

Long-term effects of integrated nutrient management on productivity and soil properties of rice (*Oryza sativa*)–rice cropping system in coastal Odisha

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ABSTRACT

A long-term experiment was initiated in 1983–84 and continued for 31 years on integrated nutrient management (INM) in rice (*Oryza sativa* L.)–rice cropping system at Bhubaneswar, Odisha. The study was conducted on sandy loams under irrigated conditions in a permanently laid out plot in randomized block design with 12 treatments and 4 replications. Application of 50% recommended dose of chemical fertilizers (RDF) coupled with 50% recommended N through green manuring of azolla or through FYM to rainy season (*kharif*) rice followed by supply of 100% RDF through chemical fertilizers to summer rice resulted in higher system yield of 9.07 and 8.75 t/ha/year respectively. This INM treatment was also most sustainable and improved the physico-chemical properties of the soil with respect to bulk density, soil organic carbon, available NPK, microbial biomass carbon and soil nutrient balance. Reduction in RDF by 100, 50 and 25% without supplementing any organic manure reduced system yield by about 52, 23 and 10%, respectively compared to 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 RDF and INM practices narrowed down with passage of time. Yield advantage due to supplementation of N through green manuring was noticed after 10 years, whereas that of FYM after 15 years. On the other hand, no yield advantage was observed with supplementation of 25% N through paddy straw even after 31 years. Application of 50% RDF through fertilizers along with 50% recommended N through green manuring of azolla to rainy season (*kharif*) rice followed by supply of RDF through fertilizers to summer rice recorded the highest system gross returns ₹1,11,870 and net returns ₹65,644 with the highest benefit: cost ratio 2.42.

Key words : Integrated nutrient management, Long-term experiment, Nutrient balance, Physico-chemical-microbial properties of soil, Rice–rice cropping system, System yield

Rice–rice is the major cropping system in the irrigated areas of Odisha. But productivity of rice in Odisha is one of the lowest in the country, mostly because of inadequate and imbalanced supply of plant nutrients. Fertilizer consumption of the state is as low as 58.7 kg/ha. Poor economic condition of the rice farmers of the state is one of the major causes of low dose of fertilizers. With regard to rice cultivation, farmers of coastal areas were applying only 20 kgN/ha without any P or K, however, application of 2 t FYM/ha was a common practice with the farmers.

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. The recommended dose of NPK fertilizers alone does not sustain soil productivity under continuous intensive cropping (Yaduvanshi and Sharma, 2010), whereas inclusion of organic manures improves physical properties, the biological status of soil, soil fertility and crop yields (Yaduvanshi *et al.*, 2013). Thus, increasing the productivity and sustainability of rice–rice system through judicious combination of organic and inorganic sources of plant nutrients is important to economise on fertilizer use, besides maintaining productivity and soil health in the long run. A permanent plot experiment on ‘integrated nutrient supply system in rice–rice crop sequence’ in Odisha was started in 1983–84 under the All India Coordinated Research Project on Integrated Farming Systems at Central Research Station of Orissa University of Agriculture and Technology, Bhubaneswar.

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MATERIALS AND METHODS

A long-term (31-years) field experiment was conducted from 1983–84 to 2013–14 at Central Research Station, Orissa University of Agriculture and Technology, Bhubaneswar (20° 26' N, 85° 81' E, 34 m above mean sea level) under irrigated conditions. The soil at the study site is a sandy loam (sand 68%, silt 15% and clay 17%) and belongs to Typic Epiaquepts having pH 5.34, bulk density 1.50 Mg/m³, organic carbon 0.43%, available N, P and K of 254.2, 20.3 and 210.4 kg/ha respectively. The climate is hot and humid with an average annual rainfall of 1482 mm, received mostly in the monsoon months from July to September. The mean maximum and minimum temperature were 31.5 and 22.3°C respectively. The experiment was conducted in a permanently laid out plot in randomized block design with 12 treatments and 4 replications and the details are given in Table 1.

