receiving 50% RDF + 50% N through green manuring in *kharif* followed by 100% RDF in summer through chemical fertilizers. Substitution of 25% N through any of the organic sources resulted in significant lower available P content in comparison to their 50% substitution. Enhanced available pool of soil P with the application of inorganic fertilizers in conjunction with organics might be due to the release of organic acids during decomposition which in turn helped in releasing P through solubilizing native P in the soil (Subehia and Sepehya, 2012). The soils under inorganic fertilization over the years exhibited a reduction in available P contents over the initial status.

Unlike N and P, the available K contents of the soils decreased from the initial status though the reduction was less in soils receiving both inorganic and organic nutrient sources. Application of inorganic fertilizers alone or in combination with organic nutrient sources recorded an increase in available K content of the soils over the control. The depletion of native K pool under inorganic fertilization is due to more crop removal compared to the addition. Higher available K under integrated treatments compared to inorganics might be due to the addition of organic matter that reduced K fixation and released K due to the interaction of organic matter with clay, besides the direct K addition to the pools of soil (Urkurkar *et al*., 2010).

Nutrient balance

The actual gain of N was observed only in soils with 50% N substitution as *Sesbania cannabina* (34.1 kg/ha) and farmyard manure (5.6 kg/ha) (Table 5). The highest N removal was registered in the treatment that received 100% RDF through fertilizers in both the seasons (5,486 kg/ha), followed by the treatment that received 50% RDF through fertilizers + 50% N through farmyard manure in *kharif* and 100% RDF through fertilizers in summer season (4,889 kg/ha). Almost all the soils exhibited positive N balance except the control, farmers' practice and 50% RDF in both the seasons. The soils under 50% N substitution through *Sesbania cannabina* registered the maximum

Table 5. Nutrient balance (kg/ha) as influenced by different nutrient management practices after completion of 31st rice–rice cropping cycles

Treatment	Nitrogen					Phosphorus					Potassium				
	Addition*	Removal*	Final soil status+	Actual gain/loss over initial status+	Balance+	Addition*	Removal*	Final soil status+	Actual gain/loss over initial status+	Balance+	Addition*	Removal*	Final soil status+	Actual gain/loss over initial status+	Balance+
T_1	0	2,113	240.0	−55.4	−2,057.4	0	1,046	7.2	−3.0	−1,043.3	0	2,741	81.4	−104.0	−2,637.0
T_2	3,100	3,556	265.0	−30.4	−425.6	677	1,341	8.1	−2.1	−662.2	1,287	3,846	96.6	−88.8	−2,470.7
T_3	4,650	4,480	263.8	−31.6	201.6	1015	1,567	8.8	−1.4	−550.5	1,930	4,345	97.8	−87.6	−2,327.7
T_4	4,650	4,460	256.0	−39.4	229.4	1015	1,565	8.7	−1.5	−548.4	1,930	4,327	98.7	−86.7	−2,310.6
T_5	6,200	5,486	270.0	−25.4	739.4	1353	1,727	9.2	−1.0	−372.5	2,573	4,720	102.1	−83.3	−2,063.7
T_6	6,200	4,889	301.0	5.6	1,305.1	1790	1,738	13.5	3.3	48.8	3,694	5,037	147.0	−38.4	−1,305.0
T_7	5,425	4,677	283.3	−12.1	759.9	1403	1,578	12.4	2.2	−177.6	2,812	4,788	137.8	−47.6	−1,928.7
T_8	6,200	4,910	294.0	−1.4	1,291.4	1419	1593	13.4	3.2	−176.8	7,658	5,495	158.6	−26.8	2,189.7
T_9	5,425	4,692	285.5	−9.9	742.9	1217	1,528	12.5	2.3	−313.0	4,794	5,023	146.9	−38.5	−190.7
T_{10}	6,200	4,842	329.5	34.1	1,323.9	1335	1,507	14.1	3.9	−176.0	2,586	4,847	153.6	−31.8	−2,229.7
T_{11}	5,425	4,656	287.3	−8.1	777.1	1175	1,478	12.5	2.3	−305.3	2,258	4,743	145.0	−40.4	−2,445.0
T_{12}	3,819	3,744	243.3	−52.1	127.3	1037	1,354	8.5	−1.7	−315.7	2,105	3,937	92.4	−93.0	−1,738.6

Details of treatment are given in Table 1; initial nutrient status in soil (1983): N, 295.4 kg/ha; P, 10.2 kg/ha; K, 185.4 kg/ha; *cumulative addition/ removal of 31cropping cycles; +after completion of 31st rice–rice cropping cycle positive N balance of 1,323.9 kg/ha.

The highest cumulative P uptake of 1,738 kg/ha was observed in the treatment with 50% N substitution as FYM (Table 5). The same treatment also registered the positive P balance of 48.8 kg/ha. The negative P balance observed in all other treatments is due to more removal of P by crops.

The maximum cumulative K uptake was observed in the soils with 50% N substituted as paddy straw (5,495 kg/ha). The soils of the same treatment also registered positive balance of 2,189 kg/ha. This may be attributed to higher addition of K through paddy straw. The soils under inorganics exhibited more negative K balance than those under integrated nutrient management because all organic sources were rich in K content and added more K to the soil without showing much variation in removal. More positive nutrient balance with organics and negative balance with chemical fertilizers were reported by Yadav *et al.* (2009).

Based on the study, it was concluded that application of 50% recommended dose of chemical fertilizers coupled with 50% recommended N through green manuring of *Sesbania cannabina* or through farmyard manure to rainy season (*kharif*) rice followed by supply of 100% recommended dose of nutrients through chemical fertilizers to summer rice can be recommended for rice–rice cropping system to maintain soil health and obtain sustainable yield and profit.

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