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Integrated Nutrient Management Effects on Soil Enzyme Activities, Yield and Proximate Composition of Elephant Foot Yam - Black Gram in *Alfisols*

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Field experiments were conducted for two consecutive years during 2018-2020 to study the effect of integrated use of inorganic fertilizers and organic manure on soil health and yield performance of elephant foot yam (*Amorphophallus paenifolius* L.) - black gram (*Vigna mungo* L.) cropping system in an acid *Alfisol*. Highest mean corm yield of elephant foot yam (26.50 t ha^{-1}), grain and haulm yields of black gram (0.63 and 1.94 t ha^{-1}, respectively) were recorded due to integrated application of farmyard manure (FYM) @ 10 t ha^{-1} + ½ NPK followed by soil test based doses of 80-30-80 kg ha^{-1} of N, P_2O_5 and K_2O. Addition of 40, 80 and 120 kg ha^{-1} of nitrogen (N) showed a corm yield response of 21, 39 and 33% over control, whereas application of 40, 80 and 120 kg ha^{-1} of potash (K_2O) fertilizers showed a yield response of 24, 39 and 46% in elephant foot yam over control, respectively. Incorporation of FYM alone recorded an increase of 24% corm yield over control. The starch, total sugars and dry matter contents in the corms of elephant foot yam were found highest due to the integrated use of FYM + ½ NPK. The soil bacteria and actinomycetes are involved in nutrient transformations in the soils and had a significant relationship with yield and proximate composition of elephant foot yam and black gram. Highest dehydrogenase (1.86 µg TPF g^{-1} h^{-1}), fluorescein diacetate hydrolysis assay (2.86 µg TPF g^{-1} h^{-1}), urease (282 µg NH_4-N g^{-1} h^{-1}), acid and alkaline phosphatase activities (82.3 and 70.3 µg PNP g^{-1} h^{-1}) were observed due to conjoint application of FYM + ½ NPK. Integrated application of organic manure and half of the soil test based NPK not only sustained the soil quality but also enhanced productivity of elephant foot yam - black gram cropping system in Alfisols.

(***Key words:*** *Alfisol, Black gram, Elephant foot yam, Enzyme activities, Inorganic fertilizers, Organic manure, Soil properties*)

Elephant foot yam (*Amorphophallus paenifolius* L.) is a tropical tuber crop that offers excellent scope for adoption in tropical countries as a cash crop due to its production potential and popularity as a vegetable in various delicious cuisines, rich in calcium and vitamin B_6. Elephant foot yam grows in the wild form in Sri Lanka, Philippines, Malaysia, Indonesia, and other Southeast Asian countries. In India, it is being grown mostly in West Bengal, Kerala, Karnataka, Andhra Pradesh, Maharashtra, Chhattisgarh, Bihar, Jharkhand and Odisha. The tuber is beneficial in the treatment of conditions such as haemorrhoids, acute rheumatism, enlarged spleen, abdominal tumours, asthma, abdominal pain, dyspepsia and elephantiasis (Dey *et al.,* 2015; Yusuf *et. al.,* 1994). It contains a wide range of phytochemicals *viz*., alkaloids, phenols, flavonoids, glycosides, saponins, steroids and tannins. The corm contains an active diastatic enzyme amylase, betulinic acid, tricontane, lupeol, stigmasterol, betasitosterol and its palmitate, and glucose, galactose, rhamnose and xylose. It responds better with the integrated use of organic amendments and chemical fertilizers.

Black gram is very nutritious as it contains high levels of protein (25 g 100 g^{-1}), potassium (983 mg 100 g^{-1}), calcium (138 mg 100 g^{-1}), iron (7.57 mg 100 g^{-1}), niacin (1.447 mg 100 g^{-1}), thiamine (0.273 mg 100 g^{-1}) and riboflavin (0.254 mg 100 g^{-1}) (Neelam *et al.,* 2021). Black gram complements the essential amino acids provided in most cereals and plays an important role in the diets of people. Legume-based cropping systems are 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 (Imai *et al.,* 1989). Borin and Frankow-Lindberg (2005) reported that intercropping increased the total dry matter of cassava and crude protein yields in cassava-legume mixtures. It was reported that intercropping two or more crops maximized output per

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hectare as compared to mono-cropping (Ossom *et al.,* 2009).

High cost of fertilizers with reduced subsidies on inputs necessitates the use of locally available low-cost organic sources *viz*., manures, green manures, biofertilizers, etc. in combination with inorganic chemical fertilizers in a synergistic manner for sustainable crop production and to safeguard the soil health. The use of inorganic fertilizers alone has not been helpful under intensive agriculture because it is often associated with reduced crop yield, soil acidity and nutrient imbalances. The intensification of land use with increased dependence on agro-chemicals resulted in stagnation of crop yields, which necessitated a change to a suitable farming system approach having combined use of inorganic, organic and biological sources to sustain the soil quality and to achieve higher crop yields (Kolambe *et al.,* 2013). Growing nutrient-exhaustive crops, the use of unbalanced and inadequate fertilizers accompanied by restricted use of organic manures have made the soils not only deficient in nutrients but also deteriorated the soil health resulting in the decline of crop response to recommended dose of fertilizers. Integrated plant nutrient systems have assumed great importance and have vital significance for the maintenance of soil productivity (Kannan *et al.,* 2013).

Soil micro-flora is responsible for the decomposition and conversion of organic substances, aggregation stability and the carbon, nitrogen, phosphorus and sulphur cycle (Gougoulias *et al.,* 2014). Dehydrogenases are respiratory chain enzymes, which play a major role in the energy production of organisms as they oxidize organic compounds by transferring two hydrogen atoms (Tosi *et al.,* 2023). Microbial and biochemical parameters of soil are choice indicators of soil quality evaluation (Winding *et al.,* 2005) because of their early response to soil disturbances than those of the physical and chemical parameters. The present investigation was taken up to study the effect of balanced fertilization, integrated use of inorganic and organic manure on residual soil fertility, microbial activities, yield and proximate composition of elephant foot yam - black gram cropping system.

