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Inorganic fractionation of nitrogen, phosphorous and potassium as influenced by INM practices in elephant foot yam - black gram system

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Abstract

A field experiment was conducted for two consecutive kharif seasons during 2018-19 and 2019-20 to study the effect of integrated application of inorganic fertilizers and organic manure on fractionation of N, P and K and yield performance of elephant foot yam – black gram cropping system in an acid Alfisol of Odisha. Higher amount of ammoniacal-N and nitrate-N (124.56, 24.19 kg ha^{-1}, respectively), reductant soluble-P (60.16 mg kg^{-1}) and exchangeable K (205.63 kg ha^{-1}) were recorded due to integrated application of FYM + ½ NPK. Available N in the soils influenced by ammoniacal N, nitrate-N and total N and the relationship was found to be positive and significant (r = 0.950**, 0.935**and 0.927**, respectively). Calcium bound P, total P, water soluble P, and Al-P contributed significantly towards the available P pool (r=0.991**, 0.955**, 0.942**, 0.930**, respectively), whereas, available K was contributed significantly with exchangeable K, total K and non-exchangeable K fractions (r = 0.979, 0.937** and 0.927**, respectively). Available N showed positive and significant relationship with starch, total sugars and dry matter (r=0.895**, 0.894**, 0.864**, respectively), whereas iron bound P had significant relationship with starch, total sugars and dry matter (r=0.869**, 0.832**, 0.686**, respectively). In conclusion, the corm yield of elephant foot yam and grain yield of black gram showed highly significant relationship with ammoniacal N, Fe-P and total K and they had been considered as major contributing fractions in respect of N, P and K towards the yield and quality of elephant foot yam – black gram crops.

Keywords: Alfisol, INM practices, Elephant foot yam, Yield, Quality, Inorganic fractions

Introduction

The crop response to applied fertilizers depends on soil organic matter which could be improved either by natural returns through roots, stubbles and crop wastes as well as application of various organic resources (Ayoola and Adeniyan, 2006). Inorganic forms of major nutrients significantly contribute to yield and quality attributes of crops. Organic forms of nutrients on mineralization converts into inorganic forms and mobilized into plant system from the soil solution. It is necessary to understand which fraction of nutrient had significant influence to enhance the productivity as well as proximate composition of crops for effective nutrient management strategies. Addition of organics not only supply the additional nutrients to the growing plants, but also affects the availability of native nutrients as well as nutrients added through chemical fertilizers. The

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release of organic acids and other microbial products during decomposition of organic manures improve the availability of nutrients (Stevenson, 1967). Hence, understanding the dynamics of nutrients under long-term cropping, fertilization and amendments is essential to develop an efficient nutrient management program.

Elephant foot yam (EFY) (*Amorphophallus paeoniifolius* L) is a South East Asian crop produced for its underground modified stem, also known as corm. Due to its high productivity, export potential, and culinary characteristics, it became a commercial crop in India. Farmers are encouraged to plant the EFY despite its extended lifetime because of high quality corms, minimal pest and disease incidence, and low labour requirements. Elephant foot yam is considered as a nutrient exhaustive crop as it requires very high amount of N, P and K fertilizers for achieving higher yields. Judicious use of nutrients and manipulation of microclimate is essential to maximize the corm yield. The tuber is useful for the treatment of piles, acute rheumatism (Chopra et al. 1958; Yusuf et al. 1994), enlarged spleen, abdominal tumors, boils, asthma (Yusuf et al. 1994), abdominal pain, dyspepsia and elephantiasis (Kirtikar and Basu, 1994). Consumption of corms is useful to control hemorrhoids. It contains a variety of therapeutic qualities, including gastro protective, antioxidant, anti-diarrheal, and anti-inflammatory properties. The corms contain glucose, galactose, and rhamnose, as well as flavonoids, phenols, coumarins, terpenoids, sterols, tannins, steroids, alkaloids and amblyone (a triterpenoid) (Nataraj et al. 2009; Yadu and Ajoy, 2010), and 3, 5-diacetylambulin (a flavonoid) (Khan et al. 2008).

Black gram (*Vigna mungo* L.) commonly known as 'King of Legumes' belongs to the Fabaceae family and is India's third most significant pulse crop. This legume is being cultivated as a mixed crop, cash crop, and sequential crop in cropping systems, as well as growing as a sole crop after harvest of rice and before and after harvest of other summer crops in semi-irrigated and dry land conditions. Legume-based cropping systems have been shown to be generally beneficial to the soil by preservation of organic matter, increasing soil nitrogen, improving soil physical properties and could also break the cycle of soil-borne diseases (Borin and Frankow-Lindberg, 2005; Imai et al. 1989).

Plant roots take up nitrogen from the soil mostly as NO_3^- and to some extent as NH_4^+-N. The NO_2 form is unstable and is usually present in soil in lesser extent. In Indian soils, total phosphorus ranged from 100 - 2000 ppm but the available P ranged from 2 - 20 ppm. The inorganic form of P constitutes about 30-35 per cent of total P (Mishal et al. 2022). The inorganic P consist of different pools such as aluminum, iron and calcium bound phosphorus constitutes active form of inorganic P. The reductant-soluble and occluded forms of phosphorus are relatively less active. Different types of phosphorus are interrelated and add to the pool of plant-accessible P as per their physical and chemical properties such as surface area, composition and solubility. Among the active forms, Ca-P usually predominates the Fe-P and Al-P in alkaline and neutral soils, whereas reverse in acidic soils. The specific surface area activity and solubility of Al-P and Fe-P is higher than the Ca-P fraction. Therefore, these two forms are the major contributors to P availability both in acidic soils and also to P uptake by many crops. Reductant-soluble phosphorus is an inorganic form of phosphorus in soil that is bound within iron and aluminum compounds and is released when these sesquioxides are reduced. This process typically occurs under anaerobic conditions, which can dissolve the inert coating around the phosphate compounds, making the phosphorus available to plants. It is a less active form of phosphorus than soluble or calcium-bound phosphorus but is still an important part of the soil's overall phosphorus pool.

