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Nutrient mobilization and crop assimilation as influenced by nutrient management strategies under direct seeded basmati rice (*Oryza sativa*) – based cropping systems

RAKESH KUMAR VERMA[1], YASHBIR SINGH SHIVAY[2], MUKESH CHOUDHARY[3], PRAKASH CHAND GHASAL[4] and RAGHAVENDRA MADAR[5]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

The field experiment was carried out for two consecutive years (2014–2016) in split-plot design to investigate the effect of integrated nutrient management and crop diversification through inclusion of legume and vegetable crops in direct seeded basmati rice (*Oryza sativa* L.)–based cropping systems (DSRB) on nutrient availability for crop uptake. The study involved four cropping systems (CS) in main plots (DSBR–wheat–fallow (CS_1), DSBR–wheat–greengram (CS_2), DSBR–cabbage–greengram (CS_3) and DSBR–cabbage–onion (CS_4) and four nutrient management strategies under subplots (unfertilized (NS_0), 100% recommended dose of fertilizers (RDF) (NS_1), 50% RDF + 25% recommended dose of nitrogen (RDN) through leaf compost (LC) + biofertilizer (NS_2), 50% RDF + 25% RDN through vermicompost (VC) + biofertilizer (NS_3)). The results revealed that diversification of rice–wheat system with legume (greengram) or vegetable (cabbage and onion) crops and integrated nutrient management strategies had positive effect on nutrient uptake and available nutrient status in the soil. Significantly higher uptake of N, P and K in all crops and Zn, Fe, Mn and Cu in rice and wheat were observed with NS_2 and NS_3 as compared to NS_0. Available N, P and K status were significantly higher in NS_2 and NS_3 as against NS_0 and NS_1. Inclusion of cereal crops in the cropping systems showed a negative apparent N balance, but inclusion of vegetable crops in the cropping systems exhibited positive apparent N balance under different nutrient management strategies except NS_0. The highest positive apparent N balance was observed in NS_1 treatment. The apparent P balance was found to be positive in all the cropping systems with all the nutrients sources except NS_0. Apparent K balance was found negative in all the cropping systems under different nutrient management strategies. Thus, cropping systems with summer greengram, cabbage and onion (CS_2, CS_3 and CS_4) under integrated nutrient management practices (NS_2 and NS_3) were found more sustainable after two years of cropping cycle and can be advocated by the farmers of IGP.

Key words: Apparent balance, Available nutrients, Cropping systems, Nutrient management, Nutrient uptake

Rice (*Oryza sativa* L.)-wheat cropping system is the predominant cropping system in Indo-Gangetic plains and occupies nearly 13.5 million ha area (Ladha *et al*. 2003). The demand of rice and wheat is expected to grow between 2% and 2.5% per annum, respectively until 2020 (Gupta and Seth 2007). Maximization of crop yields has been the only criterion to feed the ever-increasing population with scant considerations on soil and environmental quality. The continuous and imbalance use of chemical fertilizers in mono rice–wheat cropping system led to the deficiencies of secondary and micro nutrients, degradation of soil health and environmental quality (Singh *et al.* 2008), and also responsible for the decline in crop productivity as these crops are highly nutrient exhaustive (Busari *et al.* 2015). Crop diversification as a potential alternative has been well documented to sustain the farm productivity and to improve the inputs use efficiencies (Das *et al.* 2014; Congreves *et al*. 2015). Legume crops fix atmospheric nitrogen and leave litter fall in considerable amounts with narrower C: N ratio, which contributes to the residual soil fertility and helps in sustaining crop productivity. Similarly, the strategic use of multi nutrient sources, including manures, biofertilizers and inorganic fertilizers improves the soil health on long–term basis than continuous application of chemical fertilizers alone (Yadav and Kumar 2009; Bodruzzaman *et al.* 2010;

Present address: [1,5]Scientists (sherawat90rakesh@gmail.com; raghavendra4449@gmail.com), ICAR–Indian Institute of Soybean Research, Indore, Madhya Pradesh; [2]Principal Scientist & Ex–Professor (ysshivay@hotmail.com), ICAR–IARI, New Delhi; [3]Senior Scientist (selmukesh@gmail.com), ICAR–Indian Grasslands and Fodder Research Institute, Jhansi, Uttar Pradesh; [4]Scientist (pcghasal@gmail.com), ICAR–Indian Institute of Farming Systems Research, Meerut, Uttar Pradesh.