MATERIALS AND METHODS

A field experiment was conducted for two *kharif* (rainy) seasons during 2018-19 and 2019-20 at the farm of the Regional Centre, ICAR - Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India to study the effect of integrated use of inorganic nutrients and organic manure on soil fertility and yield performance of elephant foot yam - black gram cropping system. The experimental soil is fine-loamy, mixed, isohyperthermic, *Typic Haplustalf*, sandy loam in texture, acidic (pH 5.5), non-saline (Electrical conductivity 0.442 dS m^{-1}) and having 0.256% of organic carbon, 0.1344% total nitrogen, 207, 45.64 and 220 kg ha^{-1} of available nitrogen (N), phosphorus (P) and potassium (K), respectively. The soil also contains 43.44, 1.52, 76.85, 0.586 and 2.52 mg kg^{-1} of available iron (Fe), copper (Cu), manganese (Mn), zinc (Zn) and boron (B), respectively. The experiment was laid out with 14 treatment combinations replicated thrice in a randomized block design. The treatments include control, 40 kg N ha^{-1}, 80 kg N ha^{-1}, 120 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1}, 40 kg K_2O ha^{-1}, 80 kg K_2O ha^{-1}, 120 kg K_2O ha^{-1}, 80 kg N and 30 kg P_2O_5 ha^{-1}, 80 kg N and 80 kg K_2O ha^{-1}, 30 kg P_2O_5 and 80 kg K_2O ha^{-1}, 80 kg N, 30 kg P_2O_5 and 80 kg K_2O ha^{-1}, Farmyard manure (FYM) @ 10 t ha^{-1}, and FYM @ 10 t ha^{-1} + 40-15-40 kg N, P_2O_5 and K_2O ha^{-1}.

In the treatments with FYM, well-rotten farmyard manure (containing 0.50, 0.28 and 0.60% of N, P and K, respectively) was applied one month in advance to planting of elephant foot yam in the respective plots. The 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 (45 x 45 x 45 cm) at a spacing of 75 x 75 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 intercrop 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 and the balance ⅓ N and ½ K_2O at 75 days after planting 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 grain and haulm yields were recorded. 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. Total sugars in the fresh corm samples after washing were estimated in the alcohol filtrate and starch was determined in the residue as per the standard procedure (Moorthy and Padmaja, 2002). Oven dried tuber samples of elephant foot yam as well as grain and haulm samples of black gram were ground and digested in concentrated H_2SO_4 and analyzed for N content by steam distillation (Black, 1965). Plant samples were digested in di-acid mixture (HNO_3 and $HClO_4$, 7:3 ratio) and the contents of total P, K and micronutrients (Fe, Cu, Mn and Zn) were estimated in the digested plant samples (Jackson, 1973). Nutrient uptake by elephant foot yam and black gram was computed by multiplying the nutrient concentration of the plant samples with dry weights of the crops.

Soil samples were collected from individual treatments after harvest of the crops, processed and analyzed for physico-chemical properties by using standard procedures. Nutrient agar, potato dextrose agar and starch casein agar media were used for the isolation of bacteria, fungi and actinomycetes, respectively by serial dilution of fresh soil samples (10^{-4} for fungi & actinomycetes and 10^{-5} for bacteria). After the microbial colonies were clearly visible (2-7 days for bacteria & fungi and 7-14 days for actinomycetes), the number of colonies on each plate was counted and expressed as the number of CFU g^{-1} dry soil considering the moisture content in the samples. Dehydrogenase activity (DHA) in the soils was determined by the method described by Casida (1977). The fluorescein diacetate hydrolysis assay (FDA) was determined by the method outlined by Green *et al.* (2006). Urease activity in the soils was determined by the method described by Bremner and Douglas (1971). Acid and alkaline phosphomonoesterase activities were determined by the method described by Tabatabai and Bremner (1969).

The data of the experiment were analyzed by the method of analysis of variance (ANOVA) to find out the critical difference values. Correlation coefficients between microbial variables with soil properties, biometric parameters and proximate composition of crops were derived. Per cent yield response, nutrient use efficiency and apparent nutrient recovery were computed (Laxminarayana *et al.,* 2015) as given below:

$$\text{Yield response (\%)} = \frac{(Treatment\ yield - Control\ yield}{Control\ yield}\ x\ 100 \quad ...1$$

Nutrient use efficiency

$$\text{(kg tubers per kg nutrient applied)} = \frac{(Treatment\ yield - Control\ yield}{Amount\ of\ nutrient\ applied} \quad ...2$$

$$\text{Apparent nutrient recovery (\%)} = \frac{(Uptake\ in\ treated\ plot - \text{Uptake in}\ control\ plot}{Amount\ of\ nutrient\ applied}\ x\ 100 \quad ...3$$

RESULTS AND DISCUSSION

Yield performance of elephant foot yam

Significantly highest mean corm yield (26.50 t ha^{-1}) was recorded due to integrated application of FYM @ 10 t ha^{-1} + 40-15-40 kg N, P_2O_5 and K_2O ha^{-1}, respectively (Table 1) with highest yield response of 66.5% over control. Incorporation of FYM alone has recorded a mean corm yield of 19.80 t ha^{-1} with a yield response of 24.4% over control, emphasizing the beneficial effect of organic sources rather than chemical fertilizers. Organic manures typically release both macro and micronutrients gradually, supply nutrients to the crops throughout their growth period and contribute to crop yields (Adediran *et al.,* 2005). Manures also increased the soil organic matter content, improved the soil physical and chemical properties and stimulated soil microbial activities (Geng *et al.,* 2019). The tuber yield was significantly increased with the application of 80 kg N ha^{-1} and marginally decreased with further application of N fertilizers. Since the experimental soil contains a high status of available P, lower doses of P application (30 kg P_2O_5 ha^{-1}) were

Table 1. *Effect of organic manure and inorganic nutrients on yield and proximate composition of elephant foot yam - black gram cropping system (Mean of 2018-19 and 2019-20)*

