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Productivity and soil nutrient balance influenced by INM under grain amaranth (*Amaranthus hypochondriacus*)-cowpea (*Vigna unguiculata*) sequence

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ABSTRACT

Two-year field experiment was conducted during *rabi* and summer 2016–17 and 2017–18 to develop a balanced nutrient supply for grain amaranth (*Amaranthus hypochondriacus* L.) and cowpea [*Vigna unguiculata* (L.) Walp] cropping sequence. The system was assessed on the basis of GAEY, production efficiency, monetary returns, nutrient uptake and balance of cropping system. Application of RDN_{75} CF + RDN_{25} BC (T_3) to *rabi* grain amaranth and RDF_{100} to cowpea found most beneficial compared to rest of the treatments. The superiority of T_3 to grain amaranth was highlighted by the significantly higher productivity (2.60 tonnes GAEY/ha), production efficiency (14.19 kg/ha/day), net returns (₹142.1 ×10^3/ha) and B:C ratio of 3.24, followed by treatments T_1 (RDN_{100} CF) and T_2 (RDN_{75} CF + RDN_{25} FYM). Whereas, lowest negative balance of N and K_2O and highest positive balance of P_2O_5 were noted with the application of RDN_{50} FYM + RDN_{50} BC (T_6) to grain amaranth. Conspicuous improvement in terms of maximum system productivity (2.46 tonnes GAEY/ha), production efficiency (13.46 kg/ha/day), net returns (₹127.4 × 10^3/ha) and B:C ratio of 2.64 and maximum nutrient uptake by cowpea crop, lowest negative balance of N, highest positive balance of P_2O_5 and highest negative balance of K_2O was recorded with the application of RDF_{100} (F_4) directly applied to cowpea over other treatments.

Keywords: Production efficiency (PE), Recommended dose of nitrogen (RDN), Recommended dose of fertilizer (RDF)

India's cropped area has been standing around 141 mha for over decades. Therefore, the scope for horizontal expansion remains limited, thus considerable scope exists only with vertical expansion and increased productivity (Paroda 2017). Increasing crop intensity is an effective way to promote crop production where sufficient production inputs are available. Amaranth (*Amaranthus hypochondriacus* L.) and cowpea [*Vigna unguiculata* (L.) Walp] are grown for multipurpose i.e. green leaves, vegetable, fodder and grain. Grain-amaranth is the richest source of protein (12–18%), which is higher than most of cereal grains except soybeans (Bressani 2018). The grain amaranth crop is early maturing (<3 months), can be grown several times a year and tolerates drought, heat stress, high soil acidity and salinity. Due to presence of different desirable characteristics, it could be a good option for food and nutritional security and most important it can be incorporated in cropping system as an effective strategy of adaptation/mitigation to climate change (Love and Nyankanga 2018). Amaranth and cowpea have a wide range of adaptability that makes it possible to grow in adverse conditions where, heat-loving nature of cowpea makes them ideal mid-summer consumer of soil nutrients applied to previous crop. Under field conditions, legume crops minimize the fertilizer requirement and can fix more than 60% of their N requirement depending on the legume host resulting in conserve N to tune 30–40 kg/ha for succeeding crop (Annon 2015, Tewodros M and Belay Y 2015). There is a possibility to intensify the system through introduction of cowpea as a catch crop during summer.

In intensified cropping system, having high turnover of nutrients, poor recycling of organic sources and application of high analysis fertilizers caused deficiency of several micronutrients in the soil. Organics alone do not supply sufficient plant nutrients to crop, resulting in lower yield potential. Therefore, to maintain soil productivity on a sustainable basis, conjunctive use of organic and inorganic sources of nutrients need to be adopted. In this context, sustainable agriculture under a viable cropping system approach with a feasible and profitable crop management practice is needed for sustaining productivity of the land. Therefore, the experiment under amaranth-cowpea was planned to review the feasibility of adoption of Integrated Nutrient Management (INM) as a technological