The organic sources of nutrients used in the experiment such as farm yard manure (FYM), paddy straw and azolla were analysed for nitrogen content and their quantities, required to substitute a specified amount of N (50 and 25%) as per the treatments were calculated. The nutrient contents of the organic manures on air dry weight basis were 0.56% N, 0.28% P and 0.64% K of FYM, 0.45% N, 0.13% P and 1.66% K of paddy straw and 3.56% N, 0.65% P and 1.88% K of azolla. Inorganic N, P and K were given through urea, single super phosphate and muriate of potash. Soil samples were drawn at initial and at the end of each cropping cycle (up to 31st 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). The MBC was estimated from the equation, $MBC = 2.64 Ec$, where Ec is the difference between organic carbon extracted from the K₂SO₄ extract of fumigated and non-fumigated soils.

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, full quantity of P and K were applied as basal and N was applied in split doses, 25% as basal, 50% at tillering and rest 25% at panicle initiation stage. The plot size was 10 m × 5 m. The test varieties were 'Savitri', 'Swarna' and 'Pratikshya' for rainy season (*kharif*), and 'Lalat', 'Konark' and 'Naveen' for summer. Standard agronomic management practices were followed to raise the crop.

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, 1998–03, 2003–08) except for 2008–14 which was on 6-yearly average basis. Average yield for each treatment was also calculated over 31 system cycles at the end of experimentation. 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 returns) costs of inputs and prices of output were used from 2013–14 for all the years. Statistical analyses were done using standard methodology of randomized block design.

RESULTS AND DISCUSSION

Grain and straw yields

Averaged over 31-years, application of 50% recommended dose of fertilizers (RDF) coupled with 50% recommended N (RN) through green manuring of azolla to rainy season (*kharif*) rice followed by supply of RDF through chemical fertilizers to summer rice resulted in higher system yield (Table 1). These grain yields were about 125% higher over no fertilizer control. This treatment combination increased average system yield by 7 and 42% over application of RDF and farmers' practice respectively. Application of 50% RDF through fertilizers coupled with 50% RN through FYM to *kharif* rice followed by supply of RDF through chemical fertilizers to summer rice was the second best treatment combination. 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 RDF through chemical fertilizers to summer rice in new alluvial soils of West Bengal in a long-term fertility experiment. Long-term application of organic matter might have improved the physico-chemical properties of soil that resulted in increased productivity by increasing availability of plant nutrients (Chaudhary and Thakur, 2007). Further, organic matter also maintained regular supply of macro and micro-nutrients in soil resulting in higher yields (Sharma and Subehia, 2014).

Application of 50% RDF through fertilizers coupled with 50% recommended N through green manuring or FYM to *kharif* rice followed by supply of RDF through fertilizers to summer rice also recorded significantly higher system straw yield compared to supply of RDF through fertilizers to both the crops (Table 1). However, supplementation of paddy straw as organic manure had no significant beneficial effect on 31-years average system grain or straw yields. Application of 50% RDF coupled with 50% recommended N through paddy straw to *kharif*

Table 1. Effect of integrated nutrient management on system grain and straw yields (t/ha) and economics of rice-rice cropping system over years