Kalantari *et al.* 2010; Lal *et al.* 2013). The combined use of organic and inorganic sources showed positive impact on soil organic carbon, available nutrients status and soil quality indicators (Borken *et al.* 2002; Ramesh *et al.* 2006; Saha *et al.* 2008; Vajantha *et al.* 2010; Singh *et al.* 2012; Surekha *et al.* 2013). The higher soil available N, P, K and micronutrients status can be maintained with integrated use of vermicompost, compost and biofertilizers with inorganic fertilizers (Sepat *et al.* 2010; Singh *et al.* 2012; Lal *et al.* 2013; Roy *et al.* 2013; Surekha *et al.* 2013). Organic sources of nutrient enhance microbial proliferation leading to better nutrient mobilization for crop assimilation. Supplementation of recommended dose of nutrients through organic sources (vermicompost and compost) enhances the total uptake of macro (N, P and K) and micronutrient (Zn, Cu, Fe and Mn) (Shivay *et al.* 2008; Thirunavukkarasu and Vinoth 2013; Meena *et al.* 2013; Sharma *et al.* 2015). The objective of the present study was to assess the impact of integrated nutrient management strategies under DSBR–based cropping systems on total nutrient uptake, available soil nutrient content and apparent nutrient balance.

MATERIALS AND METHODS

Site and soil characteristics

A field experiment with rice, wheat, cabbage, onion and greengram was conducted during the rainy, winter and summer season of 2014–2015 and 2015–2016 at ICAR–Indian Agricultural Research Institute, New Delhi (28°38' N and 77°10' E, 228.6 m above mean sea-level). The climate of above unit is semi-arid with dry hot summers and cold winters with an average annual rainfall of 650 mm, 80% of which is received through south–west monsoons during July–September. Soils are alluvium-derived sandy clay loam (*Typic Ustochrept*) with 51.7% sand, 21.9% silt and 26.4% clay. The soil had a *p*H 7.9 (1:2.5 soil: water ratio), electrical conductivity 0.76 dS/m, Walkley–Black C (oxidizable-SOC) 0.49%, alkaline $KMnO_4$-oxidizable–N 209.7 kg/ha (Subbiah and Asija 1956), 0.5 M $NaHCO_3$-extractable P 15.3 kg/ha (Olsen *et al.* 1954), 1 N NH_4OAc-extractable K 272.4 kg/ha (Hanway and Heidel 1952).

Experimental setup, design and treatments

The experiment was laid-out in a strip-plot design. There were 16 treatment combinations with a sub-plot size of 15.0 m^2 (5.0 m length × 3.0 m width) and were replicated thrice for both the years (2014–2015 and 2015–2016) of study. Four cropping systems (CS), such as direct seeded basmati rice (DSBR)–wheat–fallow (CS_1), DSBR–wheat–greengram (CS_2), DSBR–cabbage–greengram (CS_3) and DSBR–cabbage–onion (CS_4) were assigned to vertical strips; and 4 nutrient management strategies (NMS), viz. control/unfertilized (NS_0), 100% RDF (recommended dose of fertilizers) (NS_1), 50% RDF + 25% RDN (recommended dose of nitrogen) through leaf compost (LC) + biofertilizers (NS_2) and 50% RDF + 25% RDN through vermicompost (VC) + biofertilizers (NS_3) were assigned to horizontal strips. The VC (0.60% N, 0.30% P, 0.39% K) and LC (0.37% N, 0.10% P, and 0.21% K) was applied before sowing of the crops based on the nitrogen equivalent basis and requirement of crops in respective treatments. Allocations of the treatments were done by the randomization following Fisher and Yates random number tables. In greengram N, P and K fertilizers were applied at time of sowing. For rice and