Information on P fractions is thus important for evaluation of their status in the soil and understanding its chemistry that has influence on crop productivity and soil health. Use of chemical fertilizers in conjunction with organic manures has been reported to influence the dynamics of inorganic K fractions (Basumatary, 2018). Equilibrium exists among different forms that affect level of K in the soil solution at particular time and availability of K in plants. The distribution of water soluble K, exchangeable K, non-exchangeable K (fixed K) and mineral K forms in soils is important in understanding the conditions controlling their availability to growing crops.

The present investigation was planned to assess the dynamics of inorganic fractions of nitrogen, phosphorous and potassium as influenced by application of single and dual application of graded doses of N & K in comparison to integrated application of inorganic and organic manure and to find out which fraction of the nutrient contributing towards the yield and quality of elephant foot yam – black gram cropping system in an Alfisol of Eastern India.

Materials and Methods

Field experiments were laid out at the Regional Centre of the ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha during kharif, 2018-2019 and 2019-2020. The experiment was conducted with 14 treatment combinations (Control, N_{40}, N_{80}, N_{120}, P_{30}, K_{40}, K_{80}, K_{120}, $N_{80}P_{30}$, $N_{80}K_{80}$, $P_{30}K_{80}$, $N_{80}P_{30}K_{80}$, FYM @ 10 t ha^{-1}, FYM @ 10 t ha^{-1} + $N_{40}P_{15}K_{40}$) in 3 replications in a randomized block design. Due to high status of available P in the soil, single application of graded doses and dual application of N & K. The experimental soil is fine-loamy, mixed, isohyperthermic, Typic Haplustalf, sandy loam in texture, acidic (pH 5.516), non-saline (0.442

dS m^{-1}) and having 0.256% of organic carbon, 2014.62 kg ha^{-1} total nitrogen, 136.48, 56.76 and 197.59 kg ha^{-1} of available nitrogen (N), phosphorus (P) and potassium (K), respectively. The soil also contains 43.44, 1.52, 76.85, and 0.586 mg kg^{-1} of available iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) respectively. Well rotten farmyard manure (contain 0.50-0.28-0.60% of N, P and K, respectively) was applied one month in advance of planting of elephant foot yam in the respective plots. On application of 10 t ha^{-1} of FYM, supplemented 50, 64 and 72 kg N, P_2O_5 and K_2O ha^{-1}, respectively. Elephant foot yam (*cv* Gajendra) corms were cut into pieces of 250 g size and planted in the pits (45x45x45 cm) at a spacing of 80x80 cm. Black gram seeds were dibbled in between the rows at 90 days after planting of elephant foot yam. No additional fertilizers/ manures were applied to black gram and it was grown as an inter crop with elephant foot yam.

One-third of N, entire P_2O_5 and ½ K_2O at basal, ⅓ N at 45 days after planting (DAP) and the balance ⅓ N and ½ K_2O at 75 DAP in the form of urea, single super phosphate and muriate of potash, respectively were applied as per the treatments. All the cultural practices were followed as per the schedule and black gram was harvested at 70 days after sowing and recorded grain and haulm yields. However, elephant foot yam was harvested at 8 months after planting at its maturity and senescence of the plant. Yield parameters of both the crops were recorded at harvest, collected the grain and haulm samples of black gram as well as corm samples of elephant foot yam, washed thoroughly, oven dried at 60ºC and dry weights were recorded. The plant samples were ground, sieved with 0.5 mm sieve and used for analysis of nutrients by following the standard procedures (Jackson, 1973). Post harvest soil samples were collected at harvest, shade dried, pounded, sieved with 2.0 mm sieve and used for estimation of physico-chemical properties by using standard procedures as outlined by Jackson (1973).

The processed soil samples were stored in polythene bags for determining different fractions of N, P and K. Inorganic forms of N namely NH_4-N and NO_3-N were determined by steam distillation method (Black, 1965). Total P in the soil was determined by using 60% perchloric acid digestion method as outlined by Jackson (1973). The sequential fractionation method was followed for estimation of different forms of inorganic P *viz*., Fe-P, Al-P, Ca-P and RS-P (Kovar and Pierzynski 2009) and available P_2O_5 by Bray's method. Water soluble K was determined by shaking the soil with distilled water (1:5 ratio). The 1.0 N boiling HNO_3 extractable K was estimated by using flame photometer in 1:10, soil: acid suspension boiled for 10 minutes as described by Wood and DeTurk (1941). Non-exchangeable K was calculated by subtracting available K from 1N boiling HNO_3 extractable K. Available K was derived by the sum of exchangeable K and water soluble K. The data of the experiment were analyzed by the method of Analysis of Variance (ANOVA) outlined by Panse and Sukhatme (1995) to know the variation between treatments expressed by critical difference (CD) value, which are the product of 't' value at 5% level of significance based on error degrees of freedom from the ANOVA table. Relationship of different N, P and K fractions with available nitrogen, phosphorous and potassium was worked out by computing correlation coefficients as described by Gomez and Gomez (1984).

Results and Discussion

Yield performance of elephant foot yam

Integrated use of half of the recommended doses of NPK ($N_{40}P_{15}K_{40}$) along with FYM @ 10.0 t ha^{-1} has recorded significantly highest corm yield of 26.50 t ha^{-1} with a yield response of 66.5 % over control (Table 1). Incorporation of FYM @ 10.0 t ha^{-1} alone has recorded a corm yield of 19.8 t ha^{-1} with a yield response of 24.4 % over control, which is higher than the single application of N and K fertilizers. Organic manures along with fertilizers also increased the soil organic matter content and stimulated the soil microbial activities (Geng et al. 2019). The higher yield response to the organic manure and inorganic fertilizers might be attributed to decomposition of organic manure improves the physical and biological properties and nutrient release pattern in the soil and supplementary effect of inorganic fertilizers (Ram et al. 2016). Elephant foot yam is a heavy feeder of nutrients and the yields were increased considerably as it shown significant response to application of higher doses of NPK fertilizers in low and marginal soils, where it is being cultivated extensively. These results are in corroborative with the findings of Nizamuddin et al. (2003).