Treatment	Mean		Mean		Mean		Mean		Mean		Mean*		CoC ($\times 10^3$ ₹/ha)	NMR ($\times 10^3$ ₹/ha)	Benefit: cost ratio		
	1983-84 to 1987-88	1988-89 to 1992-93	1993-94 to 1997-98	1998-99 to 2002-03	2003-04 to 2007-08	2008-09 to 2013-14	2008-09 to 2013-14	2008-09 to 2013-14	1983-84 to 2013-14	1983-84 to 2013-14	Grain	Straw				Grain	Straw
<i>Kharif</i>	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw			
<i>Rabi</i>	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw			
No manure and fertilizers (control)	3.30	5.10	3.04	5.18	3.01	4.80	3.92	5.19	5.86	8.05	4.86	6.84	4.03	5.84	39.9	10.3	1.26
50% RDF through fertilizers	5.47	7.96	5.04	7.43	4.82	7.06	6.89	9.02	8.83	12.60	7.15	9.32	6.39	8.83	41.4	37.7	1.91
50% RDF through fertilizers	6.53	9.12	6.35	9.00	6.21	8.69	8.22	10.35	10.36	14.25	8.02	9.93	7.63	10.14	42.7	51.3	2.20
75% RDF through fertilizers	6.45	9.03	6.19	8.91	5.84	8.25	8.36	11.09	9.92	14.21	8.00	9.94	7.48	10.14	42.6	49.8	2.17
100% RDF through fertilizers	7.46	10.18	7.50	10.45	7.31	10.14	9.43	12.15	10.82	15.02	8.40	10.68	8.48	11.35	43.8	60.8	2.39
100% RDF through fertilizers + 50% RDN through FYM	7.38	9.54	6.97	9.31	7.15	9.59	10.17	12.84	11.60	16.50	9.14	11.19	8.75	11.42	49.1	58.5	2.19
75% RDF through fertilizers + 25% RDN through FYM	7.09	9.50	6.87	9.37	6.54	8.98	9.67	12.21	10.93	15.50	8.92	11.17	8.36	11.04	45.8	57.2	2.25
50% RDF through fertilizers + 50% RDN through paddy straw	6.86	9.29	6.76	9.35	7.21	9.67	9.80	12.51	11.08	15.93	8.64	10.85	8.40	11.18	48.9	54.6	2.12
75% RDF through fertilizers + 25% RDN through paddy straw	6.73	9.05	6.71	9.28	6.63	9.03	9.42	12.22	10.74	15.94	8.36	10.31	8.11	10.89	45.7	54.4	2.19
50% RDF through fertilizers + 50% RDN as green manuring of <i>Azolla</i>	7.43	10.25	7.41	10.46	7.53	10.55	10.26	13.51	12.23	17.46	9.47	11.61	9.07	12.21	46.2	65.6	2.42
75% RDF through fertilizers + 25% RDN as green manuring of <i>Azolla</i>	7.13	9.66	7.40	9.77	7.33	10.06	10.09	12.95	11.10	16.03	8.72	10.64	8.63	11.43	45.5	60.9	2.34
Farmers' practice	5.64	7.35	4.89	6.79	4.95	6.71	7.34	8.92	8.69	12.44	6.75	9.19	6.39	8.51	42.6	36.2	1.85
SEM \pm	0.16	0.19	0.12	0.18	0.10	0.17	0.24	0.38	0.38	0.48	0.25	0.33	0.07	0.12			
CD (P=0.05)	0.46	0.57	0.34	0.51	0.29	0.49	0.71	1.11	1.14	1.43	0.73	0.98	0.21	0.35			

RDF, recommended dose of fertilizers; RDN, recommended dose of nitrogen; FYM, farm yard manure; CoC, cost of cultivation; NMR, net monetary returns; RDF (N-P-K kg/ha): 80-17.5-33; Farmers' practice: N-P-K @ 20-0-0 kg/ha + 2 t FYM/ha to both *kharif* and summer crops; *mean of 6 years data; †mean of 31 years data; Sale Price (₹/t): rice grain, 11,000; rice straw, 1000

rice followed by supply of RDF through chemical fertilizers to summer rice reduced average system grain yield marginally compared to application of RDF to both season crops, though the reduction was not significant. This was in conformity with the findings of Singh *et al.* (2006) in rice–wheat cropping system.

Reduction in RDF without supplementing any organic manure significantly reduced the system grain and straw yields compared to application of RDF (Table 1). Application of 50% RDF to both *kharif* and summer crops through fertilizers, 50% RDF to *kharif* and RDF to summer crop and 75% RDF to both *kharif* and summer crops reduced average system yield by 25, 10 and 12% compared to RDF. Similar results were also reported in rice–wheat cropping system by Upadhyay and Vishwakarma (2014).