Table 1 Effect of cropping systems and nutrient sources on total nitrogen (N), phosphorus (P) and potassium (K) uptake in rice, *rabi* season crops and summer greengram (average of two year)

Treatment	Total major nutrient uptake by rice (kg/ha)			Total major nutrient uptake by wheat (kg/ha)			Total major nutrient uptake by cabbage (kg/ha)			Total major nutrient uptake by greengram (kg/ha)			Total major nutrient uptake by onion (kg/ha)		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Cropping systems															
CS_1	86.6[b]	10.4[a]	109.2[a]	95.4[a]	18.1[a]	113.0[a]	-	-	-	-	-	-	-	-	-
CS_2	89.4[a]	10.6[a]	110.7[a]	100.3[a]	19.1[a]	118.6[a]	-	-	-	32.7[a]	3.6[a]	31.5[a]	-	-	-
CS_3	89.6[a]	10.6[a]	110.9[a]	-	-	-	49.3[a]	12.9[a]	52.9[a]	33.2[a]	3.7[a]	31.9[a]	-	-	-
CS_4	87.9[a]	10.4[a]	109.9[a]	-	-	-	49.0[a]	12.8[a]	52.4[a]	-	-	-	42.1	6.6	27.3
Nutrient sources															
NS_0	54.7[b]	5.5[b]	67.4[b]	69.7[b]	13.7[b]	86.7[b]	18.3[b]	4.1[b]	19.8[b]	25.4[b]	2.6[b]	25.3[b]	27.7[b]	3.4[b]	16.6[b]
NS_1	99.0[a]	12.1[a]	123.3[a]	105.2[a]	19.6[a]	122.9[a]	59.8[a]	15.8[a]	64.1[a]	34.4[a]	3.8[a]	32.7[a]	47.5[a]	7.8[a]	32.0[a]
NS_2	98.1[a]	11.9[a]	124.2[a]	105.6[a]	20.0[a]	124.1[a]	56.9[a]	14.9[a]	61.3[a]	35.6[a]	4.0[a]	34.1[a]	45.1[a]	7.3[a]	28.7[a]
NS_3	101.7[a]	12.4[a]	125.8[a]	110.9[a]	20.9[a]	129.5[a]	61.4[a]	16.4[a]	65.4[a]	36.5[a]	4.2[a]	34.9[a]	47.9[a]	8.0[a]	31.8[a]

CS_1, DSBR–wheat; CS_2, DSBR–wheat–greengram; CS_3, DSBR–cabbage–greengram; CS_4, DSBR–cabbage–onion; NS_0, Control; NS_1, 100% RDF through fertilizers; NS_2, 50% RDF + 25% RDN–leaf compost + biofertilizers; NS_3, 50% RDF + 25% RDN–vermicompost + biofertilizers; DSBR, Direct seeded basmati rice; RDF, Recommended dose of fertilizers; RDN, Recommended dose of nitrogen; LC, Leaf compost; VC, Vermicompost. Different small letters in a column indicate significant differences at the 95% probability level according to Duncan's multiple range test.

wheat one third and for cabbage and onion half of N and full dose of P and K was applied at planting. Remaining N was applied in two equal splits after first irrigation and at maximum tillering stage in rice and wheat, whereas in cabbage and onion it was applied at 45 and 30 days after planting, respectively. Seeds/seedlings of crops were treated with *Rhizobium* in greengram, with *Azotobacter* in wheat and cabbage and with *Azospirillum* in onion in respective treatments at sowing/planting.

Crop establishments given in supplementary Table 1.

Nutrients uptake

Plant samples of grains/seeds/head/bulb as well as stover/straw of different crops collected at harvest were dried in hot air oven at 60 ± 2^0C for 48 hr. The oven-dried samples were ground to pass through 40 mesh-sieves in a Macro-Wiley Mill. Nitrogen was estimated by modified Kjeldhal method (Jackson 1967), P concentration by Vanado-molybdo-phosphoric yellow colour method (Jackson 1967) and K concentration by Flame Photometer method (Jackson 1967). Nutrient uptake of grain and straw was calculated by multiplying grain and straw yield with the respective value of nutrient concentration for a particular treatment and expressed in kg/ha.