Proximate composition

Significantly highest mean dry matter in the corms of elephant foot yam (25.2%) was recorded due to integrated application of FYM + ½ NPK followed by $N_{80}P_{30}K_{80}$ (24.6%) (Table 1). Significantly highest mean starch content was recorded due to combined application of FYM + ½ NPK (12.8%) at par with $N_{80}P_{30}K_{80}$ (12.6%) and $N_{80}K_{80}$ (12.4%). Total sugars in the corms of elephant foot yam ranged from 1.097 to 1.503%, with highest being due to integrated application of FYM + ½ NPK. Incorporation of organic manure along with limited doses of NPK fertilizers has recorded significantly highest starch content, which might be attributed to increased rate of mineralization of the organic manure resulted into nutrient transformations and their mobility into the plant system.

Table 1. Effect of organic and inorganic nutrients on yield performance of elephant foot yam and black gram cropping system (Mean of 2018-2020)

Treatment	Elephant foot yam					Black gram			
	Corm yield ($t\ ha^{-1}$)	Yield response (%)	Starch (%)	Total sugars (%)	Dry matter (%)	Grain yield ($q\ ha^{-1}$)	Haulm yield ($q\ ha^{-1}$)	Yield response (%)	Crude protein (%)
1. Control	15.92	--	10.01	1.097	22.50	4.24	13.65	-	19.66
2. 40 kg N ha^{-1}	19.27	21.04	10.45	1.141	22.79	5.00	14.91	17.92	19.56
3. 80 kg N ha^{-1}	22.08	38.69	10.88	1.198	23.30	5.38	15.66	26.89	20.55
4. 120 kg N ha^{-1}	21.17	32.98	11.42	1.305	23.68	5.47	16.36	29.01	21.96
5. 30 kg P_2O_5 ha^{-1}	20.64	29.65	10.90	1.166	22.70	5.09	15.81	20.05	19.84
6. 40 kg K_2O ha^{-1}	19.69	23.68	11.04	1.203	23.14	5.17	15.42	21.93	20.43
7. 80 kg K_2O ha^{-1}	22.06	38.57	11.39	1.279	23.97	5.53	16.24	30.42	20.14
8. 120 kg K_2O ha^{-1}	23.18	45.60	11.82	1.378	24.56	5.69	17.28	34.20	21.55
9. 80-30 kg N & P_2O_5 ha^{-1}	21.84	37.19	11.82	1.366	23.63	5.69	16.72	34.20	20.16
10. 80-80 kg N & K_2O ha^{-1}	23.60	48.24	12.44	1.415	24.12	5.86	18.54	38.21	22.63
11. 30-80 kg P_2O_5 & K2O ha^{-1}	21.79	36.87	11.62	1.351	23.76	5.74	17.35	35.38	20.39
12. 80-30-80 kg N, P_2O_5 & K_2O ha^{-1}	25.55	60.49	12.64	1.443	24.59	5.99	18.89	41.27	22.84
13. FYM @ 10 t ha^{-1}	19.80	24.37	11.35	1.362	24.03	5.41	17.27	27.59	20.75
14. FYM+40-15-40 kg N, P_2O_5 & K_2O ha^{-1}	26.50	66.46	12.79	1.503	25.16	6.25	19.36	47.41	22.11
CD (P=0.05)	0.335	--	0.172	0.036	0.196	0.135	0.30	-	0.529

Yield performance of black gram

Significantly highest mean grain and haulm yields of black gram were recorded due to integrated application of FYM + $N_{40}P_{15}K_{40}$ (6.25 and 19.36 q ha^{-1}, respectively) followed by $N_{80}P_{30}K_{80}$ (5.99 and 18.89 q ha^{-1}, respectively). Incorporation of FYM has recorded a grain yield of 5.41 q ha^{-1}, which is at par with the application of 80 kg N ha^{-1} (Table 1). Balanced application of 80-30-80 kg N, P and K ha^{-1} has shown a yield response of 41.3% over control in comparison to $N_{80}K_{80}$ (38.2%), $P_{30}K_{80}$ (35.4%) and $N_{80}P_{30}$ (34.2%), indicating that application of balanced doses of $N_{80}P_{30}K_{80}$ had positive impact on crop yields rather than single or combined application of N, P, and K fertilizers. Highest crude protein content in black gram was recorded due to application of $N_{80}P_{30}K_{80}$ (22.84%) at par with application of $N_{80}K_{80}$ (22.63%). Increased doses of N or K fertilizers showed least significant effect on crude protein content of black gram, indicating that the higher doses of inorganic fertilization is not beneficial to the legumes. Similar results were obtained by Laxminarayana and Pradhan (2017).

Soil physico-chemical properties

The pH of the soil was significantly increased to 5.78 due to integrated application of FYM + ½ NPK from the initial value of 5.16 (Table 2). The soil pH showed a decreasing trend with the increased doses of N application. Addition of N or K up to 80 kg ha^{-1} has improved the soil pH to 5.64, however, combined application of NP, PK and NK showed relatively higher soil pH over that of single application of N or K fertilizers. Application of inorganic fertilizers alone showed lower values of pH in comparison to organic sources. Continuous cropping without fertilization or manuring of the soil (control) showed lowest organic C (0.258%) over that of other treatments. Addition of graded doses of N and K fertilizers showed a significant improvement in organic matter status. Highest organic C content (0.474%) was observed due to integrated use of FYM + ½ NPK at par with 80-30-80 kg N, P and K ha^{-1} (0.449%). Apart from yield gains, organic sources add organic matter, improve soil physical properties and neutralize soil acidity.

