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Effect of inorganic fertilizers and organic manures on microbial activities and yield of elephant foot yam (*Amorphophallus paenifolius* L) - black gram (*Vigna mungo* L) cropping system

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Abstract

Soil microbes and enzyme activities were assessed and derived the relationship with the yield and biochemical constituents of elephant foot yam (*Amorphophallus paenifolius* L.) – black gram (*Vigna mungo* L) cropping system as influenced by inorganic and organic amendments in an acid Alfisol. The microbial populations were relatively lower in these acid soils in which fungi are dominant over that of actinomycetes and bacteria. Highest dehydrogenase activity (1.268 µg TPF hr^{-1} g^{-1}) and fluorescein diacetate hydrolysis assay (3.011 µg TPF hr^{-1} g^{-1}) were observed due to application of super optimal doses of NPK fertilizers. However, highest acid and alkaline phosphatase activities (32.50 and 25.55 µg PNP g^{-1} h^{-1}, respectively) were observed due to the conjoint use of lime + FYM + NPK + $MgSO_4$. Significantly highest corm yield of elephant foot yam (9.25 t ha^{-1}) as well as grain and haulm yields of black gram (7.84 and 14.10 q ha^{-1}, respectively) were recorded due to integrated application of lime + FYM + NPK + $ZnSO_4$. Dehydrogenase and acid phosphatase activities had significant relationship with bio-chemical constituents of elephant foot yam.

Keywords: Acid soil, lime, inorganic fertilizers, organic manures, elephant foot yam, black gram, yield, proximate composition, microbial activities

Introduction

Elephant foot yam (*Amorphophallus paenifolius* L.) is a tropical tuber crop with high yield roots, rich in calcium and vitamin B_6. The tuber is useful in 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). Tubers, roots and corms are useful in hemorrhoids. Elephant foot yam is basically a crop of Southeast Asian origin. In India it is being grown mostly in West Bengal, Kerala, Karnataka, Andhra Pradesh, Maharashtra, Chhattisgarh, Bihar, Jharkhand and Odisha.

Black gram is very nutritious as it contains high levels of protein (25g $100g^{-1}$), potassium (983 mg $100g^{-1}$), calcium (138 mg

100g^{-1}), iron (7.57 mg 100g^{-1}), niacin (1.447 mg 100g^{-1}), Thiamine (0.273 mg 100g^{-1}) and riboflavin (0.254 mg 100g^{-1}). Black gram complements the essential amino acids provided in most cereals and plays an important role in the diets of the people of Nepal and India. Black gram is recommended for diabetes, as are other pulses however excessive consumption causes flatulence. The roots are nacrotic and are used for ostalgia, abscess and inflammation.

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 (Imai, 1990). Borin and Frankow-Lindberg (2005) reported that intercropping increased cassava total dry matter and crude protein yields in cassava-legume mixtures. Richards (1983) stated that small-scale farmers' returns tended to be more reliable with intercropping. He emphasized that intercropping could be regarded as one of the great glories of African agricultural practice. He observed that intercropping is capable of producing remarkable results such as labour productivities that might perhaps equal to, if not better than, improved, small-scale farming practised in Europe. It was reported that intercropping two or more crops maximized output per hectare compared to mono-cropping (Ossom et al., 2009).

Soil acidity and associated problems limit the production of agricultural crops in the soils of the tropics. 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 inorganics in a synergistic manner for sustainable crop production and to safe guard the soil health. The crop response to applied fertilizers depends on soil organic matter which could been improved either by natural returns through roots, stubbles and crop wastes as well as application of various organic resources (Ayoola and Adeniyan, 2006). The use of inorganic chemical fertilizers has not been helpful under intensive agriculture because it is often associated with reduced crop yield, soil acidity and nutrient imbalances. Intensive cultivation, growing of exhaustive crops, use of unbalanced and inadequate fertilizers accompanied by restricted use of organic manures have made the soils not only deficient in the nutrients, but also deteriorated the soil health resulting in decline in crop response to recommended dose of fertilizers, integrated plant nutrient system (IPNS) has assumed a great importance and has vital significance for the maintenance of soil productivity (Kannan et al., 2013).

Soil micro flora is responsible for the decomposition and conversion and conversion of organic substances, aggregation stability and the carbon, nitrogen, sulphur and phosphorus cycle. Dehydrogenases are respiratory chain enzymes, which plays the major role in energy production of organisms as they oxidize organic compounds by transferring two hydrogen atoms. Microbial and bio-chemical 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. Soil micro-flora is responsible for the decomposition and conversion of organic substances, aggregate stability and the carbon, nitrogen, sulphur and phosphorus cycle. The present investigation was taken up to study the effect of integrated use of inorganic and organic manures on yield and proximate composition of elephant foot yam - black gram cropping system and its residual effect on soil fertility and microbial activities.