Treatment	Elephant foot yam							Black gram						
	Corm yield (t ha^{-1})			Yield response (%)	Proximate composition (%)			Grain yield (t ha^{-1})			Haulm yield (t ha^{-1})			Crude protein (%)
	2018-19	2019-20	Mean		Starch	Sugars	Dry matter	2018-19	2019-20	Mean	2018-19	2019-20	Mean	
Control	14.92	16.91	15.92	--	10.01	1.10	22.50	0.41	0.44	0.42	1.51	1.23	1.37	19.66
40 kg N ha^{-1}	17.67	20.87	19.27	21.04	10.45	1.14	22.79	0.48	0.52	0.50	1.62	1.37	1.49	19.56
80 kg N ha^{-1}	19.87	24.28	22.08	38.69	10.88	1.20	23.30	0.53	0.55	0.54	1.68	1.45	1.57	20.55
120 kg N ha^{-1}	18.46	23.88	21.17	32.98	11.42	1.31	23.68	0.54	0.55	0.55	1.73	1.54	1.64	21.96
30 kg P_2O_5 ha^{-1}	18.11	23.17	20.64	29.65	10.90	1.17	22.70	0.50	0.52	0.51	1.66	1.51	1.58	19.84
40 kg K_2O ha^{-1}	17.86	21.52	19.69	23.68	11.04	1.20	23.14	0.52	0.51	0.52	1.64	1.45	1.54	20.43
80 kg K_2O ha^{-1}	19.67	24.46	22.06	38.57	11.39	1.28	23.97	0.55	0.56	0.55	1.71	1.54	1.62	20.14
120 kg K_2O ha^{-1}	20.64	25.71	23.18	45.60	11.82	1.38	24.56	0.56	0.58	0.57	1.88	1.58	1.73	21.55
80 kg N & 30 kg P_2O_5 ha^{-1}	19.17	24.51	21.84	37.19	11.82	1.37	23.63	0.55	0.59	0.57	1.75	1.59	1.67	20.16
80 kg N & 80 kg K_2O ha^{-1}	21.08	26.11	23.60	48.24	12.44	1.42	24.12	0.57	0.61	0.59	2.06	1.65	1.85	22.63
30 kg P_2O_5 & 80 kg K_2O ha^{-1}	19.30	24.27	21.79	36.87	11.62	1.35	23.76	0.55	0.60	0.57	1.89	1.58	1.74	20.39
80-30-80 kg N, P_2O_5 & K_2O ha^{-1}	23.37	27.73	25.55	60.49	12.64	1.44	24.59	0.58	0.62	0.60	2.10	1.68	1.89	22.84
FYM @ 10 t ha^{-1}	18.28	21.33	19.80	24.37	11.35	1.36	24.03	0.54	0.55	0.54	1.71	1.59	1.73	20.75
FYM + 40-15-40 kg N, P_2O_5 & K_2O ha^{-1}	24.32	28.67	26.50	66.46	12.79	1.503	25.16	0.62	0.64	0.63	2.15	1.72	1.94	22.11
CD (P=0.05)	0.485	0.731	0.335	--	0.172	0.036	0.196	0.02	0.011	0.014	0.0467	0.0196	0.030	0.529

advocated with a yield response of 29.7% over control. Application of graded doses of K fertilizers showed an increasing trend of corm yield up to 120 kg K_2O ha^{-1} and the yield response was found to be 23.7, 38.6 and 45.6% over control, respectively. A relatively higher yield response was observed to the application of K fertilizers rather than N doses as the crop responds to higher doses of K fertilization in the experimental sandy loam soil, which contains moderate status of available N and K. Combined application of $N_{80}K_{80}$ showed higher yield response (48.2%) followed by $N_{80}P_{30}$ (37.2%) and $P_{30}K_{80}$ (36.9%). Balanced application of 80-30-80 kg N, P and K has recorded a mean corm yield of 25.55 t ha^{-1} with a yield response of 60.5% over control. Application of all three essential nutrients (NPK) has shown higher yield response over that of single or dual application of NPK fertilizers, indicating that balanced fertilization is needed to enhance crop productivity. Elephant foot yam is a heavy feeder of nutrients and the yields were increased considerably due to the application of higher doses of NPK fertilizers. The crop exhibiteda significant response to higher doses of NPK rather than optimum doses of NPK in low and marginal soils, where it is being cultivated extensively. These results are corroborative with the findings of Nizamuddin *et al.* (2003).

Yield performance of black gram

Significantly highest mean grain and haulm yields of black gram (0.63 and 1.94 t ha^{-1}, respectively) as an intercrop was recorded due to the integrated application of FYM + ½ NPK with a yield response of 47.4% over control (Table 1) followed by $N_{80}P_{30}K_{80}$ (0.6 and 1.89 t ha^{-1}, respectively) with a yield response of 41.3% over control. Organic manures besides supplying nutrients to the first crop, also provide a substantial residual effect of unutilized nutrients to the succeeding crop, similar to the findings of Sathish *et al.* (2011). Organic manures not only supply macronutrients but also meet the requirements of micronutrients, besides improving soil health. Though they contain relatively low concentrations of nutrients, there has been a large increase in their use over inorganic fertilizers as a nutrient source for sustaining the productivity of pulses.

Application of graded doses of N and K fertilizers showed an increasing trend of grain yields of black gram up to 120 kg ha^{-1}, indicating that the higher doses of inorganic fertilization to elephant foot yam showed a beneficial effect on black gram that was grown as an intercrop without supplement of any nutrient sources. The incorporation of FYM alone has recorded a grain yield of 0.54 t ha^{-1}, which is higher than the application of 80 kg N ha^{-1}. A single application of N or K_2O fertilizers showed significant yield response in terms of grain and haulm yields of black gram up to 80 kg ha^{-1}. Balanced application of $N_{80}P_{30}K_{80}$ 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. The highest crude protein content in black gram (22.84%) was recorded due to the integrated application of $N_{80}P_{30}K_{80}$ which was at par with $N_{80}K_{80}$ (22.63%). Increased doses of N fertilizers showed a significant effect on the crude protein content of black gram as the crop responded positively to higher doses of N fertilization in the sandy loam soil, which has lower levels of available N.

Proximate composition of elephant foot yam and black gram

Significantly highest mean dry matter in the corms of elephant foot yam (25.2%) was recorded due to the integrated application of FYM + ½ NPK (Table 1) followed by 80-30-80 kg N, P_2O_5 and K_2O ha^{-1} (24.6%). Of all the treatment combinations, significantly highest mean starch content on fresh weight basis was recorded due to the combined application of FYM + ½ NPK (12.8%) and was 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 the highest being due to integrated application of FYM + ½ NPK. Incorporation of organic manure along with limited doses of NPK fertilizers aggravates the starch content, which might be attributed to an increased rate of mineralization of the organic manure resulting in nutrient transformations and their mobility into the plant system.