Highest total N was observed due to application of FYM + ½ NPK (2319 kg ha^{-1}) at par with $N_{80}P_{30}K_{80}$ (2273 kg ha^{-1}) over the initial status of 1876 kg ha^{-1}. However, it showed an increasing trend of total N with the application of N or K_2O fertilizers up to 120 kg ha^{-1} and a significant improvement of total N was observed due to dual application of $N_{80}K_{80}$ (2148 kg ha^{-1}). Integrated use of inorganic and organic sources showed a built up of total N status rather than the addition of inorganic fertilizers. Addition of nitrogenous fertilizers tended to increase the available N status of the soil to 141, 164 and 178 kg ha^{-1} in respect of 40, 80 and 120 kg ha^{-1} of N fertilizers

Table 2. Effect of organic and inorganic nutrients on physico-chemical properties of the soil under elephant foot yam – black gram system

Treatment	pH	Organic C (%)	Total N (kg ha^{-1})	Available nutrient (kg ha^{-1})			Exch. Ca	Exch. Mg	Available S (mg kg^{-1})	Available micro nutrient (mg kg^{-1})			
				N	P	K	[c mol (p^{+}) kg^{-1}]			Fe	Cu	Mn	Zn
Initial	5.516	0.256	2014.62	136.5	56.76	197.6	4.52	2.03	7.36	43.44	1.52	76.85	0.586
Control	5.732	0.258	1876.12	121.1	50.38	173.2	5.16	2.17	7.06	44.01	1.66	53.54	0.602
N_{40}	5.65	0.353	1924.79	140.7	54.99	190.7	5.47	2.35	7.24	47.51	1.55	48.86	0.614
N_{80}	5.639	0.412	2037.54	163.8	57.03	196.0	5.49	2.39	7.28	50.32	1.64	52.92	0.656
N_{120}	5.595	0.437	2249.98	178.1	56.25	207.5	5.82	2.39	7.23	52.23	1.76	53.89	0.714
P_{30}	5.54	0.295	1896.42	139.5	66.86	192.7	5.29	2.33	6.89	46.50	1.69	52.07	0.654
K_{40}	5.704	0.304	1910.65	134.7	53.07	207.3	5.43	2.36	7.24	49.93	1.60	49.85	0.754
K_{80}	5.637	0.349	1964.89	152.8	56.31	221.2	5.45	2.58	7.52	47.83	1.65	50.17	0.733
K_{120}	5.611	0.388	2086.51	160.8	57.70	240.7	5.70	2.57	7.67	44.98	1.74	52.93	0.719
$N_{80}P_{30}$	5.677	0.403	2039.27	164.3	68.16	197.2	5.82	2.28	7.79	47.40	1.67	51.41	0.755
$N_{80}K_{80}$	5.622	0.414	2148.32	182.7	57.52	205.5	5.81	2.45	7.75	51.94	1.74	51.13	0.746
$P_{30}K_{80}$	5.673	0.387	1975.44	159.5	69.84	218.8	5.79	2.45	7.79	46.10	1.78	50.75	0.737
$N_{80}P_{30}K_{80}$	5.656	0.449	2273.19	188.6	75.02	255.1	5.96	2.59	7.81	48.64	1.78	49.61	0.774
FYM @ 10 t ha^{-1}	5.621	0.414	2054.65	165.5	56.40	198.2	5.77	2.45	7.31	45.23	1.59	50.37	0.734
FYM + $N_{40}P_{15}K_{40}$	5.783	0.474	2319.16	204.5	73.56	250.2	5.88	2.64	7.80	44.53	1.70	52.45	0.747
CD (P=0.05)	0.061	0.008	0.0046	12.9	6.80	7.80	0.27	0.09	0.24	1.13	0.05	1.50	0.038

from the initial value of 121 kg ha^{-1} (Table 2). Addition of graded doses of K fertilizers also showed an increasing trend of available N, which may be due to synergetic effect between N and K. An increase of 51, 36, and 32% of available N was observed due to dual application of $N_{80}K_{80}$, $N_{80}P_{30}$, and $P_{30}K_{80}$, respectively. Incorporation of FYM combined with ½ NPK has recorded highest built up of available N (205 kg ha^{-1}) followed by $N_{80}P_{30}K_{80}$ (189 kg ha^{-1}), emphasizing the beneficial effect of organic manure (FYM) in combination with limited doses of NPK fertilizers.

Highest amount of available P in the soil (75.02 kg ha^{-1}) was observed due to balanced application of $N_{80}P_{30}K_{80}$ which is at par with FYM + ½ NPK (73.6 kg ha^{-1}). Increase in available P content of the soil was attributed by decomposition of organic manures which could have enhanced the labile P in the soil by complexing Ca, Mg and Al and solubilisation of phosphate rich organic compounds through release of organic acids upon decomposition of organic matter and chelation of organic anions with Fe and Al resulting effective solubilisation of inorganic phosphates in the soil (Laxminarayana, 2017). Significantly highest available K content in the soil was observed by balanced application of $N_{80}P_{30}K_{80}$ (255 kg ha^{-1}) followed by integrated application of FYM + ½ NPK (250 kg ha^{-1}). However, an increasing trend of available K was noticed with the application of K_2O up to 120 kg ha^{-1} and a significant improvement of available K was observed due to dual application of $P_{30}K_{80}$ (69.8%), and $N_{80}P_{30}$ (68.2%).

Slight improvement of exchangeable Ca and Mg was observed due to combined application of N and K fertilizers over the initial status of the soil. Highest exchangeable Ca [5.96 c mol (p^{+}) kg^{-1}] was recorded due to application of $N_{80}P_{30}K_{80}$ at par with FYM + ½ NPK [5.88 c mol (p^{+}) kg^{-1}], whereas, highest exchangeable Mg [2.64 c mol (p^{+}) kg^{-1}] was found due to application of FYM + ½ NPK. Higher buildup of exchangeable Ca and Mg and substantial reduction in the accumulation of Fe & Mn in the soil was attributed due to combined application of limited doses of inorganic fertilizers and FYM. The residual S was found lower than the critical limit of 10.0 mg kg^{-1} in all the treatment combinations and it was highest due to integrated use of FYM + ½ NPK. The available Fe, Cu, Mn and Zn contents in the post harvest soils were found higher than the critical limits of 4.0, 0.2, 2.0 and 0.6 mg kg^{-1}, respectively that was attributed to the nature of parent materials on which the soils formed and other soil forming factors (Anderson, 1988).