Yield trend analysis

Grain yield trend analysis of data averaged over five years indicates that application of sub-optimal doses of chemical fertilizers reduced system yield throughout the 31-years of experimentation compared to supply of 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 RDF and integrated nutrient management practices narrowed down with passage of time. Yield advantage due to supplementation of N through green manuring was noticed from 10th year onwards, whereas that of FYM after 15 years.

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). The control treatment without application of any manures and fertilizers reduced system yield of rice–rice sequence by 53% compared to RDF, followed by the treatment with 50% RDF to both the seasons with a yield reduction of 25% and farmers' practice with yield reduction of 24%. Similar results were also reported by Upadhyay and Vishwakarma (2014).

Economics

Application of 50% RDF through fertilizers coupled with 50% recommended N through green manuring of azolla to *kharif* rice followed by supply of 100% RDF through fertilizers to summer rice recorded the highest

system gross returns ₹1,11,870 and net returns ₹65,644 with highest benefit: cost ratio 2.42 (Table 1). This treatment increased system net returns by 68% over farmers' practice.

Bulk density

The bulk density of the soils at the end of 31-years of rice–rice cropping system ranged from 1.52 (control) to 1.46 Mg/m³ (INM with 50% N through FYM/*Azolla*). Addition of organic nutrient sources with inorganic fertilizers over the years significantly reduced the bulk density of the soils compared to the soils treated with inorganic fertilizers only. The reduction of bulk density is related to an increase in organic carbon, which results in more pore space and good soil aggregation (Yaduvanshi *et al.*, 2013). The marginal decrease in bulk density under RDF over control could be attributed to the increased biomass production with consequent increase in organic matter content of the soils (Selvi *et al.*, 2005).

Soil pH

The soil pH decreased from the initial level of 5.34 to 5.23 with the application of RDF through inorganic fertilizers (Table 2). Reduction of pH by continuous use of fertilizers over the years has also been reported by Sharma and Subehia (2014). The marginal increase in soil pH in treatments under integrated nutrient management might be due to moderating effect of FYM, paddy straw or azolla over the years as it decreases the activity of exchangeable Al³⁺ ions in soil solution due to chelating effect of organic molecules (Prasad *et al.*, 2010).

Soil organic carbon (SOC)

Application of organic nutrient sources with inorganic fertilizers over 31-years resulted in a significant increase in SOC contents over the initial status and the increase was to the tune of 89 to 128%. The maximum build-up of SOC was observed in treatment applied with 50% RDF through fertilizers + 50% N as azolla (Table 2). The increase in SOC due to integrated use of inorganic and organics can 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).

Available N, P and K

Available N increased in treatments receiving varying combination of FYM, paddy straw and azolla with RDF and the enhancement was from 254.2 kg/ha (initial) to 285.8 to 353.8 kg/ha (Table 3). Increase in available N with organics is attributed to its direct addition through organics which was released on mineralization with time

Table 2. Effect of integrated nutrient management practices in rice-rice cropping system on physico-chemical and microbial properties of soils