Materials and methods

A field experiment was conducted at the farm of the Regional Centre of the ICAR - Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India. The field experiment has been laid out in kharif (rainy) season during 2016-17. The experimental soil is fine-loamy, mixed, isohyperthermic, Typic Haplustalf and having plain topography, sandy loam, acidic (pH 5.16), non saline (0.24 dS m^{-1}) and having 0.256 % organic carbon, 0.1344 % total nitrogen, 218, 24.64 and 189 kg ha^{-1} of available nitrogen (N), phosphorus (P) and potassium (K), respectively. The soil also contains 33.44, 1.42, 112.8 and 0.52 mg kg^{-1} of available iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn), respectively. The experiment was laid out with 14 treatments replicated thrice in a randomized block design. The treatments include control, 100% NPK, 150% NPK, 50% NPK, FYM, vermicompost, neem cake, lime + 100% NPK, FYM + NPK + $ZnSO_4$, lime + FYM + NPK + $ZnSO_4$, FYM + NPK + Borax, lime + FYM + NPK + Borax, FYM + NPK + $MgSO_4$ and lime + FYM + NPK + $MgSO_4$.

Finely ground lime @ 0.5 t ha^{-1} and well rotten farmyard manure (FYM) were applied one month in advance of planting of the setts of elephant foot yam in the respective plots. A fertilizer dose of 94-30-80 kg ha^{-1} of N, P_2O_5 and K_2O in the form of urea, single super phosphate and muriate of potash were applied in respect of 100% NPK as per the soil test basis. One-third N, entire P_2O_5 and ½ K_2O at basal, ⅓ N at 45 days after sowing and the balance ⅓ N and ½ K_2O at 75 days after sowing were applied as per the treatments. Entire doses of $ZnSO_4$ @ 10 kg ha^{-1}, Borax @ 5.0 kg ha^{-1} and $MgSO_4$ @ 25 kg ha^{-1} were applied as per the treatments at one month after sprouting of elephant foot yam. 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 75 x 75 cm. Black gram seeds were dibbled in between the rows at 90 days after planting of elephant foot yam. No fertilizers were applied to black gram and it was grown as an inter crop with elephant foot yam. All the cultural practices were followed as per schedule and black gram was harvested at 70 days after sowing and elephant foot yam was harvested at 8 months after planting. Grain and haulm yields of black gram were recorded at harvest. Average corm weight and corm yield were recorded at harvest of elephant foot yam. The grain & haulm samples of black gram as well as elephant foot yam corm samples were collected at harvest, 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.

Soil samples were collected from individual treatments after harvest of the corms, processed and analyzed for physico-chemical properties by using standard procedures as outlined by Jackson (1973). Fresh soil samples after removal of gravels, roots, etc. were preserved in refrigerator at $4^{\circ}C$ and used for estimation of microbial variables. Nutrient Agar, Potato Dextrose Agar and Starch Casein Agar media were used for isolation of bacteria, fungi and actinomycetes, respectively. After the serial dilution, 1.0 ml of required dilution (10^{-4} for fungi and actinomycetes and 10^{-5} for bacteria) was inoculated in to respective petri plates. The soil sample was spread over the media via a flame sterilized bent glass rod and all the plates were incubated in the dark at $37^{\circ}C$. After the microbial colonies are readily visible (2-7 days for bacteria & fungi and 7-14 days for actinomycetes), the number of colonies on each plate were counted and calculated. The no. of cfu g^{-1} dry soil was estimated by taking the soil dilution factor and soil moisture content in to account. Soil biological activity was determined by the method as described by Casida et al. (1964). The fluorescein diacetate hydrolysis assay (FDA) was determined by the method outlined by Green et al. (2006). Acid and Alkaline phosphatase activities were determined by the method described by Tabatabai and Bremner (1969). The fresh samples of corms were washed thoroughly with distilled water, oven dried and dry weights were recorded. Total sugars in the corms were estimated in the alcohol filtrate and starch was determined in the residue as per the procedure outlined by Moorthy and Padmaja (2002). The oven dried tuber samples of elephant foot yam as well as grain and haulm samples of black gram were ground and digested in conc. H_2SO_4 and analyzed for N content by the steam distillation and N uptake was computed. Plant samples were digested in di-acid mixture (HNO_3 & $HClO_4$, 7:3) and the contents of total P and K were estimated by using spectrophotometer and flame photometer, respectively and the uptake of P & K was computed. The data of the experiment were analyzed by the method of analysis of variance (ANOVA) to find out the critical difference values for making interpretations. Correlation coefficients between microbial variables with soil properties and proximate composition of crops were derived. Per cent yield and uptake response were computed as

$$\text{Yield response (\%)} = \frac{\text{(Treatment yield – Control yield)}}{\text{Control yield}} \times 100$$

$$\text{Uptake response (\%)} = \frac{\text{(Nutrient uptake in treatment – Nutrient uptake in control)}}{\text{Nutrient uptake in treatment}} \times 100$$

Results and discussion

Effect of graded doses of NPK

The tuber yield was significantly increased with the application of graded doses of NPK and the yield response was 26, 75 and 79 per cent due to addition of 50, 100 and 150% of NPK over control, respectively. Higher yield response to the super optimal doses i.e. 150% NPK was observed as the crop responds to higher doses of N and K fertilization in the experimental sandy loam soil, which contains lower status of available N and medium status of available K. Addition of lime combined with optimum doses of NPK showed a marginal increase of tuber yield in the acid soil as the liming neutralizes the soil acidity and influence the transformation of native soil nutrients and enhances their mobility in the plant system. Elephant foot yam is a heavy feeder of nutrients and the yields were increased considerably due to application of excess doses of NPK fertilizers in low and marginal soils as it shown significant response to higher doses of NPK rather than the optimum doses of NPK, where it is being cultivated extensively. These results are in concurrent with the findings of Halavatau *et al*. (1998).