Distribution of inorganic nitrogen fractions

Total nitrogen ranged from 1876.12 to 2319.16 kg ha^{-1} (Table 3). Significant increase of total N was recorded due to application of graded doses of N and K. Combined application of $N_{80}K_{80}$ showed an increase of 2148 kg ha^{-1} which is at par with $N_{80}P_{30}$ (2039 kg ha^{-1}). Combined application of FYM and half of the recommended doses of NPK resulted a higher value of total N (2319 kg ha^{-1}) followed by $N_{80}P_{30}K_{80}$ (2273 kg ha^{-1}). The increase in fertilizer application rate, the amount of total N was also found increased significantly (Babita, 2010) and Nayak et al. 2013). Available N in the soils ranged from 121 to 204 kg ha^{-1}. Significant increase of available N was observed due to application of graded doses of N and K. Combined application of $N_{80}K_{80}$ showed an increase of 183 kg ha^{-1} followed by $N_{80}P_{30}$ (164 kg ha^{-1}) and $P_{30}K_{80}$ (160 kg ha^{-1}). Application of FYM along with ½ NPK resulted a higher value of available N (204.5 kg ha^{-1}) followed by $N_{80}P_{30}K_{80}$ (189 kg ha^{-1}). Application of graded doses of N and K resulted in significant increase in NH_4-N. Significantly highest value of ammoniacal N was recorded due to integrated application of FYM + ½ NPK (124.56 kg ha^{-1}). Relatively higher NH_4-N was observed due to combined application of 80-30-80 kg N, P and K (113.96 kg ha^{-1}) followed by $N_{80}K_{80}$ (104.7 kg ha^{-1}), $N_{80}P_{30}$ (96.9 kg ha^{-1}) and $P_{30}K_{80}$ (89.2 kg ha^{-1}).

Significant increase of nitrate N in the soils was observed due to application of graded doses of N and K. Balanced application of 80-30-80 kg N, P and K has recorded higher value of NO_3-N (23.42 kg ha^{-1}) rather than dual application of $N_{80}K_{80}$ (21.34 kg ha^{-1}) followed by $P_{30}K_{80}$ (21.06 kg ha^{-1}) and $N_{80}P_{30}$ (20.86 kg ha^{-1}). Highest value of Nitrate N (24.19 kg ha^{-1}) was recorded due to integrated application of FYM @ 10 t ha^{-1} + ½ NPK, which was ascribed to organic source of nutrients along with inorganics enhances the plant utilizable nitrogen fractions during its growth period and also the NH_4^+-N on mineralization transformed to the useful NO_3-N fractions (Duraisami et al. 2001). Organic matter on decomposition, mineralization takes place and releases NH_4^+-N during ammonification and NO_3-N during the process of nitrification (Brady and Weil, 2008)

Distribution of inorganic phosphorous fractions

Total phosphorus in the soils ranged from 269.42 to 296.57 mg kg^{-1} with a mean of 283.24 mg kg^{-1} (Table 3). Balanced application of $N_{80}P_{30}K_{80}$ recorded highest total P (296.6 mg kg^{-1}) followed by FYM + ½

Table 3. Effect of inorganic and organic manures on distribution of inorganic fractions of N, P and K

Treatment	Inorganic N fractions (kg ha^{-1})			Inorganic P fractions (mg kg^{-1})						Inorganic K fractions (mg kg^{-1})			
	Total N	NH_4-N	NO_3-N	Total P	Water Soluble P	Fe-P	Al-P	Ca-P	Reductant Soluble-P	Total K	Water Soluble K	Exchange-able K	Non exchan-geable K
Initial	2014.6	81.65	16.88	280.3	2.31	38.09	28.16	37.25	46.21	2081.6	24.53	173.06	63.70
Control	1876.1	75.78	14.13	269.4	2.04	34.68	25.60	36.14	47.87	1845.3	20.26	152.96	56.32
N_{40}	1924.8	82.25	16.96	273.2	2.42	36.78	27.18	36.58	49.85	2058.4	25.63	165.06	60.21
N_{80}	2037.5	94.39	18.74	282.5	2.63	38.26	28.32	37.92	53.25	2162.6	28.40	167.58	66.79
N_{120}	2250.0	110.17	21.49	280.4	2.74	40.08	28.76	37.44	53.12	2303.3	31.56	175.93	70.36
P_{30}	1896.4	80.76	14.93	290.5	2.91	42.19	34.18	40.24	56.71	2046.8	23.48	169.22	58.20
K_{40}	1910.7	82.46	15.75	271.5	2.48	37.18	27.50	36.40	48.14	2230.6	29.48	177.82	64.82
K_{80}	1964.9	88.29	17.18	275.3	2.59	38.34	28.41	37.09	49.67	2456.2	35.43	185.76	77.44
K_{120}	2086.5	92.36	19.02	280.3	2.64	39.96	30.73	37.76	50.81	2638.1	40.72	199.96	89.26
$N_{80}P_{30}$	2039.3	96.95	20.86	294.6	3.53	43.56	35.42	40.82	58.94	2259.5	27.52	169.69	69.30
$N_{80}K_{80}$	2148.3	104.67	21.34	279.3	2.98	43.39	34.60	38.18	55.32	2617.3	39.08	166.44	85.66
$P_{30}K_{80}$	1975.4	89.22	21.06	292.7	3.45	44.62	37.93	41.24	58.76	2548.6	28.46	190.30	79.82
$N_{80}P_{30}K_{80}$	2273.2	113.96	23.42	296.6	4.12	46.38	40.42	42.35	60.04	2879.4	49.56	205.57	118.27
FYM @ 10 t ha^{-1}	2054.7	85.38	17.56	283.3	2.83	40.48	33.17	37.86	50.24	2136.7	28.92	169.23	73.58
FYM + ½ NPK	2319.2	124.56	24.19	295.8	4.06	46.09	40.58	42.49	60.16	2843.3	44.56	205.63	108.60
Mean	2054.1	94.37	19.05	283.2	2.96	40.86	32.34	38.75	53.78	2359.0	32.36	178.65	77.05
S.Ed	140.53	14.08	3.05	9.03	0.62	3.56	4.94	2.17	4.76	309.06	8.33	15.82	17.99
S.Em (±)	38.87	3.80	0.83	2.496	0.164	0.968	1.338	0.593	1.203	83.36	2.24	4.37	4.90