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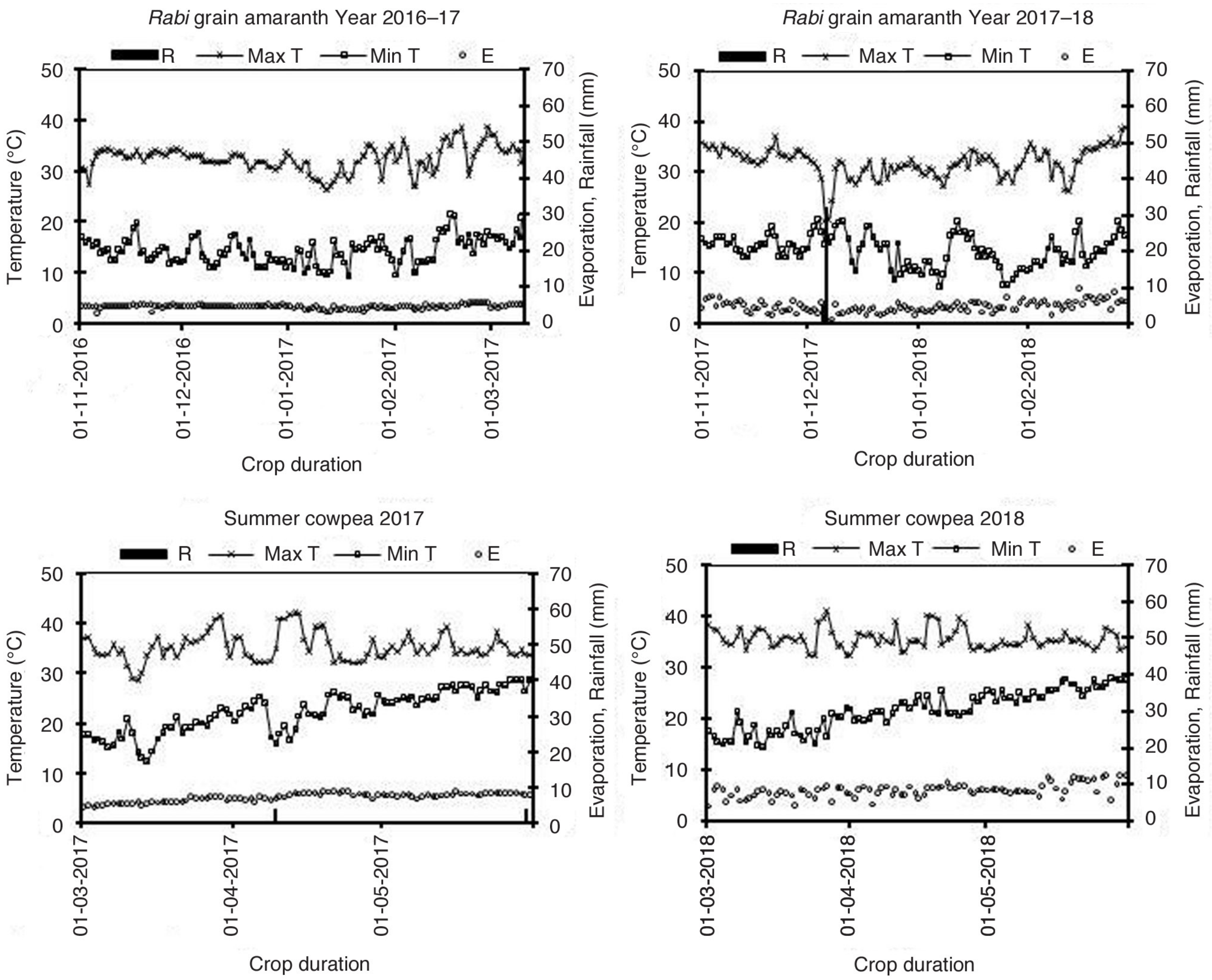

Fig 1 Daily weather parameters recorded throughout *rabi* (2016–17 and 2017–18) and summer (2017 and 2018) of the experimental site.

breakthrough in agro-techniques and nutrient management to improve the system productivity.