The zinc (Zn), manganese (Mn), copper (Cu) and iron (Fe) concentrations in rice and wheat were determined as described by Prasad *et al.* (2006) using Atomic Absorption Spectrophotometry (AAS). The Zn, Mn, Cu and Fe concentrations was expressed as mg/kg and its uptake was computed by multiplying the Zn, Mn, Cu and Fe concentrations with different part of plant biomass (grain and straw).

Soil sampling and its analysis

The soil samples from 0–15 cm depth were collected just before initiation of study, harvest of each crop in both the season and at the end of study for determining the available nitrogen (N), phosphorus (P) and potassium (K). Available nitrogen, phosphorus, potassium was estimated by using standard methods (Baruah and Barthakur 1999). The apparent nutrient balance of nitrogen, phosphorus and potassium were computed as the difference of nutrients added through fertilizer and organic sources, and nutrients removed by crops.

RESULTS AND DISCUSSION

The results of the present two-year study were pooled and only the average values are discussed throughout this paper.

Total nutrient uptake

The total N uptake by rice under DSBR–wheat (CS_1) system was significantly lower as compared to DSBR–wheat-greengram (CS_2), DSBR–cabbage–greengram (CS_3) and DSBR–cabbage–onion (CS_4) (Table 1). However, no significant differences were observed in total N uptake with the cropping systems CS_2, CS_3 and CS_4. Moreover, there was no significant variation in total P and K uptake by rice under different diversified cropping systems tried in this study. Among the nutrient management strategies, the treatment supplemented with 100% RDF (NS_1), and integrated nutrient management (NS_2 and NS_3) exhibited significantly higher total uptake of N, P and K in rice under different cropping systems undertaken in the study over control (NS_0), but remained statistically non-significant among the treatments NS_1, NS_2 and NS_3. The perusal of the data on total N, P and K uptake by wheat, cabbage, greengram and onion did not significantly vary under DSBR–based cropping systems. However, the influence of nutrient management through inorganic and organic sources (NS_1, NS_2 and NS_3) on N, P and K uptake did not differ significantly between themselves and were significantly higher as compared to NS_0 by all the crops. The total N uptake was significantly highest (3.50% and 1.50%) in rice when it was grown with legume and vegetables. This might be due to beneficial effect received through the inclusion of greengram, cabbage

Table 2 Effect of cropping systems and nutrient sources on total uptake of Zn, Fe, Mn and Cu by direct seeded basmati rice and wheat (average of two year)

Treatment	Total uptake of micronutrients by rice (g/ha)				Total uptake of micronutrients by wheat (g/ha)			
	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu
Cropping systems								
CS_1	436.7^a	2321.5^a	392.7^a	234.6^a	290.8^a	1937.0^a	274.6^a	128.4^a
CS_2	437.5^a	2362.6^a	385.3^a	238.3^a	307.6^a	2029.2^a	287.0^a	135.1^a
CS_3	450.4^a	2355.8^a	407.8^a	238.0^a	-	-	-	-
CS_4	434.7^a	2347.4^a	389.0^a	240.8^a	-	-	-	-
Nutrient sources								
NS_0	245.9^b	1487.8^b	215.3^b	147.5^b	228.0^b	1455.0^b	216.3^b	98.5^b
NS_1	502.9^a	2623.3^a	456.1^a	266.0^a	309.8^a	2121.6 ^{a}	296.5^a	141.5^a
NS_2	493.4^a	2618.9^a	435.4^a	266.2^a	319.8^a	2132.2 ^{a}	296.0^a	140.4^a
NS_3	517.2^a	2657.3^a	467.9^a	272.1^a	339.1^a	2223.7 ^{a}	314.4^a	146.6^a

The details of treatments are given in Table 1.