NPK (295.8 mg kg^{-1}), $N_{80}P_{30}$ (294.6 mg kg^{-1}), $P_{30}K_{80}$ (292.7 mg kg^{-1}) and $N_{80}P_{30}$ (279.3 mg kg^{-1}). Significantly highest available P (33.49 mg kg^{-1}) was noticed due to combined application of 80-30-80 kg N, P and K at par with FYM + ½ NPK (32.84 mg kg^{-1}). Dual application of $P_{30}K_{80}$ has recorded relatively more available P (31.18 mg kg^{-1}) over that of $N_{80}P_{30}$ (30.43 mg kg^{-1}) and $N_{80}P_{30}$ (25.68 mg kg^{-1}). Fertilizer use efficiency of P in acid soils is less than 20% due to P fixation through P precipitation by soluble Fe and Al, and adsorption by Fe oxides. Water soluble P in the soils ranged from 2.04 to 4.12 mg kg^{-1}. Balanced application of $N_{80}P_{30}K_{80}$ resulted higher value of water soluble P (4.12 mg kg^{-1}) at par with FYM + ½ NPK (4.06 mg kg^{-1}). Dual application of $N_{80}P_{30}$ showed relatively higher water soluble P (3.53 mg kg^{-1}) followed by $P_{30}K_{80}$ (3.45 mg kg^{-1}) and $N_{80}K_{80}$ (2.98 mg kg^{-1}). When intensity factor of the soil solution goes down, these inorganic P fractions may contribute to the P nutrition of crops.

Fe-P fraction in the soils ranged from 34.68 to 46.38 mg kg^{-1} with a mean of 40.86 mg kg^{-1}. Highest value of Fe-P was recorded due to balanced application of $N_{80}P_{30}K_{80}$ (46.38 mg kg^{-1}) followed by integrated application of FYM + ½ NPK (46.09 mg kg^{-1}), respectively. Dual application of $P_{30}K_{80}$ showed relatively higher Fe-P (44.62 mg kg^{-1}) followed by $N_{80}P_{30}$ (43.56 mg kg^{-1}) and $N_{80}K_{80}$ (43.39 mg kg^{-1}). Highest value of Al-P (40.58 mg kg^{-1}) was recorded due to integrated application of FYM + ½ NPK at par with balanced application of 80-30-80 kg N, P and K (40.42 mg kg^{-1}). Dual application of $P_{30}K_{80}$ has recorded relatively higher Al-P (37.93 mg kg^{-1}) rather than $N_{80}P_{30}$ (35.42 mg kg^{-1}) and $N_{80}K_{80}$ (34.60 mg kg^{-1}). Among active forms, Ca-P usually predominates the Al-P and Fe-P in alkaline soils whereas reverse in acidic soils. These two forms (Al-P & Fe-P) are the major contributors to P availability in acidic and also to P uptake by many crops (Tiwari, 2002). Calcium bound P in the soils ranged from 36.14 to 42.49 mg kg^{-1}. Dual application of $P_{30}K_{80}$ showed relatively higher Ca-P (41.24 mg kg^{-1}) followed by $N_{80}P_{30}$ (40.82 mg kg^{-1}) and $N_{80}K_{80}$ (38.18 mg kg^{-1}). Application of FYM along with half of the recommended doses of NPK resulted higher value of Ca-P (42.49 mg kg^{-1}) followed by $N_{80}P_{30}K_{80}$ (42.35 mg kg^{-1}). Among the inorganic P fractions, reductant soluble P recorded highest values ranged from 47.87 to 60.16 mg kg^{-1} with a mean of 53.78 mg kg^{-1}. Reductant soluble P content in the soil was found highest due to application of FYM + ½ NPK (60.16 mg kg^{-1}) at par with $N_{80}P_{30}K_{80}$ (60.04 mg kg^{-1}). Highest reductant soluble-P was observed Incorporation of FYM alone showed as RS-P of 50.24 mg kg^{-1}. Incorporation of FYM alone recorded 33.17, 37.86 and 50.24 mg kg^{-1} of Al-P, Ca-P and RS-P, respectively.

Distribution of inorganic potassium fractions

Total potassium in the soils of the present study ranged from 1845 to 2879 kg ha^{-1} with a mean of 2359 kg ha^{-1} (Table 3). Highest total K was recorded due to combined application of $N_{80}P_{30}K_{80}$ (2879 kg ha^{-1}) followed by FYM + ½ NPK (2843 kg ha^{-1}). Dual application of $N_{80}K_{80}$ showed relatively higher total K (2617 kg ha^{-1}) followed by $P_{30}K_{80}$ (2549 kg ha^{-1}) and $N_{80}P_{30}$ (2039 kg ha^{-1}). Incorporation of FYM alone contributed a buildup of 2136.68 kg ha^{-1} total K. Balanced application of $N_{80}P_{30}K_{80}$ resulted higher buildup of available K (255.13 kg ha^{-1}) followed by application of FYM + 1/2 NPK (250.19 kg ha^{-1}). Ram *et al.* (2016) reported that available K content improved when farmyard manure was added with inorganic fertilizers, similar to the findings of the present study. Relative abundance of different forms of soil K determines its supplying capacity and availability to crops. Cropping without K fertilization deplete the plant available K in the soils in long run and more rapidly at high fertility levels (Biswas et al. 1977).

The water soluble K in the soils showed an increasing trend due to application of graded doses of N and K. Combined application of $N_{80}K_{80}$ showed relatively higher water soluble K (39.1 kg ha^{-1}) followed by $P_{30}K_{80}$ (28.5 kg ha^{-1}) and $N_{80}P_{30}$ (27.5 kg ha^{-1}). Higher amount of water soluble K (49.6 kg ha^{-1}) was recorded due to application of $N_{80}P_{30}K_{80}$ in comparison to integrated application of FYM + ½ NPK (44.6 kg ha^{-1}). Addition of potassic fertilizers and organic manures which contains significant amount of K released the water soluble K in the soil. Similar findings were reported by Sawarkar et al. (2013), Habib et al. (2014) and Meena and Biswas (2014).