Nutrient uptake by elephant foot yam and blackgram

Significantly highest mean uptake of N by the corms of elephant foot yam (135 kg ha^{-1}) was recorded due to the integrated application of FYM + ½ NPK (Table 2)

Table2. *Effect of organic manure and inorganic nutrients on nutrient uptake by the corms of elephant foot yam and black gram (Mean of 2018-19 & 2019-20)*

Treatment	Nutrient uptake by elephant foot yam										Total nutrient uptake by black gram									
	N	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn	N	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn
	($kg\ ha^{-1}$)			($g\ ha^{-1}$)							($kg\ ha^{-1}$)			($g\ ha^{-1}$)						
Control	96.7	33.0	143.3	678	598	273	859	165	532	345	39	6.26	28	752	653	242	345	14	366	49
40 kg N ha^{-1}	106.1	35.5	156.2	747	621	280	933	182	546	354	39	6.71	29	821	714	266	379	15	395	57
80 kg N ha^{-1}	113.3	35.7	168.4	819	674	302	980	190	616	369	44	7.02	31	869	754	280	409	16	427	62
120 kg N ha^{-1}	122.3	38.3	174.2	856	697	315	1013	203	623	387	47	7.26	33	906	786	294	435	17	427	64
30 kg P_2O_5 ha^{-1}	98.6	38.5	160.6	770	636	278	920	165	536	346	39	7.22	29	829	727	268	389	16	383	52
40 kg K_2O ha^{-1}	105.3	39.5	162.8	715	638	278	897	160	550	379	42	6.82	32	848	739	273	383	16	405	60
80 kg K_2O ha^{-1}	108.4	42.8	177.1	772	674	309	986	193	629	414	45	7.40	35	902	789	295	403	17	426	64
120 kg K_2O ha^{-1}	119.2	43.9	192.8	878	697	327	1083	199	673	411	48	8.20	37	931	820	309	430	19	445	66
80 kg N & 30 kg P_2O_5 ha^{-1}	108.5	38.4	163.9	797	660	322	1015	200	609	387	45	8.40	34	928	806	306	421	19	446	63
80 kg N & 80 kg K_2O ha^{-1}	127.7	40.9	201.2	873	743	351	1157	221	680	429	52	8.42	40	964	842	321	466	20	488	73
30 kg P_2O_5 & 80 kg K_2O ha^{-1}	114.2	39.5	174.1	836	719	310	1022	189	640	394	47	8.30	36	949	830	315	449	19	456	62
80-30-80 kg N, P_2O_5 & K_2O ha^{-1}	134.2	44.9	206.3	972	792	368	1204	235	724	493	53	9.07	41	1006	876	336	502	21	510	71
FYM @ 10 tha^{-1}	112.7	39.1	167.5	832	705	310	954	180	594	390	42	7.56	32	871	762	284	381	17	409	61
FYM + 40-15-40 kg N, P_2O_5 & K_2O ha^{-1}	134.5	46.6	210.1	1046	809	377	1201	237	720	506	54	8.88	41	1011	895	346	498	21	521	75
CD (P=0.05)	2.96	1.01	5.89	33.1	14.4	6.5	32.6	8.9	16.7	11.4	0.9	0.18	1.0	8.9	9.8	3.4	12.3	0.5	11.5	2.2

at par with $N_{80}P_{30}K_{80}$ (134 kg ha^{-1}). An increasing trend of N uptake (106, 113 and 122 kg ha^{-1}) was observed due to graded doses of N application in respect of 40, 80 and 120 kg N ha^{-1}. It was also noticed that increased doses of K application showed an increasing trend of N uptake. Relatively higher uptake of N was recorded due to the dual application of $N_{80}K_{80}$ (128 kg ha^{-1}) rather than $P_{30}K_{80}$ (114 kg ha^{-1}) and $N_{80}P_{30}$ (109 kg ha^{-1}). Application of organic manure in combination with limited doses of NPK has recorded higher N concentration by the corms over that of optimal doses of NPK. Integrated application of FYM + ½ NPK has recorded the highest mean uptake of P (47 kg ha^{-1}) and K (210 kg ha^{-1}). Zhang *et al.* (1998) reported that organic manures increased the labile, moderately stable and stable organic P contents in soil and contributed to P uptake by plants. Increased doses of K fertilizers showed an increasing trend of K uptake with an uptake response of 14, 24 and 35% over control due to the application of 40, 80 and 120 kg ha^{-1} of K_2O, respectively, however, increased doses of N fertilizers showed an increase of 9, 18 and 22% K uptake over control. Integrated use of organic and inorganic fertilizers significantly increased the K uptake. Similar findings were reported by Sreelatha *et al.* (2006). The addition of N fertilizers had a synergistic effect on K concentration in the corms and contributed to higher K uptake by the crop (Fageria, 2001). The mean uptake of Ca, Mg and S by the corms of elephant foot yam was found highest due to the combined application of FYM + ½ NPK (1046, 809 and 377 g ha^{-1}, respectively). Highest mean uptake of Fe and Mn by the corms of elephant foot yam (1204 and 724 g ha^{-1}, respectively) were observed due to the application of $N_{80}P_{30}K_{80}$, whereas the highest uptake of Cu and Zn were noticed due to the combined application of FYM + ½ NPK (237 and 506 g ha^{-1}, respectively). Graded doses of N fertilizers showed an increasing trend of Fe & Mn uptake, whereas organic manures resulted in a substantial reduction of Fe and Mn uptake by elephant foot yam.

Significantly highest total (grain and haulm) uptake of N (54 kg ha^{-1}) and K (41 kg ha^{-1}) by black gram was recorded due to the integrated application of FYM + ½ NPK (Table 2) at par with $N_{80}P_{30}K_{80}$. An increase of 33, 21 and 15% of total N uptake was observed due to the dual application of NK, PK and NP, respectively over control. Highest total uptake of P (9.1 kg ha^{-1}) was noticed due to the balanced application of $N_{80}P_{30}K_{80}$. An increase of 14, 25 and 32% of K uptake was observed due to the addition of graded doses of K fertilizers over control in respect of 40, 80 and 120 kg K_2O ha^{-1}. Significantly highest total uptake of Ca, Mg, S, Cu and Zn (1011, 895, 346, 21, and 75 g ha^{-1}, respectively) was recorded due to the integrated application of FYM + ½ NPK. Incorporation of FYM in combination with limited doses of NPK fertilizers has recorded the highest total uptake of nutrients by black gram at par with optimum doses of NPK chemical fertilizers. Added organic manures not only acted as a source of nutrients but also increased the availability leading to higher uptake of nutrients (Amanullah *et al.,* 2007).