and onion in the cropping systems which might have contributed to substantial amount of biomass and nitrogen in the soil. There were no significant differences among the different cropping systems with respect to the total uptake of micronutrient namely; Zn, Fe, Mn and Cu studied with the diversified nutrient sources (Table 2). Among the nutrient management strategies, the similar trends were observed as in case of major nutrients. The total uptake of Zn (110.3%), Fe (78.6%), Mn (117.3%) and Cu (84.5%) in direct seeded rice increased under the treatment NS_3 as against treatments NS_0. Similarly, the total uptake of Zn (48.7%), Fe (52.8%), Mn (45.4%) and Cu (48.8%) in wheat also increased under the treatment NS_3 as compared to NS_0. Overall, there were no significant differences among the treatment NS_1, NS_2 and NS_3. Although, application of nutrients through integrated sources performed better in terms of total macro– and micronutrients uptake as compared to chemical fertilizers applications alone.

Application of inorganic (NS_1) and organic sources (NS_2 and NS_3) significantly increased the total N, P and K uptake in all the crops and Zn, Fe, Mn and Cu uptake by rice and wheat, as compared to no fertilizer application. The vermicompost, leaf compost and biofertilizers added substantial amounts of N, P, K and micronutrients in soil essential for plant growth and the continuous supply of nutrients throughout the crop growth duration as the nutrients from inorganic sources were available to the crop in the early stages of growth and in the later stages of the crop growth, the slow and continuous release of nutrients from the organic sources can increase nutrient availability for longer time. Similar observations were also reported by Kharub and Chander (2008); Singh *et al.* (2010); Garai *et al.* (2013) and Verma *et al.* (2017). Application of biofertilizer might have positive effect on the microbiome which may have also encouraged profuse rooting system, resulting in better absorption of moisture and nutrient and thus, resulting in higher biomass production. The similar trend of increase in nutrients uptakes under integrated nutrient application were also reported by Davari and Sharma (2010); Gogoi *et al.* (2010); Ahmad *et al.* (2011); Singh *et al.* (2011); Vidyavathi *et al.* (2012); Meena *et al.* (2013) and Verma *et al.* (2017).

Available N, P and K content at harvest of rainy, winter and summer season crops and apparent N, P and K balance

The significant differences were observed among the different cropping systems and nutrient sources with respect to changes in available soil N, P and K content in soils after harvest of direct seeded basmati rice. The inclusion of greengram as a summer season crop in the cropping sequence increased 14.3% under CS_2 and 13.6% under CS_3 available N content and did not differ significantly with CS_4 (Table 3). However, there were also no significant differences between CS_1 and CS_4 with regards to changes in available N content. Significantly higher soil P (19.9%) content was recorded with DBSR–cabbage–greengram as compared to other DSBR–based cropping systems. There was no significant variation in available soil K content among the diversified DSBR–based cropping systems after harvest of rice. Application of NS_2 and NS_3 significantly increased available soil N and P content over NS_0 and NS_1. Significantly higher soil K content was observed with NS_3 as compared to other nutrient sources tried. There were no significant differences in soil N content after the harvest of winter season crops (wheat, cabbage and onion), with the exception being CS_1. Cropping systems CS_3 and CS_4 significantly increased soil P content as compared to CS_1 and CS_2. There were no significant differences in soil available K content between different cropping systems tried after the harvest of winter season crops. Among the nutrient management strategies, adoption of NS_3 significantly increased soil available N (13.8%), P (49.6%) and K (11.5%) content as against NS_0. After the harvest of greengram (summer season crop) significantly higher soil N and P content was recorded with diversified cropping

Table 3 Effect of cropping systems and nutrient sources on available nitrogen (N), phosphorus (P) and potassium (K) status of soil at harvest of rice, *rabi* season crops and summer greengram (average of two year)