Exchangeable K in the soils varied from 152.96 to 205.63 kg ha^{-1} (Table 3). An increase of exchangeable K was observed due to application of graded doses of K up to 120 kg K_2O ha^{-1}. Highest exchangeable K (205.6 kg ha^{-1}) in the soils was observed due to integrated application of FYM + ½ NPK, which is at par with $N_{80}P_{30}K_{80}$ (205.6 kg ha^{-1}). Dual application of $P_{30}K_{80}$ showed relatively higher exchangeable K (190.3 kg ha^{-1}) rather than $N_{80}P_{30}$ (169.7 kg ha^{-1}) and $N_{80}K_{80}$ (166.4 kg ha^{-1}). Incorporation of FYM alone contributed an accumulation of 169.23 kg ha^{-1} of exchangeable K in the residual soil. In both the years, the content of exchangeable K was higher under the treatment where FYM was applied in combination with inorganic fertilizers, which might be due to reduction in K fixation caused by repeated addition of manures along with potassic fertilizers (Sepehya, 2011). Non-exchangeable K fraction in the soils ranged from 56.32 kg ha^{-1} to 118.27 kg ha^{-1} and it was found highest due to balanced application of 80-30-80 kg ha^{-1} of N, P_2O_5 and K_20 followed by integrated application of FYM + ½ NPK (108.60 kg ha^{-1}). Dual application of $N_{80}K_{80}$ showed relatively higher amount of non-exchangeable K (85.66 kg ha^{-1}) rather than $P_{30}K_{80}$ (79.82 kg ha^{-1}) and $N_{80}P_{30}$ (69.30 kg ha^{-1}). The additional supply of organic manures increased the CEC of the soil, which can hold more exchangeable K and solubilization of non-exchangeable to exchangeable form, consequent to mass action effect (Sawarkar et al. 2013; Meena and Biswas, 2014).

Relationship between available N and inorganic nitrogen fractions

Significantly highest relationship between total N and NH_4-N (r = 0.950**) was observed followed by NO_3-N (r=0.935**) and available N (r=0.927**) (Table 4) as the total N is the primary source for various inorganic N fractions. Positive and significant interrelationship between NH_4-N and NO_3-N (r=0.930**), indicating that NH_4-N transformed into NO_3-N by nitrification and available to the uptake by the crops. Significant correlation among the nitrogen fractions could be due to the fact that these fractions are dependent on each other for their synthesis during mineralization process. Similar significant and positive relationship between inorganic nitrogen forms and N uptake had been observed by Duraisami et al. (2001) and Subehia and Dhanika (2013).

Table 4. Correlation coefficients (r) between available N and inorganic N fractions

N Fractions	Total N	Ammoniacal N	Nitrate N	Available N
Total N	-	0.953**	0.890**	0.927**
Ammoniacal N	0.953**	-	0.930**	0.950**
Nitrate N	0.890**	0.930**	-	0.935**
Available N	0.927**	0.950**	0.935**	-

** Significant at 1.0 percent level

Relationship between Available P with inorganic phosphorous fractions

Total P in the soils showed significant relationship with various inorganic P fractions in the order of Ca-P (r=0.97**)>Fe-P (r=0.91**)>Al-P (r=0.91**)>water soluble P (r=0.90**)>RS-P (r=0.89**) (Table 5). Total P in the soil was mineralized and contributed significantly in the buildup of various inorganic P fractions Buildup of available P in the soils was influenced by Ca-P> Total P>water soluble P Al-P>Fe-P>RS-P, indicating that Ca-P was the dominant inorganic P fraction that contributed the available P pool in the soil. Water soluble P fraction in the soils significantly contributed by Al-P (r=0.96**) followed by Ca-P (r=0.95**), Fe-P (r=0.95**) and RS-P (r=0.92**).

Significantly positive relationship between Fe bound-P and other inorganic P fractions was observed and the 'r' values were found to be 0.98**, 0.95**, 0.93**, 0.92**, and 0.91** in respect of Al-P, water soluble P, Ca-P, RS-P and available P. However, the relationship between Al bound-P with other inorganic P fractions was followed the order: Fe-P (r=0.98**)>water soluble P (r=0.956**)> Ca-P (r=0.95**)>RS-P (r=0.90**). Accumulation of Ca bound-P in the soils was influenced by water soluble P (r=0.95**)>Al-P (r=0.95**)>Fe-P (r=0.93**) = RS-P (r=0.93**), whereas, the 'r' values between RS-P and other inorganic P fractions was in the order of Ca-P (0.93**)>water soluble P (0.92**)>Fe-P (0.92**)>Al-P (0.90**).

Relationship between Available K and inorganic potassium fractions

The potassium dynamics in soil based on the magnitude of equilibrium among various forms of potassium and generally controlled by the physicochemical properties of soil. Available K content in the soil was influenced by mostly exchangeable K followed by non -exchangeable K and water soluble K, which was revealed by 'r' values of 0.98**, 0.93** and 0.92**, respectively (Table 6). The total K content of the soil showed highly significant relationship with non-exchangeable K (r=0.94**), water soluble K (0.94**) and exchangeable K (r=0.88**), indicating that the total K was transformed into various forms of K. Available K in the soils was influenced by mostly exchangeable K (r=0.979**) followed by total K (r=0.94**) and non-exchangeable K (r=0.93**). The relationship between non exchangeable K with other forms of K was in the order of water soluble K (r=0.96**)>total K (r=0.94**)>available K (r=0.93**)>exchangeable K (r=0.85**). The non exchangeable form of K present largely within clay minerals and become available to plants slowly and it is in equilibrium with the available forms and consequently acts as an important reservoir of slowly available K

Table 5. Correlation coefficients (r) between available P and inorganic P fractions

P fractions	Total P	Available P	Water soluble P	Fe-P	Al-P	Ca-P	Reductant soluble-P
Total P	-	0.955**	0.904**	0.909**	0.907**	0.966**	0.892**
Available P	0.955**	-	0.942**	0.914**	0.930**	0.991**	0.909**
Water soluble P	0.904**	0.942**	-	0.950**	0.956**	0.953**	0.919**
Fe-P	0.909**	0.914**	0.950**	-	0.977**	0.933**	0.917**
Al-P	0.907**	0.930**	0.956**	0.977**	-	0.952**	0.897**
Ca-P	0.966**	0.991**	0.953**	0.933**	0.952**	-	0.933**
Reductant soluble-P	0.892**	0.909**	0.919**	0.917**	0.897**	0.933**	-

** Significant at 1.0 percent level

Table 6. Correlation coefficients (r) between available K and inorganic K fractions

K fractions	Total K	Available K	Water soluble K	Exchangeable K	Non-Exchangeable K
Total K	-	0.937**	0.942**	0.875**	0.944**
Available K	0.937**	-	0.921**	0.979**	0.927**
Water Soluble K	0.942**	0.921**	-	0.821**	0.955**
Exchangeable K	0.875**	0.979**	0.821**	-	0.854**
Non-Exchangeable K	0.944**	0.927**	0.955**	0.854**	-

** Significant at 1.0 percent level

(Perkins, 1973). Non exchangeable K has contributed more towards the total K rather than exchangeable K as the non-exchangeable K is not bonded within the crystal structures of soil mineral particles present largely within clay minerals.