Effect of INM on nutrient use efficiency under elephant foot yam - black gram system

Balanced application of 80-30-80 kg ha^{-1} of N, P_2O_5 and K_2O recorded the highest N use efficiency (120.4 kg tubers kg^{-1} of N) (Table 3) followed by integrated application of FYM + ½ NPK (117.6 kg tubers kg^{-1} of N). Increased doses of N application showed a decreasing trend of N use efficiency, however, combined application of 80 kg ha^{-1} each of N and K_2O showed higher N use efficiency (96 kg tubers kg^{-1} of N). Thus, the results emphasized the need for balanced soil test-based fertilization to obtain higher productivity as well as to increase the efficiency of applied nutrients. Application of $N_{80}P_{30}K_{80}$ recorded the highest P use efficiency (736 kg tubers kg^{-1} P) followed by 80-30 kg ha^{-1} of N and P_2O_5 (452 kg tubers kg^{-1} P). The K use efficiency was found maximum due to the combined application of $N_{80}P_{30}K_{80}$ (144 kg tubers kg^{-1} K) followed by $N_{80}K_{80}$ (115 kg tubers kg^{-1} K). Application of FYM alone has recorded nutrient use efficiency of 78, 139 and 65 kg tubers kg^{-1} N, P and K, respectively. However, the integrated application of FYM + ½ NPK recorded a nutrient use efficiency with respect to P (258 kg tubers kg^{-1} P) and K (113 kg tubers kg^{-1} K). The results emphasized that the organic manure (FYM) contributed maximum towards the efficiency of N, P and K when it was applied along with half of the recommended doses of NPK and enhanced the productivity of elephant foot yam.

Effect of INM on apparent nutrient recovery under elephant foot yam - black gram system

The recovery of N, P and K (Table 3) was found maximum due to the combined application of $N_{80}P_{30}K_{80}$ (47, 91 and 95%, respectively), which may be ascribed to higher response towards the biomass production and nutrient uptake by the crop that was due to optimal doses of fertilization. Graded doses of N application have recorded N recovery of 24, 21 and 21% in respect of 40, 80 and 120 kg N ha^{-1}. Integrated use of FYM + ½ NPK has recorded an N recovery of 42%, whereas dual application of $N_{80}K_{80}$ has recorded a relatively lower N recovery of 39%. Combined application of PK showed relatively higher P recovery (50%) rather than NP (41%). The K recovery was found in decreasing trend due to the application of 40, 80 and 120 kg ha^{-1} of K_2O (59, 51 and 50%, respectively). However, dual application of 80-80 kg ha^{-1} of N and K_2O recorded relatively higher K recovery (95%). Integrated application of FYM + ½ NPK has recorded a nutrient recovery in terms of N (42%), P (33%) and K (72%), whereas FYM alone has recorded nutrient recovery of 32, 22 and 40% in respect of N, P and K, respectively. The contribution of organic manure (FYM) towards nutrient recovery may also be the result of native as well as applied sources of the nutrient concerned (Laxminarayana *et al.,* 2015).

Effect of INM on residual soil fertility under elephant foot yam - black gram system

The pH of the soil increased to 5.78 due to the integrated application of FYM + ½ NPK from the initial value of 5.52 (Table 4). A significant reduction of soil pH was observed due to the application of graded doses of N and K fertilizers. Incorporation of FYM has improved the soil pH to 5.62 and FYM in combination with limited doses of NPK has further improved the soil pH to 5.78. The soils were non-saline with an electrical conductivity (EC) of 0.51 to 0.63 dS m^{-1}. The highest organic C content was observed due to the integrated application of FYM + ½ NPK (0.474 %) followed by $N_{80}P_{30}K_{80}$ (0.45%) from the initial status of 0.256%. Higher build up of organic C was found by conjoint use of organic

Table 3. *Effect of organic manure and inorganic nutrients on nutrient use efficiency and apparent nutrient recovery in elephant foot yam*

Treatment	Nutrient use efficiency (kg tubers kg^{-1} nutrient)			Apparent nutrient recovery (%)		
	N	P	K	N	P	K
40 kg N ha^{-1}	83.8	-	-	23.5	-	-
80 kg N ha^{-1}	77.0	-	-	20.8	-	-
120 kg N ha^{-1}	43.8	-	-	21.3	-	-
30 kg P_2O_5 ha^{-1}	-	360.6	-	-	42.0	-
40 kg K_2O ha^{-1}	-	-	113.1	-	-	58.5
80 kg K_2O ha^{-1}	-	-	92.1	-	-	50.7
120 kg K_2O ha^{-1}	-	-	72.6	-	-	49.5
80 kg N & 30 kg P_2O_5 ha^{-1}	74.0	452.3	-	14.8	41.3	-
80 kg N & 80 kg K_2O ha^{-1}	96.0	-	115.2	38.8	-	86.9
30 kg P_2O_5 & 80 kg K_2O ha^{-1}	-	448.4	88.1	-	49.7	46.2
80-30-80 kg N, P_2O_5 & K_2O ha^{-1}	120.4	735.7	144.4	46.9	90.9	94.5
FYM @ 10 t ha^{-1}	77.6	138.6	64.7	32.0	21.8	40.3
FYM + 40-15-40 kg N, P_2O_5 & K_2O ha^{-1}	117.6	257.5	113.4	42.0	33.1	71.6

Table 4. *Effect of organic manure and inorganic nutrients on soil physico-chemical properties (after harvest of 2nd cropping season)*