Treatment	Available major nutrient status of soil at harvest of rice (kg/ha)			Available major nutrient status of soil at harvest of winter season crops (kg/ha)			Available major nutrient status of soil at harvest of summer greengram (kg/ha)		
	N	P	K	N	P	K	N	P	K
Cropping systems									
CS_1	220.3^b	16.9^c	274.6^a	212.0^b	16.2^b	273.4^a	196.9^c	16.1^b	271.8^a
CS_2	222.7^a	17.9^b	278.0^a	217.2^a	16.6^a	275.1^a	225.0^a	18.8^a	274.9^a
CS_3	222.5^a	18.3^a	278.4^a	219.9^a	18.5^a	275.4^a	223.7^a	19.3^a	275.0^a
CS_4	221.9^a	17.8^b	277.3^a	217.5^a	18.8^a	274.6^a	217.6^b	17.4^b	275.0^a
Nutrient sources									
NS_0	205.0^c	15.2^c	263.1^d	206.4^c	12.7^c	258.6^c	198.4^c	13.7^c	255.1^c
NS_1	222.2^b	17.6^b	277.4^c	212.9^b	18.2^b	274.5^b	215.4^b	17.4^b	274.3^b
NS_2	229.4^a	18.9^a	282.5^b	223.1^a	19.3^a	282.0^a	223.9^a	19.9^a	282.9^a
NS_3	230.8^a	19.0^a	285.3^a	224.4^a	19.9^a	283.4^a	225.7^a	20.5^a	284.5^a

The details of treatments are given in Table 1.

systems CS_2 and CS_3. Nutrient management treatment NS_2 and NS_3 recorded significantly higher soil N, P and K content as compared to NS_0 and NS_1 after the harvest of greengram. NS_3 treatment increased N, P and K content by 12.6%, 25.0% and 8.4% over NS_0 and 3.9%, 8.0% and 2.8% over NS_1, respectively after the harvest of the direct seeded basmati rice. Similarly, the same trend was observed after harvest of the winter and summer season crops. The available N, P and K content was increased by 13.8%, 49.6% and 11.5% over NS_0 and 3.2%, 17.8% and 3.7% over NS_1 under the NS_3 treatment, respectively after harvest of the summer greengram.

The positive as well as negative changes were observed in apparent balance of N, P and K after the end of two years of cropping cycle of direct seeded basmati rice–based cropping systems under integrated nutrient management strategies (Table 4, 5, 6). Inclusion of the cereals crops in the cropping systems shows negative apparent N balance, but inclusion of vegetable crops in the cropping systems exhibited positive apparent N balance across most of the nutrient sources, except NS_0. The highest positive apparent N balance was observed in NS_1 treatment. The apparent P balance was found positive in all the cropping systems with all the nutrients sources except NS_0 and the highest negative value being in CS_4 under control. This showed that application of nutrients either through fertilizers or substitution part of RDN though organic manure and biofertilizers could meet the P demands of crops. The highest positive P apparent balance was observed under NS_1 treatment followed by NS_3 and then NS_2. Contrary to apparent N and P balance, the apparent K balance was found negative in all the cropping systems with all the nutrient management strategies.

Generally, maintenance and improvement in available nutrient status as a consequence of differential integrated crop management practices is critical for sustaining crop productivity and maintaining soil fertility on long–term basis. Available nutrient status brings about significant influences on soil physical and chemical characteristics as a result of agronomic interventions. The N and P availability was differed significantly among the different cropping systems after harvest of all the crops. The availability of K in soil was not affected significantly by different cropping systems after harvest of every season crops, attributed to higher K requirement by all these crops. All most similar trend was observed between CS_2, CS_3 and CS_4 where, greengram and vegetable crops (cabbage and onion) were involved. The higher N and P status after vegetables (cabbage and onion) was due to higher requirement of the nutrients. That's why higher dose of organic manures, biofertilizers and chemical fertilizers was applied to these crops resulted into higher residual fertility compared to rice–wheat system.