Relationship between yield and biochemical constituents of elephant foot yam and black gram with inorganic fractions of NPK

The results in Table 7 revealed that the corm yield of elephant foot yam showed highly significant relationship with available N (r= 0.882**), K (r=0.862**) and P (r=0.715**). Ammoniacal N showed higher positive and significant relationship with corm yield (r=0.850**) rather than nitrate N (r=0.848**), whereas the biochemical constituents had higher significant relationship with NO_3-N in comparison to NH_4-N. Among the inorganic P fractions, Fe-P showed highly significant relationship with corm yield (r=0.808**), starch (r=0.869**), total sugars (r=0.832**) and dry matter (r=0.686**), emphasizing that Fe-P mainly contributed towards the yield and proximate composition of elephant foot yam. Among the inorganic K fractions, non-exchangeable or fixed K recorded higher 'r' values with corm yield (r=0.875**), starch (r=0.891**), total sugars (r=0.862**) and dry matter (r=0.905**), indicating that this fraction of K transferred into exchangeable and water soluble K fractions maintaining the equilibrium between different fractions and contributed towards the enhancement of yield and quality parameters of the crop. Water soluble K which is readily permeable form of K nutrition of the crop also showed significant relationship with yield and quality parameters of EFY rather than exchangeable K.

Grain yield of black gram had positive and significant relationship with total K (r=0.901**) and total N

Table 7. Correlation coefficients (r) between yield and biochemical constituents with inorganic fractions of N, P and K under elephant foot yam - black gram cropping system

Inorganic fractions	Elephant foot yam				Black gram	
	Corm yield	Starch	Sugars	Dry Matter	Grain yield	Crude Protein
Inorganic N fractions						
Total N	0.792**	0.819**	0.817**	0.817**	0.768**	0.902**
Available N	0.882**	0.895**	0.894**	0.864**	0.896**	0.846**
Ammoniacal N	0.850**	0.845**	0.801**	0.786**	0.809**	0.849**
Nitrate N	0.848**	0.877**	0.872**	0.804**	0.883**	0.789**
Inorganic P fractions						
Total P	0.683**	0.671**	0.657**	0.523*	0.694**	0.377
Available P	0.715**	0.688**	0.634**	0.525**	0.686**	0.379
Water Soluble P	0.808**	0.838**	0.802**	0.691**	0.815**	0.572*
Fe-P	0.808**	0.869**	0.832**	0.686**	0.840**	0.621*
Al-P	0.751**	0.819**	0.799**	0.665**	0.773**	0.547*
Ca-P	0.713**	0.706**	0.665**	0.544*	0.692**	0.408
Reductant Soluble-P	0.717**	0.708**	0.643*	0.481*	0.703**	0.455*
Inorganic K fractions						
Total K	0.920**	0.927**	0.878**	0.907**	0.901**	0.801**
Water Soluble K	0.884**	0.877**	0.818**	0.897**	0.812**	0.863**
Available K	0.862**	0.817**	0.781**	0.879**	0.810**	0.701**
Non-Exchange-able K	0.875**	0.891**	0.862**	0.905**	0.819**	0.818**
Exchangeable K	0.798**	0.737**	0.715**	0.817**	0.760**	0.576*

** & * Significant at 1% and 5% level, respectively (r=0.768**), whereas the crude protein content was influenced by total N (r=0.902**) and total K (r=0.801**). Among the inorganic N fractions, NO_3-N, showed higher relationship with grain yield (r=0.883**), whereas, NH_4-N mainly contributed towards the crude protein content with 'r' value of 0.849** rather than NO_3-N (r=0.789**). Among the inorganic P fractions, Fe-P showed highly significant relationship with grain yield (r=0.840**) followed by water soluble P (r=0.815**), Al-P (r=0.773**), RS-P (r=0.703**) and Ca-P (r=0.692**). Crude protein content had significant relationship with Fe-P (r=0.621**) followed by water soluble P (r=0.572**) and Al-P (r=0.547*). The results indicating that Fe-P, water soluble P and Al-P fractions mostly contributed towards the yield and quality of black gram in the soils of the present study. Non exchangeable K had highly positive and significant relationship with grain yield followed by water soluble K, available K and exchangeable K forms and the 'r' values were found to be 0.819**, 0.812**. 0.810** and 0.760** respectively. However, crude protein content had highly significant relationship with water soluble K (r=0.863**), non-exchangeable K (r=0.818**), available K (r=0.701**) and exchangeable K (r=0.576**). The contribution of non-exchangeable K towards the yield and quality attributes was relatively more in comparison to exchangeable K in the soil, similar to the findings of Ganeshamurthy and Biswas (1985). Thus, the results revealed that non exchangeable K, water soluble K and available K forms greatly influenced the yield and protein content of black gram.

Conclusion

It is evident from the study that application of half of the recommended doses of NPK fertilizers in combination with organic manure (FYM) not only enhanced the yields of both elephant foot yam and black gram crops but also improved the soil fertility in the acid Alfisols of Eastern India. Integrated application of organic manure and inorganic chemical fertilizers at balanced proportion not only helps to augment the crop yields but also enhances the available nutrient status in elephant foot yam - black gram system. Cultivation of pulses as inter crops in between tropical root and tuber crops not only enhances the total farm productivity but also enrich the soil fertility by accumulation of its biomass that facilitates the biological activity of the soils.

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