Kharif	Treatment		Bulk density (Mg/m ³)	pH	Soil organic carbon (%)	Microbial population (cfu/g)			MBC (µg C/g)
	Kharif	Rabi				Bacteria (× 10 ⁷)	Fungi (× 10 ⁴)	Actinomycetes (× 10 ⁶)	
	No manure and fertilizers (control)		1.52	5.40	0.55	19.6	11.7	12.3	101.4
	50% RDF through fertilizers		1.51	5.29	0.61	24.7	14.1	15.2	133.6
	50% RDF through fertilizers		1.50	5.23	0.64	26.9	15.3	15.9	164.3
	75% RDF through fertilizers		1.51	5.25	0.61	24.2	14.0	15.0	131.3
	100% RDF through fertilizers		1.50	5.23	0.66	27.5	15.9	16.6	177.4
	50% RDF through fertilizers + 50% RDN through FYM		1.46	5.64	0.92	32.3	18.8	19.5	266.7
	75% RDF through fertilizers + 25% RDN through FYM		1.48	5.64	0.81	30.7	17.4	18.4	223.3
	50% RDF through fertilizers + 50% RDN through paddy straw		1.47	5.50	0.85	31.5	18.2	19.0	241.3
	75% RDF through fertilizers + 25% RDN through paddy straw		1.48	5.59	0.83	30.9	17.7	18.7	232.3
	50% RDF through fertilizers + 50% RDN as green manuring of Azolla		1.46	5.61	0.98	33.3	19.2	20.4	289.3
	75% RDF through fertilizers + 25% RDN as green manuring of Azolla		1.47	5.54	0.84	31.2	18.0	18.8	237.6
	Farmers' practice		1.51	5.32	0.64	25.3	14.3	15.7	162.7
	SEm±		0.007	0.06	0.023	0.91	0.54	0.56	7.61
	CD (P=0.05)		0.02		0.068	2.70	1.60	1.67	22.86
	Initial		1.50		0.43	15.8	9.7	10.1	77.3

RDF, recommended dose of fertilizers; RDN, recommended dose of nitrogen; FYM, farm yard manure; MBC, microbial biomass carbon in soil; cfu, colony forming units; RDF (N-P-K kg/ha): 80-17.5-33; Farmers' practice: N-P-K @ 20-0-0 kg/ha + 2 t FYM/ha to both *kharif* and summer crops

(Sharma and Subehia, 2014). The soils under control and imbalanced nutrient management exhibited a reduction in available N over the initial.

The available P content of the soils varied from 7.4 kg/ha in control to 22.0 kg/ha in treatments receiving 50% RDF + 50% N through azolla in *kharif* followed by RDF in summer through inorganics. Substitution of 25% N through any of the organic sources resulted in significant lower available P content in comparison to their 50% substitution. Application of 50% RDN through FYM and paddy straw supplied an additional 11.65 and 2.75 kg P/ha, respectively over the 50% recommended P (8.75 kg/ha). 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 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. This might be due to the fact that application of 50% RDN through azolla, FYM and paddy straw supplied additional 5, 31.2 and 131 kg K/ha respectively over the 50% recommended K (16.5 kg/ha). Application of inorganic fertilizers alone or in combination with organic nutrient sources recorded an increase in available K of the soils over 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).

Microbial population

Growing rice-rice cropping system for 31-years in succession enhanced the microbial densities of the soils (Table 2). The maximum population of bacteria, fungi and actinomycetes was recorded from the soils receiving 50% RDF + 50% N as azolla in *kharif* and RDF in summer.

Table 3. Nutrient balance (kg/ha) as influenced by different nutrient management practices after completion of 31st rice-rice cropping system cycle