Improvement in organic matter in soil health might have favoured the availability of the nutrients in the soil. Integrated nutrient management significantly increased available N, P and K content as these management approaches might have

Table 4 Nitrogen balance sheet under different cropping systems as influenced by nutrient sources

Treatment		Inputs					Outputs			
		Available soil N (Initial) (kg/ha)	Fertilizer N (kg/ha)	Manure N (kg/ha)	Fixed N (kg/ha)	Total N (kg/ha)	N uptake (total) (kg/ha)	Available soil N (Final) (kg/ha)	Total N (kg/ha)	Apparent N balance (kg/ha)
		1	2	3	4	1+2+3+4 = 5	6	7	6+7 = 8	5 –7 = 8
CS_1	NS_0	209.7	–	–	–	209.7	241.3	173.3	414.6	–204.9
	NS_1	209.7	480.0	–	–	689.7	396.0	203.3	599.3	90.4
	NS_2	209.7	240.0	120.0	–	569.7	407.0	211.0	618.0	–48.3
	NS_3	209.7	240.0	120.0	–	569.7	411.8	215.1	626.9	–57.2
CS_2	NS_0	209.7	–	0.0	100.0	309.7	303.8	208.0	511.9	–202.2
	NS_1	209.7	510.0	0.0	100.0	819.7	487.1	223.3	710.4	109.3
	NS_2	209.7	255.0	127.5	100.0	692.2	477.6	233.0	710.6	–18.4
	NS_3	209.7	255.0	127.5	100.0	692.2	510.3	241.6	751.9	–59.7
CS_3	NS_0	209.7	–	–	100.0	309.7	197.5	210.1	407.6	–97.9
	NS_1	209.7	570.0	–	100.0	879.7	391.8	222.9	614.7	265.0
	NS_2	209.7	285.0	142.5	100.0	737.2	385.4	232.6	618.0	119.2
	NS_3	209.7	285.0	142.5	100.0	737.2	401.6	232.5	634.1	103.1
CS_4	NS_0	209.7	–	–	–	209.7	198.6	192.1	390.7	–181.0
	NS_1	209.7	740.0	–		949.7	400.5	214.7	615.2	334.5
	NS_2	209.7	370.0	185.0	–	764.7	389.3	233.6	622.9	141.8
	NS_3	209.7	370.0	185.0	–	764.7	412.4	234.9	647.3	117.4

Table 5 Phosphorus balance sheet under different cropping systems as influenced by nutrient sources

Treatment		Inputs				Outputs			
		Available soil P (Initial) (kg/ha)	Fertilizer P (kg/ha)	Manure P (kg/ha)	Total P (kg/ha)	P uptake (Total) (kg/ha)	Available soil P (Final) (kg/ha)	Total P (kg/ha)	Apparent P balance (kg/ha)
		1	2	3	1+2+3 = 4	5	6	5+6 = 7	4 –7 = 8
CS_1	NS_0	15.3	0.0	0.0	15.3	37.5	12.3	49.7	–34.4
	NS_1	15.3	103.2	0.0	118.5	60.2	13.9	74.1	44.4
	NS_2	15.3	51.6	36.7	103.6	63.9	18.5	82.4	21.2
	NS_3	15.3	51.6	56.9	123.8	65.8	19.7	85.5	38.3
CS_2	NS_0	15.3	0.0	0.0	15.3	44.3	11.8	56.1	–40.8
	NS_1	15.3	129.0	0.0	144.3	73.6	19.4	93.0	51.3
	NS_2	15.3	64.5	38.9	118.7	71.4	20.3	91.7	27.1
	NS_3	15.3	64.5	60.7	140.5	76.5	25.4	101.9	38.6
CS_3	NS_0	15.3	0.0	0.0	15.3	24.6	15.4	40.1	–24.8
	NS_1	15.3	137.6	0.0	152.9	64.6	19.1	83.7	69.2
	NS_2	15.3	68.8	43.3	127.4	62.0	22.3	84.3	43.2
	NS_3	15.3	68.8	67.7	151.8	65.8	20.8	86.6	65.2
CS_4	NS_0	15.3	0.0	0.0	15.3	26.1	11.6	37.7	–22.4
	NS_1	15.3	154.8	0.0	170.1	71.0	19.2	90.2	79.9
	NS_2	15.3	77.4	54.7	147.4	68.1	20.4	88.4	59.0
	NS_3	15.3	77.4	88.3	181.0	73.1	18.2	91.3	89.7