Effect of organic manures

Among the organic sources, incorporation of vermicompost has shown higher tuber yield (7.36 t ha^{-1}) at par with neem cake (7.08 t ha^{-1}) and FYM (6.44 t ha^{-1}) with a yield response of 63, 57 and 43 per cent over control, respectively. Application of organic manures showed higher yield response in comparison to 50% NPK with an increase of 14, 30 and 25 per cent corm yield in respect of FYM, vermicompost and neem cake over that of half of the recommended doses of NPK, emphasizing the beneficial effect of organic sources over that of chemical fertilizers. Addition of lime had profound influence when it applied in combination with organic sources in comparison to inorganic fertilizers might be ascribed to enhanced nutrient transformations and improvement in soil physical properties that contributed in augmenting the crop yields (Ossom and Rhykerd, 2008; Laxminarayana, 2013).

Table 1: Effect of integrated use of lime, inorganic and organic manures on yield performance of elephant foot yam and black gram.

Treatment	Elephant foot yam		Black gram		
	Corm yield (t ha^{-1})	Yield response (%)	Grain yield (q ha^{-1})	Yield response (%)	Haulm yield (q ha^{-1})
1. Control	4.508	-	4.31	-	8.29
2. 50% NPK	5.665	25.7	5.44	26.2	10.07
3. STBF (100% NPK)	7.894	75.1	6.85	58.9	12.82
4. 150% NPK	8.053	78.7	7.33	69.8	12.49
5. FYM	6.438	42.8	6.98	61.9	12.15
6. Vermicompost	7.358	63.2	6.44	49.4	12.25
7. Neem cake	7.081	57.1	6.13	42.2	12.13
8. Lime + 100% NPK	7.935	76.0	7.26	68.4	12.10
9. FYM + NPK + $ZnSO_4$	9.035	100.4	7.52	74.4	13.50
10. Lime + FYM + NPK + $ZnSO_4$	9.253	105.3	7.84	81.9	14.10
11. FYM + NPK + B	8.497	88.5	7.02	62.7	13.24
12. Lime + FYM + NPK + B	8.612	91.1	7.35	70.3	13.25
13. FYM + NPK + $MgSO_4$	8.516	88.9	7.25	68.1	13.57
14. Lime + FYM + NPK + $MgSO_4$	8.763	94.4	7.57	75.4	13.68
CD (P=0.05)	0.978	-	0.76	-	0.99

Table 2: Effect of lime, inorganic and organic sources on proximate composition of elephant foot yam and black gram.

Treatment	Elephant foot yam			Black gram
	Starch (%)	Total Sugars (%)	Dry matter (%)	Crude protein (%)
1. Control	14.36	1.29	20.92	22.53
2. 50% NPK	14.75	1.37	22.64	24.23
3. 100% NPK	15.25	1.46	24.50	25.06
4. 150% NPK	15.40	1.47	23.77	26.23
5. FYM	14.96	1.40	23.48	24.14
6. Vermicompost	15.13	1.36	22.89	23.79
7. Neem cake	15.23	1.43	23.19	24.19
8. Lime + 100% NPK	15.39	1.49	24.94	25.20
9. FYM + NPK + $ZnSO_4$	15.79	1.51	25.22	25.14
10. Lime + FYM + NPK + $ZnSO_4$	16.13	1.55	26.15	25.62
11. FYM + NPK + B	15.96	1.52	24.78	24.43
12. Lime + FYM + NPK + B	16.53	1.61	26.46	24.50
13. FYM + NPK + $MgSO_4$	15.86	1.53	25.08	25.16
14. Lime + FYM + NPK + $MgSO_4$	16.17	1.54	25.48	25.93
CD (P=0.05)	0.19	0.03	0.45	0.93

Table 3: Effect of lime, inorganic and organic sources on nutrient uptake by elephant foot yam and black gram.