Treatment	Rabi	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*
No manure and fertilizers (control)		0	2,056	190.5	-63.7	-1992.1	0	649	7.4	-12.9	-636.1	0	2,667	72.1	-138.3	-2528.7
50% RDF through fertilizers		2,480	3,280	216.5	-37.7	-762.0	541	966	9.2	-11.1	-413.1	1,029	3,591	92.2	-118.2	-2443.6
50% RDF through fertilizers		3,720	3,867	241.0	-13.2	-133.7	812	1,118	14.8	-5.5	-300.4	1,544	4,044	95.7	-114.7	-2385.5
75% RDF through fertilizers		3,720	3,835	226.5	-27.7	-87.1	812	1,116	14.2	-6.1	-297.8	1,544	4,030	96.5	-113.9	-2372.3
100% RDF through fertilizers		4,960	4,930	254.0	-0.2	30.2	1,083	1,308	14.1	-6.2	-219.0	2,058	4,253	100.8	-109.6	-2085.0
50% RDF through fertilizers + 50% RDN through FYM		4,960	4,650	323.5	69.3	240.7	1,432	1,339	20.0	-0.3	93.0	2,961	4,433	156.0	-54.4	-1418.1
75% RDF through fertilizers + 25% RDN through FYM		4,340	4,260	285.8	31.6	48.4	1,122	1,260	17.0	-3.3	-134.6	2,252	4,184	143.5	-66.9	-1864.6
50% RDF through fertilizers + 50% RDN through paddy straw		4,960	4,690	302.0	47.8	222.2	1,170	1,282	20.2	-0.1	-111.9	6,118	5,065	183.4	-27.0	1080.0
75% RDF through fertilizers + 25% RDN through paddy straw		4,340	4,250	294.0	39.8	50.2	991	1,170	16.9	-3.4	-175.4	3,831	4,463	161.1	-49.3	-582.8
50% RDF through fertilizers + 50% RDN as green manuring of <i>Azolla</i>		4,960	4,610	353.8	99.6	250.4	1,038	1,205	22.0	1.7	-168.3	2,199	4,420	168.4	-42.0	-2179.5
75% RDF through fertilizers + 25% RDN as green manuring of <i>Azolla</i>		4,340	4,210	312.5	58.3	71.7	925	1,172	17.2	-3.1	-243.6	1,871	4,302	151.1	-59.3	-2371.5
Farmers' practice		1,934.4	3,237	237.3	-16.9	-1,285.7	347.2	931	11	-9.3	-574.5	793.6	2,904	95.7	-114.7	-1995.7

RDF, recommended dose of fertilizers; RDN, recommended dose of nitrogen; FYM, farm yard manure; RDF, (N-P-K kg/ha): 80-17.5-33; Farmers' practice: N-P-K @ 20-0-0 kg/ha + 2 t FYM/ha to both *kharif* and summer crops; Initial nutrient status in soil (1983): N, 254.2 kg/ha; P, 20.3 kg/ha; K, 210.4 kg/ha; *Cumulative addition/ removal of 31 cropping system cycles; †after completion of 31st rice-rice cropping system cycle

Addition of organic nutrient sources with inorganic fertilizers showed a profound increase in the microbial population in comparison to chemical fertilizers used alone. The FYM, paddy straw or azolla act as a source of nutrients to the microbes and also as a substrate for decomposition and mineralization of nutrients. This creates a favourable condition for the proliferation of microbes in the soil (Bahadur *et al.*, 2012).

Microbial biomass carbon (MBC)

Although soil microbial biomass 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 productive capacity. The MBC of soils varied from 101.4 µg C/g in control to the highest level of 289.3 µg C/g in soils treated with 50% RDF + 50% N through azolla (Table 2). 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 organics might be responsible for higher microbial activity and MBC in treatments applied with organics (Sharma and Subehia, 2014).

Nutrient balance

The soils receiving inorganic fertilizers, control and farmers' practice exhibited actual loss of N over initial status (Table 3). On the contrary, the soils applied with both inorganic and organic nutrients registered actual gain of N. The maximum cumulative N uptake of 4930 kg/ha was observed with RDF in both the seasons followed by 50% RDF + 50% N through paddy straw in *kharif* and RDF in summer (4690 kg/ha). All the soils under integrated nutrient management and RDF in both the seasons registered positive N balance.

The highest cumulative P uptake of 1,339 kg/ha was observed in 50% N substitution as FYM (Table 3). The same treatment also registered the positive P balance. The negative P balance observed in all other treatments is due to more uptake of P by crops.

The maximum cumulative uptake was observed in the soils with 50% N substituted as paddy straw (Table 3). The soils of the same treatment also registered positive balance of 1,080 kg K/ha. This might 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. Depletion of soil K reserves leading to negative K balance in soils under INM was also reported by Surekha and Satishkumar (2014).

Application of 50% recommended dose of chemical fertilizers coupled with 50% recommended N through green manuring of azolla or through farm yard manure to *kharif* rice followed by supply of recommended dose of chemical fertilizers to summer rice can be recommended for rice–rice cropping system in coastal Odisha to obtain higher and sustainable yield and maintain soil health.

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