MATERIALS AND METHODS

Locality and soil description: The field study was carried out at Navsari Agricultural University, Navsari during *rabi* and summer 2016–17 and 2017–18. Soil conditions of the experimental site were deep black soil, dominant with smectite type of clay minerals having clay content range from 60–68% (Kaswala 1978) and comes under the order Inceptisols, iso-hyperthermic family of *Vertic Ustrochrepts*, soil series Jalalpur. The soil analysis data indicates that the soil of experimental site is slightly saline having *p*H 8.1 and EC 0.145 dS/m (1:2.5 soil: water ratio), low in organic carbon (0.39%), available nitrogen (200.70 kg/ha), moderately high in available phosphorus (37.79 kg/ha) and very high in available potassium (311.70 kg/ha). The field experiment was carried out on same site during both the years. The average climatic condition (2016–18) and weather conditions in the course of the investigated growing seasons of grain amaranth and cowpea are presented in Fig 1.

Treatments imposed on grain amaranth crop: Grain amaranth cv. GA 2 was sown with spacing of 30 cm × 10 cm in November and harvested in March during both the years. The seed of grain amaranth was treated with bio-fertilizer *Azotobacter* @200 ml, suspended in 400 ml water and used for inoculating 10 kg seed. The grain amaranth crop was provided with a uniform fertilizer dose as per the treatment through chemical fertilizers and organic manures. The experiment was laid out in randomized block design with six (6) treatments and replicated four (4) times (24 plots) and field experiment consisted of integrated nutrient management, viz. T_1 - RDN_{100} CF, T_2 - RDN_{75} CF + RDN_{25} FYM, T_3 - RDN_{75} CF + RDN_{25} BC, T_4 - RDN_{50} CF + RDN_{50} FYM, T_5 - RDN_{50} CF + RDN_{50} BC and T_6 - RDN_{50} FYM + RDN_{50} BC to grain amaranth in *rabi* season as main plot treatments.

Treatments imposed on cowpea crop: After grain amaranth harvest, cowpea crop was grown in the same layout. The cowpea cv. GC 4 was sown with spacing of 45 cm × 10 cm in March and harvested in May during both the years. During summer season each main plot treatment was split into four sub plot treatments with four levels of recommended dose of fertilizers, viz. F_1 - RDF_{00}, F_2 - RDF_{50}, F_3 - RDF_{75} and F_4 - RDF_{100} to cowpea resulting in twenty-four treatment combinations replicated four times hence total number of plots became 96 with split plot design (SPD). Thus, the residual effect of nitrogen sources applied to *rabi* grain amaranth crop with direct application of chemical fertilizer to cowpea was studied.

Manures and fertilizer application: RDF for grain amaranth is 60 N + 40 P_2O_5 + 00 K_2O kg/ha and for cowpea is 20 N + 40 P_2O_5 + 00 K_2O kg/ha. FYM and bio-compost was applied as per treatment before sowing and mixed well in that particular bed. The 50% dose of nitrogen and full dose of phosphorus were applied at the time of sowing and remaining 50% dose of nitrogen was applied at 30 days after sowing. In case of phosphorus fertilizer, the quantity of phosphorus from FYM and bio-compost was counted and deducted from the quantity of recommended dose of phosphorus and remaining phosphorus was applied in the form of SSP. In cowpea crop, all fertilizers were applied as per treatments at the time of sowing. The nitrogen was applied through urea and phosphorus through single superphosphate in both the crops. Before application of organic manures i.e. FYM and bio-compost to grain amaranth crop, it was analysed for nutrient content (N, P_2O_5 and K_2O) on dry weight basis. Nutrient content of FYM was 0.61 and 0.60% N, 0.38 and 0.39% P_2O_5 and 0.62 and 0.58% K_2O during the year 2016 and 2017, respectively. Nutrient content of bio-compost was 1.50 and 1.49% N, 0.87 and 0.85% P_2O_5 and 1.12 and 1.09% K_2O during the year 2016 and 2017, respectively.