Treatment	Nutrient uptake by corms of elephant foot yam							Total nutrient uptake by black gram						
	N	P	K	Fe	Cu	Mn	Zn	N	P	K	Fe	Cu	Mn	Zn
	--------- (kg ha^{-1}) ---------			--------------- (g ha^{-1}) --------------				--------- (kg ha^{-1})---------			--------------- (g ha^{-1})-------------			
1. Control	38.82	3.10	42.29	388.4	16.6	262.4	107.2	33.09	6.65	27.32	286.2	5.43	558.8	37.6
2. 50% NPK	43.62	3.41	55.81	334.4	18.9	178.8	152.0	40.43	8.16	30.04	349.3	6.10	618.6	46.1
3. 100% NPK	50.28	5.37	69.44	477.2	28.9	366.8	181.4	51.35	9.74	41.59	442.5	8.56	857.5	59.1
4. 150% NPK	67.05	5.82	77.63	541.9	28.6	318.0	193.8	56.20	9.70	43.06	446.6	8.05	883.5	62.7
5. FYM	41.38	4.17	62.39	322.1	25.4	223.9	172.0	51.17	11.05	42.31	394.4	8.21	783.4	55.6
6. Vermicompost	52.82	5.04	68.65	322.9	29.9	227.8	233.0	49.72	10.10	39.73	413.3	8.30	858.2	57.9
7. Neem cake	43.96	4.64	65.00	311.5	25.3	227.8	202.9	50.14	9.85	37.09	379.7	7.79	769.6	45.2
8. Lime + 100% NPK	52.04	5.04	64.11	456.4	29.4	300.9	191.8	54.86	10.58	40.04	398.8	8.20	821.2	54.6
9. FYM + NPK + $ZnSO_4$	62.29	5.61	78.21	670.4	34.2	440.7	256.3	56.68	11.46	45.76	444.0	9.42	978.4	61.9
10. Lime + FYM + NPK + $ZnSO_4$	62.79	5.69	99.55	597.7	34.5	335.4	262.9	62.28	12.07	45.75	488.0	10.36	996.4	74.3
11. FYM + NPK + B	59.68	5.43	83.43	518.9	32.0	335.5	182.1	52.73	11.07	41.59	422.4	9.38	904.6	56.4
12. Lime + FYM + NPK + B	66.44	5.75	94.14	472.0	34.1	214.9	190.9	56.74	11.22	43.69	422.3	9.68	880.9	58.1
13. FYM + NPK + $MgSO_4$	64.48	5.56	85.34	446.5	29.5	327.4	235.3	61.81	11.35	42.73	443.5	9.50	995.5	61.6
14. Lime + FYM + NPK + $MgSO_4$	67.75	6.05	92.19	460.4	16.6	262.4	107.2	64.74	11.86	44.61	448.1	9.78	963.5	63.7
CD (P=0.05)	4.50	0.49	4.72	40.77	2.50	33.93	15.0	4.33	1.10	3.39	33.84	0.69	58.92	4.88

Table 4: Effect of lime, inorganic and organics on physico-chemical properties of the soil.

Treatment	pH	Org. C (%)	Total N (%)	Available nutrient (kg ha^{-1})			Exch. Ca	Exch. Mg	Available micro nutrient (mg kg^{-1})			
				N	P_2O_5	K_2O	--- c mol (p^+) kg^{-1}---		Fe	Cu	Mn	Zn
Initial	5.16	0.256	0.1344	225.8	24.64	189.4	3.72	1.35	33.4	1.42	112.8	0.52
1. Control	6.12	0.176	0.0812	168.9	89.57	227.7	3.45	1.31	85.9	2.08	72.2	0.74
2. 50% NPK	6.38	0.304	0.0943	192.1	119.41	245.6	4.93	1.92	112.9	2.21	93.2	0.93
3. 100% NPK	6.37	0.407	0.1034	207.9	142.46	288.7	5.56	2.17	115.9	2.33	95.8	1.19
4. 150% NPK	6.28	0.537	0.1776	227.5	156.74	306.5	4.07	1.77	108.7	2.18	97.3	1.07
5. FYM	6.36	0.491	0.1182	213.6	102.07	242.7	4.23	1.66	91.4	2.35	87.0	0.98
6. Vermicompost	6.42	0.440	0.1334	192.7	128.46	320.2	4.22	1.63	96.1	2.27	81.6	1.63
7. Neem cake	6.31	0.429	0.1249	190.3	127.62	254.8	3.99	1.44	94.7	2.28	68.7	1.12
8. Lime + 100% NPK	6.48	0.424	0.1138	215.6	115.20	323.2	5.43	2.09	82.1	2.04	68.8	1.24
9. FYM + NPK + $ZnSO_4$	6.48	0.443	0.1457	217.1	146.71	343.9	5.02	1.96	96.1	2.23	86.6	2.78
10. Lime + FYM + NPK + $ZnSO_4$	6.55	0.567	0.1593	222.3	148.93	359.3	5.68	2.43	89.0	2.43	74.8	3.25
11. FYM + NPK + B	6.40	0.439	0.1394	219.7	148.10	340.4	4.89	1.89	78.4	2.23	65.1	1.67
12. Lime + FYM + NPK + B	6.56	0.507	0.1476	220.2	154.29	345.2	5.46	2.25	63.0	2.26	55.0	1.69
13. FYM + NPK + $MgSO_4$	6.42	0.468	0.1442	222.6	156.15	352.9	5.78	2.36	75.6	2.33	82.8	1.58
14. Lime + FYM + NPK + $MgSO_4$	6.66	0.583	0.1619	236.5	161.20	359.6	6.56	2.71	66.8	2.39	64.5	1.60
CD (P=0.05)	0.05	0.044	0.007	6.59	5.02	11.5	1.03	0.15	4.61	0.14	3.25	0.02

Table 5: Effect of inorganic and organic sources on soil microbes and enzyme activities.