Treatment	pH	EC (dSm^{-1})	Organic C (%)	Total N (%)	Available nutrient ($kg\ ha^{-1}$)			Exch. Ca	Exch. Mg	Avail. S ($mg\ kg^{-1}$)	Available micronutrients ($mg\ kg^{-1}$)			
					N	P	K	--- [c mol (p+) kg^{-1}] ----		Fe	Cu	Mn	Zn	
Initial	5.516	0.442	0.256	0.1344	206.8	45.64	215.4	4.53	2.04	7.36	43.44	1.52	76.85	0.586
1.Control	5.732	0.506	0.258	0.0967	136.5	68.17	256.4	5.16	2.17	7.06	44.01	1.66	53.54	0.602
2. N_{40}	5.650	0.513	0.353	0.1123	155.6	70.26	267.3	5.47	2.35	7.24	47.51	1.55	48.86	0.614
3. N_{80}	5.639	0.531	0.412	0.1286	186.4	73.76	274.6	5.49	2.39	7.28	50.32	1.64	52.92	0.656
4. N_{120}	5.595	0.547	0.437	0.1425	198.1	75.92	277.6	5.82	2.39	7.23	52.23	1.76	53.89	0.714
5. P_{30}	5.540	0.524	0.295	0.0975	145.5	76.93	259.8	5.29	2.33	6.89	46.50	1.69	52.07	0.654
6.K_{40}	5.704	0.513	0.304	0.1199	148.9	71.53	279.3	5.43	2.36	7.24	49.93	1.60	49.85	0.754
7. K_{80}	5.637	0.621	0.349	0.1325	157.2	74.61	287.5	5.45	2.58	7.52	47.83	1.65	50.17	0.733
8. K_{120}	5.611	0.552	0.388	0.1407	166.8	74.69	302.4	5.70	2.57	7.67	44.98	1.74	52.93	0.719
9. $N_{80}P_{30}$	5.677	0.555	0.403	0.1337	160.4	78.58	279.4	5.82	2.28	7.79	47.40	1.67	51.41	0.755
10. $N_{80}K_{80}$	5.622	0.543	0.414	0.1456	171.2	75.46	307.7	5.81	2.45	7.75	51.94	1.74	51.13	0.746
11. $P_{30}K_{80}$	5.673	0.542	0.387	0.1398	164.2	85.35	304.5	5.79	2.45	7.79	46.10	1.78	50.75	0.737
12. $N_{80}P_{30}K_{80}$	5.656	0.574	0.449	0.1548	198.7	89.29	319.8	5.96	2.59	7.81	48.64	1.78	49.61	0.774
13. FYM @ 10 tha^{-1}	5.621	0.507	0.414	0.1282	181.5	73.03	278.1	5.77	2.45	7.31	45.23	1.59	50.37	0.734
14. FYM + $N_{40}P_{15}K_{40}$	5.783	0.631	0.474	0.1525	223.6	84.86	322.7	5.88	2.64	7.80	44.53	1.70	52.45	0.747
CD (P=0.05)	0.061	0.045	0.017	0.0046	12.9	6.80	6.80	0.27	0.09	0.24	1.13	0.05	1.50	0.038

and inorganic nutrient combinations over control, which might be due to enhanced root growth and production of more crop residues leading to accumulation of more organic matter in the soil (Kumari *et al.,* 2019). Incorporation of FYM alone showed an improvement of organic C (0.414%), emphasizing that apart from yield gains, organic sources add organic matter, improve the soil physical and chemical properties and neutralize the soil acidity (Fageria, 2012). Addition of graded doses of N fertilizers showed a significant improvement in organic C status, however, the dual application of NK showed relatively higher organic C (0.414%) rather than NP (0.403%) and PK (0.387%). Organic carbon in the soil acts as an energy substrate for proliferating microorganisms and enhancing nutrient availability to the crops (Pallavi *et al.,* 2016).

Significantly highest total N was observed due to the application of $N_{80}P_{30}K_{80}$ (0.1548%) at par with FYM + ½ NPK (0.1525%) over the initial status of 0.1344%. 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 the dual application of NK (0.1456%) and PK (0.1398%). Integrated use of inorganic and organic sources showed a build up of total N status rather than the addition of inorganic fertilizers. The available N was found decreased in all the treatment combinations over the initial status. Integrated use of FYM + ½ NPK recorded an increase of 64% available N over control. The addition of nitrogenous fertilizers tended to increase the available N status of the soil by 14, 37 and 45% over control with respect to 40, 80 and 120 kg ha^{-1} of N fertilization. Higher availability of N may be due to the integrated application of mineral fertilizer N along with organic sources which have contributed to the reduction of C:N ratio and thus increased the rate of decomposition resulting in faster availability of nutrients from manures. These results are in corroboration with the findings of Varalakshmi *et al.* (2005). Relatively higher status of available P in the soil was observed in all the treatments over the initial status of 45.6 kg P ha^{-1}, whereas significantly highest available P (89 kg P ha^{-1}) was noticed due to application of $N_{80}P_{30}K_{80}$ at par with $P_{30}K_{80}$ and FYM + ½ NPK (85 kg P ha^{-1}). The increase in available P content of the soil was attributed to the decomposition of organic manures which could have enhanced the labile P in the soil by complexing Ca, Mg and Al and solubilization of phosphate-rich organic compounds through the release of organic acids upon decomposition of organic matter and chelation of organic anions with Fe and Al resulting in effective solubilization of inorganic phosphates in the soil (Laxminarayana, 2017).

Significantly highest available K content in the soil (Table 4) was observed due to the integrated application of FYM + ½ NPK (323 kg ha^{-1}) at par with $N_{80}P_{30}K_{80}$ (320 kg ha^{-1}). The magnitude of increase in residual K of the soil by 9, 12 and 18% was observed due to the application of 40, 80 and 120 kg ha^{-1} of K_2O, respectively over control. A relatively higher status of available K was noticed due to the dual application of NK (308 kg ha^{-1}) followed by PK (305 kg ha^{-1}). A slight improvement of exchangeable Ca and Mg was observed due to the combined application of N and K fertilizers over the initial status of the soil. The highest exchangeable Ca [5.96 cmol (p+) kg^{-1}] was recorded due to the application of $N_{80}P_{30}K_{80}$ at par with FYM + ½ NPK [5.88 cmol (p+) kg^{-1}], whereas, the highest exchangeable Mg [2.64 cmol (p+) kg^{-1}] was found due to application of FYM + ½ NPK. The higher build up of exchangeable Ca and Mg and substantial reduction in the accumulation of Fe and Mn in the soil was attributed to the 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 improved due to the 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 was attributed to the nature of parent materials on which that soils formed and other soil forming factors (Anderson, 1988).