Analytical methods: Crop yield and efficiency indices: Yields were recorded from the net plot of 31.50 and 6.21 m^2 after discarding border plants in each gross plot measuring of 55.35 m^2 and 12.15 m^2 for grain amaranth and cowpea, respectively. Harvested grain/seed of both the crop were weighed and subsequent yields were converted to hectare basis.

The effect of treatments on the cropping sequence was judged on the basis of grain amaranth equivalent yield (GAEY). This was calculated by converting the seed yield of cowpea into equivalent yield of grain amaranth (based on the price of amaranth grain and cowpea seed) followed by summing with the yield of the grain amaranth crop. GAEY was calculated by the following equation for respective treatments for both the years.

$$\text{GAEY (kg/ha)} = \frac{\text{Grain amarnath grain yield (kg/ha)} \times \text{Market rate of grain amarnath grain (₹/kg)} + \text{Cowpea seed yield (kg/ha)} \times \text{Market rate of cowpea seed (₹/kg)}}{\text{Market rate of grain amarnat (₹/kg)}}$$

The production efficiency (PE) was worked out by dividing the total production of the sequence divided by the total duration of the crops grown in sequence.

Monetary efficiency: The economics of grain amaranth-cowpea sequence was worked out by considering the prevailing market rates for different inputs and produces. The treatment-wise cost of cultivation and gross realization (₹/ha) were calculated considering the item-wise prices/rates for respective years. The net realization (₹/ha) for individual treatment was worked out by subtracting the total cost of cultivation of each treatment from gross realization of respective treatment. In addition, the benefit:cost ratio of each treatment was also calculated.

Plant analysis: Plant samples of grain/seed and straw/stover of grain amaranth and cowpea collected at harvest were cleaned, dried and milled as needed before chemical analysis. The nutrient (NPK) uptake was worked out by using following formula.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{Biomass (kg/ha)} \qquad (2)$$

Soil analysis: The composite soil samples were taken from 0–22.5 cm depth initially and after harvest of each crop during both the years. The soil samples were dried under shade, ground and then sieved through 2 mm size sieve and used to determine available nutrients through standard methods prescribed, viz. for available N determination alkaline $KMnO_4$ method, for available P_2O_5, colorimetric method and for available K_2O, flame photometric method was used. The soil nutrient balance in respect of available NPK at commencement of experimentation, addition of these nutrients, nutrient uptake by the crops and left over nutrients in the soil after harvest of crops in the sequence during both the cycles of experimentation was calculated.

Statistical analysis: Data were analysed according to RBD design during *rabi* and SPD during summer by analysis of variance (ANOVA). The source of variation were year, source of nitrogen fertilization and their maximum two-order interaction for *rabi* grain amaranth and year, source of nitrogen application to previous crop, different levels of fertilization and their maximum three-order interactions for summer cowpea crop. Before performing the ANOVA, the homogeneity of variance of all characteristics was verified according to Bartlett's tests. Comparison of means was done by critical difference (CD) procedure ($P \leq 0.05$). Pooled analysis of cropping system analysed for two years was worked out as per the method described by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Cumulative and direct effect of INM on system productivity: Cumulative effect of *rabi* grain amaranth crop treatment: Apart from the treatment effects, prevailing price became an additional important factor in choosing the better treatment combinations in a cropping sequence. System productivity calculated on a pooled analysis basis in terms of GAEY, revealed significant response in yield with the INM to preceding grain amaranth (Table 1). Significantly higher GAEY of 2.60 tonnes/ha obtained with RDN_{75} CF + RDN_{25} BC (T_3) which remained significantly

Table 1 Amaranth grain and cowpea seed yield, grain amaranth equivalent yield (GAEY), production efficiency (PE) and economics of system (average 2016–17 and 2017–18) as influenced by cumulative fertility and direct fertilizer application