Treatment	Fungi ($1x10^4$ cells g^{-1})	Bacteria ($1x10^5$ cells g^{-1})	Actinomycetes ($1x10^4$ cells g^1)	Dehydrogenase (µg TPF hr^{-1} g^{-1})	Fluorescein diacetate hydrolysis assay (µg g^{-1} hr^{-1})	Acid phosphatase (µg PNP g^{-1} h^{-1})	Alkaline phosphatase (µg PNP g^{-1} h^{-1})
Control	21	25	14	0.503	1.531	21.188	19.724
50% NPK	23	26	15	0.626	1.568	23.887	20.693
100% NPK	27	30	15	0.825	1.873	25.529	22.523
150% NPK	32	31	16	1.268	3.011	29.023	24.379
FYM	30	30	14	0.984	1.976	24.810	21.548
Vermicompost	27	35	19	1.022	2.564	26.227	22.649
Neem cake	33	28	16	0.921	2.522	25.020	21.873
Lime + 100% NPK	32	31	17	0.838	1.934	25.392	21.892
FYM + NPK + $ZnSO_4$	28	30	19	0.962	1.982	25.940	22.954
Lime + FYM + NPK + $ZnSO_4$	31	33	20	1.184	2.486	26.870	23.586
FYM + NPK + B	31	28	19	0.921	1.899	28.872	22.983
Lime + FYM + NPK + B	35	31	19	1.172	2.275	29.214	23.541
FYM + NPK + $MgSO_4$	36	31	21	0.976	2.169	30.864	24.129
Lime + FYM + NPK + $MgSO_4$	38	32	23	1.249	2.631	32.501	25.546

Table 6: Correlation coefficients ® between the soil micro-flora and enzyme activities.

Soil microbes	Dehydrogenase	FDA	Acid Phosphatase	Alkaline Phosphatase
Total fungi	0.772**	0.626*	0.858**	0.815**
Total bacteria	0.757**	0.680**	0.537*	0.672**
Total actinomycetes	0.618*	0.447**	0.815**	0.802**

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

Microbes/enzyme	pH	Org. C	Total N	Available N	Available P	Available K
Fungi	0.701**	0.571*	0.462*	0.571*	0.474*	0.494*
Bacteria	0.280	0.257	0.284	0.231	0.417	0.278
Actinomycetes	0.354	0.249	0.213	0.168	0.181	0.308
Dehydrogenase	0.741**	0.552*	0.446	0.441	0.417	0.421
FDA	0.463*	0.259	0.188	0.046	0.191	0.130
Acid phosphatase	0.727**	0.535**	0.520*	0.631*	0.674**	0.637*
Alkaline phosphatase	0.748**	0.571*	0.587*	0.607*	0.660**	0.623*

Table 8: Correlation coefficients (r) between yield & proximate composition of crops and soil microbial activities.

Parameter	Fungi	Bacteria	Actinomycetes	DHA	FDA	Acid phosphatase	Alkaline phosphatase
Elephant foot yam							
Corm yield	0.469*	0.424	0.710**	0.382	0.060	0.530*	0.531*
Starch	0.641*	0.395	0.781**	0.526*	0.158	0.681**	0.637*
Sugars	0.630*	0.289	0.661**	0.446	0.056	0.622*	0.569*
Dry matter	0.586*	0.387	0.670**	0.483*	0.088	0.583*	0.555*
Blackgram							
Grain yield	0.491*	0.490*	0.568*	0.420	0.039	0.482*	0.494*
Haulm yield	0.519*	0.450	0.670**	0.439	0.119	0.548*	0.529*
Crude protein	0.261	0.340	0.210	0.190	0.030	0.215	0.313

* and ** Significant at 5 and 1.0 per cent level, respectively

Effect of secondary and micronutrients

Significantly highest corm yield (9.25 t ha^{-1}) was recorded due to integrated application of lime + FYM + NPK + $ZnSO_4$ (Table 1) with highest yield response of 105 % over control and 15 per cent higher yields over that of super optimal doses of NPK (150% NPK). Integrated application of lime + FYM + NPK + $MgSO_4$ has recorded a corm yield of 8.76 t ha^{-1} with an increase of 94 and 9 per cent over that of control and 150% NPK, respectively. However, addition of borax @ 5 kg ha^{-1} along with lime, optimum doses of NPK and FYM has recorded a corm yield of 8.61 t ha^{-1} with an increase of 6.9 per cent yield over that of 150% NPK. Highest yield response due to liming and addition of $MgSO_4$ in these acidic soils attributed to neutralization of soil acidity contributed in higher absorption of all the essential nutrients both from native as well as applied sources (Bennett et al., 2014).