Table 6 Potassium balance sheet under different cropping systems as influenced by nutrient sources

Treatment		Inputs				Outputs			
		Available soil K (Initial) (kg/ha)	Fertilizer K (kg/ha)	Manure K (kg/ha)	Total K (kg/ha)	K uptake (Total) (kg/ha)	Available soil K (Final) (kg/ha)	Total K (kg/ha)	Apparent K balance (kg/ha)
		1	2	3	1 + 2 + 3 = 4	5	6	5 + 6 = 7	4–7 = 8
CS_1	NS_0	272.4	0.0	0.0	272.4	304.4	250.2	554.6	–282.2
	NS_1	272.4	199.2	0.0	471.6	479.6	275.1	754.7	–283.1
	NS_2	272.4	98.4	76.7	447.5	490.1	285.3	775.4	–328.0
	NS_3	272.4	98.4	84.3	455.1	503.1	287.8	790.9	–335.8
CS_2	NS_0	272.4	0.0	0.0	272.4	362.5	253.4	616.0	–343.6
	NS_1	272.4	199.2	0.0	471.6	567.6	278.0	845.6	–374.0
	NS_2	272.4	98.4	81.4	452.2	563.1	287.6	850.7	–398.5
	NS_3	272.4	98.4	90.0	460.8	592.9	291.0	883.9	–423.1
CS_3	NS_0	272.4	0.0	0.0	272.4	224.5	253.3	477.9	–205.5
	NS_1	272.4	215.8	0.0	488.2	437.6	279.2	716.8	–228.6
	NS_2	272.4	106.6	90.6	469.6	447.6	287.9	735.4	–265.8
	NS_3	272.4	106.6	100.3	479.3	456.2	290.9	747.1	–267.9
CS_4	NS_0	272.4	0.0	0.0	272.4	226.8	253.7	480.5	–208.1
	NS_1	272.4	298.8	0.0	571.2	475.7	278.8	754.5	–183.3
	NS_2	272.4	147.6	114.5	534.5	458.1	290.3	748.4	–213.9
	NS_3	272.4	147.6	130.8	550.8	474.4	287.5	761.9	–211.1

been due to shift in below ground rhizo and microbiome which in turn increased microbial built up resulting in the hastening of nutrient mineralization (Bhattacharyya *et al.* 2008; Khaliq and Abbasi 2015). Treatments NS_3 and NS_2 found best in available N content as compared to NS_1 and NS_0 in all the three seasons. This could be attributed to increased rate of mineralization of organic matter in the soil which was enhanced by the addition of organic manure (vermicompost, leaf compost and biofertilizers), leading to a build-up of nutrient content in soil (Shilpashree *et al.* 2012; Khaliq and Abbasi 2015; Sacco *et al.* 2015). The addition of vermicompost and leaf compost increased Olsen-P because of its P content and possibly by increasing retention of P in soil through release of various organic acid and CO_2 during process of decomposition of organic matter (Rajkhowa *et al.* 2003). The increase in available K under integrated treatments ascribed to more release of non-exchangeable K from the soils as organic manures and increased soil cation exchange capacity (Blake *et al.* 1999; Bhattacharyya *et al.* 2008) and also reduced fixation of K in soil (Prasad and Mathur 1997).

Conclusions

The investigation clearly brought out the fact that the cropping systems and integrated nutrient management strategies have bearing effects on soil fertility. The results revealed that inclusion of greengram and vegetable crops in rice–based cropping system with supplementation of nutrients through the organic manures and biofertilizer had significantly increased the availability of soil nutrients thereby increasing crop nutrient uptake. The cropping systems with summer greengram, cabbage and onion (CS_2, CS_3 and CS_4) with the application of integrated nutrient sources (NS_2 and NS_3) were found more sustainable after two years of cropping cycle and can be advocated by the farmers of IGP.

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