Treatment	Amaranth grain yield (t/ha)		Cowpea seed yield (t/ha)		GAEY (t/ha)*	PE (kg/ha/day)*	Gross monetary returns (₹×10³/ha)	Cost of cultivation (₹×10³/ha)	Net monetary returns (₹×10³/ha)	B:C ratio
	2016–17	2017–18	2017	2018						
I) Rabi grain amaranth crop treatment										
T_1 : RDN_{100} CF	1.62^{ab}	1.72^{ab}	0.75^{d}	0.79^{d}	2.43^{ab}	13.25^{ab}	173.3	43.6	129.7	2.97
T_2 : RDN_{75} CF + RDN_{25} FYM	1.54^{abc}	1.68^{ab}	0.79^{cd}	0.82^{cd}	2.40^{ab}	13.10^{a}	171.1	47.9	123.2	2.57
T_3 : RDN_{75} CF + RDN_{25} BC	1.70^{a}	1.85^{a}	0.85^{bc}	0.88^{bcd}	2.60^{a}	14.19^{a}	185.9	43.8	142.1	3.24
T_4 : RDN_{50} CF + RDN_{50} FYM	1.33^{cd}	1.42^{bc}	0.91^{ab}	0.92^{abc}	2.27^{b}	12.41^{b}	162.3	52.3	110.0	2.11
T_5 : RDN_{50} CF +RDN_{50} BC	1.37^{bcd}	1.44^{bc}	0.94^{a}	0.95^{ab}	2.33^{b}	12.72^{b}	166.1	44.0	122.1	2.77
T_6 : RDN_{50} FYM + RDN_{50} BC	1.22^{d}	1.30^{c}	0.97^{a}	1.01^{a}	2.23^{b}	12.17^{b}	158.7	52.7	106.0	2.01
CD (P=0.05)	0.25	0.33	0.08	0.10	0.21	1.15	-	-	-	-
CV (%)	11.25	13.82	11.49	14.87	17.57	17.38	-	-	-	-
II) Summer cowpea crop treatment										
F_1 : Control	-	-	0.76^{c}	0.78^{c}	2.27^{c}	12.38^{d}	162.1	46.2	115.8	2.51
F_2 : RDF_{50}	-	-	0.84^{b}	0.88^{bc}	2.35^{b}	12.84^{c}	168.0	47.2	120.8	2.56
F_3 : RDF_{75}	-	-	0.92^{a}	0.93^{ab}	2.42^{a}	13.20^{b}	172.4	47.8	124.7	2.61
F_4 : RDF_{100}	-	-	0.95^{a}	0.99^{a}	2.46^{a}	13.46^{a}	175.6	48.3	127.4	2.64
CD (P=0.05)	-	-	0.05	0.06	0.04	0.20	-	-	-	-
CV (%)	-	-	9.34	11.88	3.92	3.88	-	-	-	-
Interaction (M × S)										
CD (P=0.05)	-	-	NS	NS	NS	NS	-	-	-	-
CV (%)	-	-	9.34	11.88	3.92	3.88	-	-	-	-

*Pooled data of 2016–17 and 2017–18.

RDN, recommended dose of nitrogen; RDF, recommended dose of fertilizer; CF, chemical fertilizer; FYM, farm yard manure; BC, bio-compost (Subscript digit showed the quantity of RDN and RDF in kg/ha applied through respective manures and chemical fertilizers).

different from other treatments except T_1 (RDN_{100} CF) and T_2 (RDN_{75} CF + RDN_{25} FYM). The percent increased in GAEY with treatments T_3, T_1 and T_2 with corresponding values of 16.59%, 8.97% and 7.62%, respectively over T_6 (RDN_{50} FYM + RDN_{50} BC). However, the residual effect of these nutrients combinations applied to the previous crops relative to the mean productivity of cowpea was meagre to the increase in its yield under the nutrient combination of RDN_{50} FYM + RDN_{50} BC (T_6). This might be due to a balanced combination of sources which provide nutrient to present as well as succeeding crops, relatively in higher amount as compared to other combinations. These results were in conformity with findings of Patel (2018) in finger millet-green gram and Patil *et al*. (2018) in sorghum-green gram cropping sequence.