Effect of inorganic and organic manures on yield performance of black gram

Significantly highest grain and haulm yields of black gram (7.84 and 14.10 q ha^{-1}, respectively) as an inter crop was recorded due to integrated application of lime + FYM + NPK + $ZnSO_4$ with a yield response of 82 per cent over that of control (Table 1) at par with lime + FYM + NPK + $MgSO_4$ (7.57 and 13.68 q ha^{-1}, respectively). Application of soil test based fertilizers (100% NPK) has recorded a grain yield of 6.85 q ha^{-1} with a yield response of 59 per cent over that of control, however, super optimal doses of NPK showed a marginal increase of 6.9 per cent grain yield over that of 100% NPK, indicating that the higher doses of inorganic fertilization is not beneficial to the legumes. Lime addition along with 100% NPK showed a marginal yield response (6 %) over that of application of NPK alone in the acid soil of the present study. Among the organic manures, incorporation of FYM has recorded highest grain yield (6.98 q ha^{-1}) at par with vermicompost (6.44 q ha^{-1}). Incorporation of organic sources showed almost equal yield response in comparison to 100% NPK. The organic manures besides supplying nutrients to the first crop, also provides substantial residual effect of unutilized nutrients on the succeeding crop. Organic manures, particularly FYM and vermicompost, not only supply macronutrients but also meet the requirements of micronutrients, besides improving soil health. Though, they contain relatively low concentrations of nutrients and handling them is labour intensive, there has been large increase in their use over inorganic fertilizers as nutrient source for sustaining the productivity of pulses (Gaur, 1991; Kannan et al., 2005).

Proximate composition

Significantly highest dry matter (26.46 %) was recorded due to integrated application of lime + FYM + NPK + B followed by lime + FYM + NPK + $ZnSO_4$ (26.15 %). Among the organic sources, incorporation of FYM has recorded highest dry matter (23.48 %) followed by neem cake (23.19 %). Of all the treatment combinations, significantly highest starch content on fresh weight basis was recorded due to application of lime + FYM + NPK + Borax (16.5 %) followed by lime + FYM + NPK + $MgSO_4$ (16.2 %). Among the organic manures, application of neem cake has recorded highest starch (15.2 %) at par with vermicompost (15.1 %) and FYM (15.0 %). Total sugars in the corms of elephant foot yam ranged from 1.29 to 1.61 %, with highest being due to integrated application of lime + FYM + NPK + Borax. Addition of super optimal doses of NPK showed significant response in respect of starch and dry matter in comparison to application of soil test based fertilizers (100% NPK). Significantly highest crude protein in black gram (26.23 %) was observed due to application of super optimal doses of NPK followed by lime + FYM + NPK + $MgSO_4$ (25.93 %). Addition of secondary or micro nutrients in these acid soils along with lime, organic manure and optimum doses of NPK showed significant increase in bio-chemical constituents in comparison to application of soil test based fertilizers. These results are in accordance with the findings of Laxminarayana (2016).

Effect of inorganic and organic manures on nutrient uptake by elephant foot yam

Significantly highest uptake of N by elephant foot yam (67.75 kg ha^{-1}) was recorded due to integrated application of lime + FYM + NPK + $MgSO_4$ (Table 3) at par with 150 % NPK (67.05 kg ha^{-1}). Application of super optimal doses of NPK (150 % NPK) has recorded higher N concentration (3.37 %) and contributed in N uptake by the corms. Integrated application of lime + FYM + NPK + $MgSO_4$ has recorded highest uptake of P (6.05 kg ha^{-1}) at par with 150% NPK (5.82 kg ha^{-1}) and lime + FYM + NPK + Borax (5.75 kg ha^{-1}). Highest P concentration (0.285 %) was observed in the corms of elephant foot yam due to combined application of lime + FYM + NPK + Borax. Zhang et al. (1998) reported that organic manures increased labile, moderately stable and stable organic P contents in soil and uptake by plants. Highest uptake of K by the corms was recorded due to integrated use of lime + FYM + NPK + $ZnSO_4$ (99.6 kg ha^{-1}) followed by lime + FYM + NPK + B (94.4 kg ha^{-1}). These results are in agreement with the findings of Sreelatha et al. (2006) who reported that application of organic manure and chemical fertilizers significantly increased the K uptake by rice.

However, lime addition along with FYM, NPK, secondary and micro nutrients aggravated the uptake of N, P and K in elephant foot yam. Significantly highest uptake of Fe & Mn was recorded due to application of FYM + NPK + $ZnSO_4$ (670 and 441 g ha^{-1}, respectively), however, the uptake of Cu and Zn was highest (34.5 and 263 g ha^{-1}, respectively) due to integrated application of lime + FYM + NPK + $ZnSO_4$. Addition of graded doses of NPK showed an increasing trend of Fe & Mn uptake, whereas incorporation of organic manures resulted relatively lower uptake of Fe & Mn in elephant foot yam.

Effect of inorganic and organic manures on nutrient uptake by black gram

Significantly highest total uptake of N (64.74 kg ha^{-1}) by black gram was recorded due to integrated application of lime + FYM + NPK + $MgSO_4$ (Table 3) at par with lime + FYM + NPK + $ZnSO_4$ (62.28 kg ha^{-1}). Total N uptake tended to an increase of 22, 55 and 70 per cent due to application of 50, 100 and 150% NPK, respectively over control. Incorporation of organic sources showed N uptake at par with 100% NPK. Integrated application of lime + FYM + NPK + $ZnSO_4$ has recorded highest uptake of P (12.1 kg ha^{-1}) at par with lime + FYM + NPK + $MgSO_4$ (11.9 kg ha^{-1}). An increase of 23, 46 and 46 per cent uptake of P was observed due to addition of graded doses of NPK over control. Application of all the organic manures showed relatively higher P uptake over that of 100% NPK. Among the organic sources, highest P uptake was noticed due to incorporation of FYM (11.1 kg ha^{-1}) followed by vermicompost (10.1 kg ha^{-1}) and neem cake (9.9 kg ha^{-1}).