Effect of INM on soil microbial activities

Integrated application of FYM + ½ NPK has recorded higher counts of total fungi (45 x 10^4 cells g^{-1}) and bacteria (45 x 10^5 cells g^{-1}), while the actinomycetes were found highest (36 x 10^4 cells g^{-1}) due to application of balanced doses of $N_{80}P_{30}K_{80}$ (Table 5). The microbial diversity was found relatively higher due to the integrated use of FYM and half of the recommended doses of NPK over that of higher doses of NPK. The incorporation of

Table 5. Effect of organic manure and inorganic nutrients on soil microbial activities (after harvest of 2nd cropping sequence)

Treatment	Fungi ($1x10^4$ cells g^{-1})	Bacteria ($1x10^6$ cells g^{-1})	Actinomycetes ($1x10^5$ cells g^{-1})	Dehydrogenase (µg TPF g^{-1} h^{-1})	Fluorescein diacetate hydrolysis assay (µg g^{-1} h^{-1})	Urease (µg NH4-N g^{-1} h^{-1})	Acid phosphatase (µg PNP g^{-1} h^{-1})	Alkaline phosphatase (µg PNP g^{-1} h^{-1})
Control	31	28	22	0.974	1.256	182.9	35.19	28.62
N_{40}	31	29	22	1.162	1.524	213.5	46.27	31.20
N_{80}	35	34	24	1.416	2.154	243.8	52.39	35.48
N_{120}	36	33	27	1.348	1.955	256.4	59.17	37.72
P_{30}	25	29	23	1.042	1.845	216.7	66.20	50.91
K_{40}	23	31	23	1.216	2.134	207.2	49.20	32.30
K_{80}	28	33	27	1.329	2.345	223.5	51.12	36.79
K_{120}	34	34	32	1.348	2.472	240.8	56.79	39.27
$N_{80}P_{30}$	38	36	32	1.339	2.537	249.6	61.92	55.13
$N_{80}K_{80}$	42	41	34	1.527	2.658	276.5	62.01	58.14
$P_{30}K_{80}$	37	35	32	1.297	2.469	261.4	65.62	60.32
$N_{80}P_{30}K_{80}$	44	43	36	1.625	2.389	256.9	74.38	65.92
FYM @ 10 t ha^{-1}	34	32	29	1.394	2.135	246.5	61.50	56.30
FYM + $N_{40}P_{15}K_{40}$	45	45	35	1.860	2.856	281.8	82.27	70.28

organic manures showed higher microbial counts over that of inorganic chemical fertilizers, which may be ascribed to a greater build up of organic matter, which is beneficial to soil microbes (Kannan *et al.,* 2013).

The dehydrogenase activity (DHA), fluorescein diacetate hydrolysis assay (FDA) and urease activities in the soils after 2 years of continuous cropping were found highest due to integrated application of FYM + ½ NPK (1.860 µg TPF g^{-1} h^{-1}; 2.856 µg g^{-1} h^{-1} and 281.8 µg NH_4-N g^{-1} h^{-1}, respectively) (Table 5). Lower biological activities in the soils of the experimental field were observed due to single application of N, P and K fertilizers in comparison to the combined application of N, P and K fertilization, which was probably due to low organic matter status, coarse texture of the soil and presence of soil biota that influences nutrient transformations (Vaughan and Malcolm, 1985). Increased doses of NPK showed an increasing trend of urease activity in the soil. The highest acid and alkaline phosphatase activities (82.27 and 70.28 µg PNP g^{-1} h^{-1}, respectively) were recorded due to integrated use of FYM + ½ NPK followed by $N_{80}P_{30}K_{80}$ (74.38 and 65.92 µg PNP g^{-1} h^{-1}, respectively). Incorporation of organic manure in combination with limited doses of chemical fertilizers showed higher biological activities rather than inorganics, which might be due to the stimulation of bioactivity as influenced by organic sources (Laxminarayana, 2017; Zelles *et al.,* 1987).

Relationship between soil micro-flora and enzyme activities

A perusal of the data in Table 6 revealed that DHA had a significant relationship with total bacteria (r = 0.934**) followed by fungi (r = 0.808**) and actinomycetes (r = 0.801**), whereas FDA showed a significant relationship with actinomycetes (r = 0.844**) followed by bacteria (r = 0.819**) and fungi (r = 0.593**). Urease activity showed significant relationship with actinomycetes (r = 0.842**) > bacteria (r = 0.840**) > fungi (r = 0.815**). The acid phosphatase activity had a highly significant relationship with bacteria (r = 785**) followed by actinomycetes (r = 0.769**), whereas alkaline phosphatase had a highly significant relationship with actinomycetes (r = 0.831**) followed by bacteria (r = 0.787**). The results indicate that soil bacteria and actinomycetes play a major role in the enzyme mediated reactions in soils, however, P solubilization as influenced by phosphatase activities was mostly regulated by the microbes in the order of soil bacteria > actinomycetes > fungi. Dehydrogenase had a significant relationship with FDA (r = 0.806**) and urease (r = 0.854**), however, acid phosphatase showed a significant relationship with alkaline phosphatase activity (r = 0.917**).

Relationship between physico-chemical properties and microbial activities of the soil

The data in Table 7 revealed that the soil physico-chemical properties positively and significantly influenced the multiplication of bacteria as revealed by the 'r' values of 0.80**, 0.86**, 0.76**, 0.77**, 0.91**, 0.79**, 0.69**, 0.82**and 0.68** in respect of organic C, total N, available N, P, K, Ca, Mg, S, and Zn, which plays a significant role in enzyme activities and transformation of nutrients. Similarly, actinomycetes and fungi showed a positive and significant relationship with the available nutrient status of the soil. The available Fe and Mn had a negative or non-significant relationship with soil microbes. Increased available nutrient (N, P and K) status of the soil significantly influenced the multiplication of total bacteria and actinomycetes, which plays a significant role in organic matter decomposition and nutrient transformations.

Dehydrogenase activity of the soil showed a positive and significant relationship with soil properties (Table 7). Urease activity showed a significant relationship with soil properties and the 'r' values were found to be 0.92**, 0.88**, 0.79**, 0.69**, 0.78**, 0.90**, 0.62*, 0.74** and 0.66* in respect of organic C, total N, available N, P, K, Ca, Mg, S, and Zn. Soil microbial activities showed non-significant or negative relationship with available Fe and Mn. Organic matter is the storehouse of various groups of microbes and hence improvement in organic matter had a significant role in the accumulation of micro-flora and various groups of enzymes involved in different bio-chemical processes in the soil. Acid phosphatase activity had a significantly higher relationship over that of alkaline phosphatase activity). Available P in the soil showed a significantly higher relationship with acid phosphatase activity (r = 0.87**) rather than alkaline phosphatase activity (r = 0.84**), indicating that P solubilization was mostly

Table 6. *Correlation coefficients (r) between soil micro-flora and enzyme activities*