Direct effect of summer cowpea crop treatment: The GAEY improved with increased nutrition applied to cowpea crop (Table 1). Without fertilization or reduced fertilization to crop grown in sequence resulted in lower values of GAEY (2.27 tonnes/ha for F_1, 2.35 tonnes/ha for F_2 and 2.42 tonnes/ha for F_3) than the RDF_{100} (2.46 tonnes/ha) and found superior over other treatments. The higher value of GAEY in the RDF_{100} treated plot also suggests that the productivity of grain amaranth-based cropping system can not only be improved but also sustained with balanced fertilization. Significantly higher rice equivalent yield was recorded with application of 100% RDN (100 kg N/ha) through chemical fertilizers followed by 100% RDF (20 N + 40 P_2O_5 + 00 K_2O kg/ha) to *rabi* chickpea under rice-chickpea cropping sequence (Mansuri 2016).

Cumulative and direct effect on production efficiency (PE)

Cumulative effect of *rabi* grain amaranth crop treatment: The PE, i.e. per day production of the cropping sequence, mirrored the yield responses to different nutrient management practices (Table 1). The mean PE of the system, calculated over the two year cropping sequence varied from 12.17 kg/ha/day (T_6) to 14.19 kg/ha/day (T_3). Application of RDN_{75} FYM + RDN_{25} BC (T_3) registered maximum PE and remained at par with treatments T_1 (RDN_{100} CF) and T_2 (RDN_{75} CF + RDN_{25} FYM).

Direct effect of summer cowpea crop treatment: Irrespective of the various doses of fertilization, improvement in PE with different treatments applied to cowpea crop grown in sequence was noticed in comparison to the control (Table 1). The PE of the system calculated over the two years (pooled) cropping sequence varied from 12.84 kg/ha/day (F_2) to 13.46 kg/ha/day (F_4) compared to 12.38 kg/ha/day under absolute control (F_1). The highest PE was recorded in treatment consisting RDF_{100} (F_4) and remained significantly different from other treatments. The declining trend of PE was observed with nutrient inadequacy or imbalanced fertilization. These results are supported by previous study of Sheoran *et al*. (2017) which showed significantly maximum PE of the potato-sunflower-green-gram cropping sequence over the 4 year obtained with 150% NPK application (27.98 kg/ha/day) over control.

Cumulative and direct effect of INM on economics

Cumulative effect of *rabi* grain amaranth crop treatment: On the basis of average of 2016–17 and 2017–18, the gross monetary returns, net monetary returns and B:C ratio of the grain amaranth-cowpea sequence were computed for different treatments (Table 1). Economic analysis highlighted favourable turnover with the soil incorporation of bio-compost in grain amaranth supplemented with chemical fertilization, compensating additional costs incurred. Application of RDN_{75} CF + RDN_{25} BC (T_3) recorded higher net returns (₹142.1 × 10^3/ha) and B:C (3.24) when compared with the fully chemically fertilized plot (net returns ₹129.7 × 10^3/ha and B:C 2.97) and organic manure treated plots (net returns ₹106.0 × 10^3/ha and B:C 2.01) grown in sequence. Sole reliance on either chemical fertilizers or organic manure or imbalanced combinations of nutrient sources is not a cost-cutting measure to achieve optimum yields as it resulted in lower returns and B:C compared to the balanced combinations. Consistent with our results the higher net realization and B:C from nutrient management under potato-sunflower-green-gram cropping sequence was reported by Sheoran *et al*. (2017).

Direct effect of summer cowpea crop treatment: The net monetary returns and B:C of cropping sequence with INM to preceding *rabi* grain amaranth followed by various levels of RDF to cowpea was highest with RDF_{100} (₹127.4 ×10^3/ha and 2.64) (Table 1). Results are in agreement with those reported by Nag (2006) in wheat-cowpea; Mansuri (2016) in rice-chickpea; Patel (2018) in finger millet-green-gram and Patil *et al*. (2018) sorghum-green-gram sequence.