Highest total uptake of K by black gram (45.8 kg ha^{-1}) was recorded due to integrated use of lime + FYM + NPK + $ZnSO_4$ followed by lime + FYM + NPK + $MgSO_4$ (44.9 kg ha^{-1}). Among the organic sources, incorporation of FYM has recorded highest uptake of K (42.3 kg ha^{-1}) followed by vermicompost (39.7 kg ha^{-1}) and neem cake (37.1 kg ha^{-1}). Addition of graded doses of NPK showed an increase of 10, 52 and 58 per cent K uptake by black gram over control in respect of 50, 100 and 150% NPK. Significantly highest total uptake of Fe, Cu, Mn and Zn (488, 10, 996 and 74 g ha^{-1}, respectively) was recorded due to integrated application of lime + FYM + NPK + $ZnSO_4$ followed by lime + FYM + NPK + $MgSO_4$ (448, 9.8, 964 and 64 g ha^{-1}, respectively). Incorporation of vermicompost has recorded highest uptake of Fe, Cu, Mn and Zn over that of other organic manures. 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). Lime addition has substantially reduced the concentration of Fe & Mn over that of un-limed treatments, similar to the findings of Blamey and Chapman (1982).

Physico-chemical properties

The pH of the soil increased to 6.66 due to integrated application of lime + FYM + NPK + $MgSO_4$ followed by Lime + FYM + NPK + B (6.56) from the initial value of 5.16. Significant reduction of soil pH was observed due to application of super optimal doses of NPK in comparison optimal and sub optimal doses of NPK. Incorporation of vermicompost has improved the soil pH to 6.42 rather than FYM (6.36) and neem cake (6.31). Application of inorganic fertilizers alone showed lower values of pH in comparison to organic sources. Addition of lime has positive effect on neutralization of soil pH (Blamey and Chapman, 1982).

Continuous cropping without fertilization or manuring of the soil (control) showed lowest organic C (0.18%) from the initial status of 0.26%. Addition of graded doses of NPK showed a significant improvement in organic matter status. Highest organic C content (0.58 %) was observed due to integrated use of lime + FYM + NPK + $MgSO_4$ at par with lime + FYM + NPK + $ZnSO_4$ (0.57 %) and 150% NPK (0.54 %). Among the organic sources, incorporation of FYM showed higher build up of organic C (0.49 %) followed by vermicompost (0.44 %). Apart from yield gains, organic sources add organic matter, improve soil physical properties and neutralize soil acidity. Slight built up of organic carbon was found by conjoint use of organic and inorganic nutrient combinations over control. This might be due to enhanced root growth and production of more crop residues leading to the accumulation of more organic residues in soil. Organic carbon in the soil acts as energy substrate for proliferating microorganisms and enhancing nutrient availability to the crops (Pallavi et al., 2016).

Significantly highest total N was observed due to application of super optimal doses of NPK (0.178%), whereas the sub optimal and optimal doses of NPK had lower status of total N in comparison to the initial status. Addition of nitrogenous fertilizers tended to increase the available N status of the soil to 192, 208 and 228 kg ha^{-1} in respect of 50, 100 and 150% NPK from the initial value of 226 kg ha^{-1}, whereas the un-manured or unfertilized plots (control) showed a significant reduction of available N to 169 kg ha^{-1}. An increase of 14, 23 and 35 per cent of available N was observed due to application of 50, 100 and 150% NPK, respectively. Higher availability of N may be due to 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 corroborates with the findings of Varalakshmi et al. (2005).

It was observed that a great build up of available P in the soils over the initial level of 24.6 kg ha^{-1} (Table 4). The magnitude of increase in available P of the soil by 33, 59 and 75 per cent was observed due to application of 50, 100 and 150% NPK, respectively over control. Increase in available P content of the soil attributed by decomposition of organic manures which could have enhanced the labile P in the soil by complexing Ca, Mg & Al and solubilization of phosphate rich organic compounds through release of organic acids upon decomposition of organic matter and chelation of organic anions with Fe & Al resulting effective solubilization of inorganic phosphates in the soil (Subba Rao, 1999).

Significantly highest available K_2O content in the soil was observed due to integrated application of lime + FYM + NPK + $MgSO_4$ (360 kg ha^{-1}) at par with lime + FYM + NPK + $ZnSO_4$ (359 kg ha^{-1}). An increase of 8, 27 and 35 per cent of available K_2O was noticed due to application of 50, 100, and 150% NPK, respectively. Significantly highest exchangeable Ca and Mg [6.56 and 2.71 c mol (p^+) kg^{-1}, respectively] were recorded due to integrated application of lime + FYM + NPK + $MgSO_4$. Addition of both Ca and Mg through lime and $MgSO_4$ has contributed to higher build up of exchangeable Ca and Mg in the soil.