Soil microbes	Fungi	Bacteria	Actinomycetes	DHA	FDA	Urease	Acid phosphatase	Alkaline phosphatase
Fungi	--	0.870**	0.839**	0.808**	0.593*	0.828**	0.647*	0.720**
Bacteria	0.870**	--	0.889**	0.934**	0.819**	0.840**	0.785**	0.787**
Actinomycetes	0.839**	0.889**	--	0.801**	0.844**	0.842**	0.769**	0.831**
Dehydrogenase	0.808**	0.934**	0.801**	--	0.806**	0.854**	0.759**	0.698**
FDA	0.593*	0.819**	0.844**	0.806**	--	0.829**	0.736**	0.707**
Urease	0.828**	0.840**	0.842**	0.854**	0.829**	--	0.810**	0.777**
Acid phosphatase	0.647*	0.785**	0.769**	0.759**	0.736**	0.810**	--	0.917**
Alkaline phosphatase	0.720**	0.787**	0.831**	0.698**	0.707**	0.777**	0.917**	--

* P <0.05; ** P <0.01

Table 7. *Correlation coefficients (r) between soil properties with soil micro-flora and enzyme activities*

Soil microbes/ Enzymes	pH	Org. C	Total N	Avail. N	Avail. P	Avail. K	Exch. Ca	Exch. Mg	Avail. S	Avail. Fe	Avail. Cu	Avail. Mn	Avail. Zn
Fungi	0.302	0.838**	0.782**	0.758**	0.668*	0.745**	0.817**	0.458	0.754**	0.051	0.559*	0.115	0.431
Bacteria	0.343	0.797**	0.860**	0.762**	0.768**	0.908**	0.791**	0.685**	0.820**	0.133	0.548*	-0.050	0.683**
Actinomycetes	0.178	0.763**	0.872**	0.614*	0.776**	0.904**	0.885**	0.673*	0.910**	-0.039	0.659*	-0.065	0.771**
Dehydrogenase	0.324	0.894**	0.883**	0.893**	0.654*	0.858**	0.802**	0.778**	0.734**	0.131	0.358	-0.048	0.664*
FDA	0.153	0.700**	0.831**	0.559*	0.651*	0.839**	0.748**	0.718**	0.842**	0.106	0.463	-0.084	0.842**
Urease	0.026	0.916**	0.875**	0.793**	0.692**	0.783**	0.901**	0.621*	0.738**	0.244	0.565*	0.056	0.659*
Acid phosphatase	0.026	0.724**	0.665*	0.718**	0.867**	0.725**	0.750**	0.641*	0.569*	-0.039	0.533*	-0.052	0.639*
Alk. phosphatase	0.136	0.642*	0.606*	0.573*	0.837**	0.715**	0.738**	0.509*	0.652*	-0.154	0.502*	-0.155	0.630*

Table 8. *Relationship (r) between soil microbial activities with yield and proximate composition of elephant foot yam - black gram*

Parameter	Fungi	Bacteria	Actinomycetes	DHA	FDA	Urease	Acid phosphatase	Alkaline phosphatase
Elephant foot yam								
Corm yield	0.704**	0.906**	0.820**	0.892**	0.863**	0.828**	0.838**	0.712**
Starch	0.768**	0.939**	0.945**	0.883**	0.900**	0.868**	0.847**	0.819**
Total sugars	0.794**	0.884**	0.966**	0.875**	0.884**	0.886**	0.815**	0.821**
Dry matter	0.717**	0.847**	0.888**	0.900**	0.845**	0.796**	0.729**	0.674**
Black gram								
Grain yield	0.706**	0.874**	0.877**	0.886**	0.937**	0.911**	0.847**	0.763**
Haulm yield	0.776**	0.911**	0.934**	0.888**	0.869**	0.898**	0.889**	0.875**
Crude protein	0.740**	0.816**	0.760**	0.785**	0.623*	0.765**	0.615*	0.554*

* $P < 0.05$; ** $P < 0.01$

influenced by acid phosphatase. Non-significant or negative relationships between soil microbial activities with Fe and Mn were observed as the increase in Fe and Mn contents in the acid soil showed a detrimental effect on soil enzyme activities.

Relationship between microbial activities with yield of elephant foot yam - black gram cropping system

A positive and significant relationship was observed between corm yield and bio-chemical constituents of elephant foot yam as well as black gram in the order of total bacteria > actinomycetes > fungi (Table 8). Dehydrogenase activity showed a significant relationship with corm yield (r = 0.89**), dry matter (r = 0.90**), sugars (r = 0.88**) and starch content (r = 0.88**) of elephant foot yam. A highly significant relationship between FDA with grain yield, haulm yield and crude protein content of black gram was observed and the 'r' values were found to be 0.94**, 0.87** and 0.62*, respectively. The FDA, urease and phosphatase activities also showed a positive and significant relationship with yield and proximate composition of elephant foot yam - black gram cropping system. Acid phosphatase activity showed a highly significant relationship with yield and bio-chemical constituents of elephant foot and black gram over that of alkaline phosphatase activity. Thus, the results indicate that long term application of organic and inorganic chemical fertilizers at balanced proportions not only helps to augment crop yields, but also enhances microbial activities (Geng *et al.,* 2019). Soils receiving inputs of organic residues through amendments, or with higher levels of plant residues, showed greater FDA hydrolytic, dehydrogenase and alkaline phosphatase activities than the soils that received inorganic chemical fertilizers alone or no source of nutrients. Organic amendments and associated plant residues may supply additional sources of labile C and P to the soil, which can stimulate microbial growth and biochemical activity in the soil (Carpenter-Boggs *et al.,* 2000).

In conclusion, the application of half of the recommended doses of NPK fertilizers in combination with organic manure (FYM) sustains the soil quality and enhances the productivity and proximate composition of elephant foot yam - black gram cropping system in acid *Alfisols* of Eastern India. Application of soil test-based N, P and K fertilizers were found equally effective in obtaining higher crop yields, nutrient use efficiency, and residual soil fertility over that of single or dual application of N, P and K fertilizers. The incorporation of organic manure along with limited doses of inorganic chemical fertilizers improves microbial activities, which helps in nutrient transformations and availability to the crops. Cultivation of pulses as intercrops in between the tropical root and tuber crops not only enhances the total farm productivity but also enriches the soil fertility by the accumulation of its biomass that facilitates the biological activity of the soils.

CONFLICTS OF INTEREST

The author has no competing interests.

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