Cumulative and direct effect of INM on nutrient uptake and apparent balance

Cumulative effect of rabi grain amaranth crop treatment: The maximum nutrient uptake by grain amaranth and cowpea crop, highest negative balance of N and K_2O and lowest positive balance of P_2O_5 were recorded with the application of RDN_{75} CF + RDN_{25} BC (T_3) to grain amaranth followed by chemical fertilizer treatment, only (T_1) indicating mining of nutreints from native soil reserves in the absence of suboptimal application of nutreints (Table 2). Lowest nutreint uptake by both the crops (207.89, 330.51 and 234.85 kg/ha N, P_2O_5 and K_2O) and lowest negative balance of N (-87.89 kg/ha) and K_2O (-131.02 kg/ha) and highest positive balance of P_2O_5 (49.49 kg/ha) were noted with the application of RDN_{50} FYM + RDN_{50} BC (T_6) to grain amaranth. The net negative soil nutrient stock for N and K_2O with all the treatments indicates its high requirement for the crops. The apparent P_2O_5 balance in the soil was positive with all treatments of grain amaranth.

Table 2 Nutrient uptake by cropping system and apparent balance as influenced by cumulative fertility and direct fertilizer application (average 2016–17 and 2017–18)

Treatment	Total input[a] (kg/ha)			Total output[b] (kg/ha)			Apparent balance (kg/ha)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
I) Rabi grain amaranth crop treatment									
T_1 : RDN_{100} CF	120	80	0.00	262.34	46.94	252.71	-142.34	33.06	-252.71
T_2 : RDN_{75} CF + RDN_{25} FYM	120	80	29.75	245.33	41.26	255.16	-125.33	38.74	-225.41
T_3 : RDN_{75} CF + RDN_{25} BC	120	80	22.18	272.51	47.17	280.35	-152.51	32.83	-258.17
T_4 : RDN_{50} CF + RDN_{50} FYM	120	80	59.49	214.44	33.99	239.73	-94.44	46.01	-180.24
T_5 : RDN_{50} CF + RDN_{50} BC	120	80	44.34	233.59	36.72	247.97	-113.59	43.28	-203.63
T_6 : RDN_{50} FYM + RDN_{50} BC	120	80	103.83	207.89	30.51	234.85	-87.89	49.49	-131.02
II) Summer cowpea crop treatment									
F_1 : Control	00	00	00	73.29	5.57	66.18	-73.29	-5.57	-66.18
F_2 : RDF_{50}	20	40	00	82.01	6.05	69.95	-62.01	33.95	-69.95
F_3 : RDF_{75}	30	60	00	89.13	6.42	73.42	-59.13	53.58	-73.42
F_4 : RDF_{100}	40	80	00	94.99	6.77	76.51	-54.99	73.23	-76.51

[a]Total inputs included NPK added through fertilizers + FYM + BC to grain amaranth and cowpea as per the treatments; [b] Total outputs included total NPK uptake by grain amaranth and cowpea.

Direct effect of summer cowpea crop treatment: The maximum nutrient uptake by cowpea and lowest negative balance of N (-54.99 kg/ha), highest positive balance of P_2O_5 (73.23 kg/ha) and highest negative balance of K_2O (-76.51 kg/ha) were recorded with RDF_{100} (F_4) applied to cowpea. P_2O_5 balance in the soil was positive with all fertilization treatment except control (F_1). The lowest nutrient uptake and the highest negative balance were recorded with control except apparent balance of K_2O, which recorded lowest under this treatment (Table 2). Sheoran *et al*. (2017) observed the lowest nutrient uptake and the highest negative balance with the control, followed by treatments involving nutrient inadequacy or imbalance under potato-sunflower-green-gram system.

The addition of organic manures (FYM and bio-compost) along with different levels of chemical fertilizer to preceding crop showed the positive impact on system productivity, economics, nutrient uptake and balance of grain amaranth-cowpea sequence during both the years of experimentation (2016–2017 and 2017–2018). From two years of experimentation, it can be concluded that in grain amaranth-cowpea sequence, grain amaranth should be nourished with 60 kg N (RDN_{75} CF + RDN_{25} BC) along with recommended dose of 40 kg P_2O_5 and summer cowpea should be fertilized with RDF_{100} (20 N + 40 P_2O_5 + 00 K_2O kg/ha) through chemical fertilizer for getting sustainable cropping system yield.

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