The available Fe content (Table 4) was found highest due to application of 150% NPK (115.9 mg kg^{-1}) at par with 100% NPK (112.9 mg kg^{-1}). Addition of 150% NPK has recorded highest available Mn (97.3 mg kg^{-1}). Both Fe & Mn contents in the post harvest soils were found higher than the critical limits of 4.0 and 2.0 mg kg^{-1}, respectively is due to the nature of parent materials on which the soils formed and other soil forming factors. Incorporation of lime along with inorganic chemical fertilizers and organic manures showed lower available Fe & Mn over that of un-limed treatments. The available Cu and Zn contents in the soils of the present study were higher than the critical limits of 0.2 and 0.60 mg kg^{-1}, respectively. Significantly highest available Zn (3.25 mg kg^{-1}) was recorded due to integrated use of lime + FYM + NPK + $ZnSO_4$, which might be ascribed to accumulation of added Zn through $ZnSO_4$ to elephant foot yam.

Soil micro-flora and Enzyme activities

Integrated application of lime + FYM + NPK + $MgSO_4$ (Table 5) has recorded higher counts of fungi (38 x10^4 cells g^{-1}) and actinomycetes (23 x10^4 cells g^{-1}) , whereas higher bacterial counts (35x10^5 cells g^{-1}) were observed due to application of vermicompost. Incorporation of vermicompost has recorded higher microbial counts than FYM and neem cake, which may be ascribed to greater build up of organic matter with the vermicompost. However, the microbial counts of total fungi, bacteria and actinomycetes were found relatively higher due to integrated use of micro or secondary nutrients combined with lime, organic manure and optimum doses of NPK over that of super optimal doses of NPK. The use of organics plays a major role in maintaining soil health due to build up of soil organic matter, which is beneficial to soil microbes (Kannan et al., 2013).

Application of super optimal doses of NPK has shown higher dehydrogenase (1.268 µg TPF hr^{-1} g^{-1} soil) and Fluorescein diacetate hydrolysis assay (3.011 µg g^{-1} hr^{-1}) followed by lime + FYM + NPK + $MgSO_4$ (1.249 µg TPF hr^{-1} g^{-1} and 2.631 µg g^{-1} hr^{-1}, respectively) (Table 5). The soils of the experimental field showed lower biological activities, which was probably due to lower organic matter, texture of the soil and soil biota that influences nutrient transformations (Vaughan and Malcolm, 1985). Increased doses of NPK showed an increasing trend of dehydrogenase and fluorescein diacetate activities of the soil. Application of vermicompost has recorded relatively higher soil biological activities over that of neem cake and FYM. Incorporation of lime combined with organic manures showed higher biological activities rather than un-limed plots. Liming and incorporation of organics stimulate the bioactivity and resulted higher values of FDA rather than unlimed plots. These results are in accordance to the findings of Zelles *et al*. (1987). Highest acid and alkaline phosphatase activities (32.5 and 25.5 µg PNP g^{-1} h^{-1}, respectively) were recorded due to combined application of lime + FYM + NPK + $MgSO_4$. Integrated application of lime, FYM, NPK along with secondary/ micro nutrients showed higher biological activities. Application of lime had positive effect on phosphatase activities as it improves the soil pH, which can limit the enzyme-mediated reaction rates by affecting the maximum activities of enzymes, and the solubility of substrates and cofactors (Dick, 1997).

Relationship between soil micro-flora and enzyme activities

Perusal of the data in Table 6 revealed that dehydrogenase activity significantly correlated with total fungi ($r = 0.772^{**}$) followed by bacteria ($r =0.757^{**}$) and actinomycetes ($r = 0.618^{**}$), whereas fluorescein diacetate activity had significant relationship with total bacteria (r = 0.680**) and total fungi (r = 0.626*). The acid phosphatase activity had highly significant relationship with fungi (r = 0.858**) followed by total actinomycetes (r = 815**) and total bacteria (r = 0.537**), however, alkaline phosphatase had highly significant relationship with total fungi (r = 0.815**) followed by actinomycetes **(**r = 0.802****)** and bacteria (r = 0.672**). The results indicating that soil fungi and bacteria plays major role in enzyme mediated reactions in the soil, however, P solubilization as influenced by phosphatase activities were mostly regulated by soil fungi > actinomycetes > bacteria.

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

The data in Table 7 showed that the soil pH had positive and significant relationship with fungi (r = 0.70**), indicating that the increase in soil pH favorably influenced the multiplication of fungi which plays significant role in enzyme activities and transformation of nutrients. All other physico-chemical properties positively and significantly influenced the multiplication of fungi as revealed from the data which was in respect of organic C (r = 0.57*) and total N (r = 0.46*). Increased available nutrient (N, P & K) status of the soil significantly influenced the multiplication of total fungi, which plays significant role in organic matter decomposition and nutrient transformations.

Soil biological activities showed significant relationship with soil reaction, indicating that increase of soil pH improve the enzyme activities. It was observed that all the soil properties showed significant relationship with dehydrogenase activity of the soil and the ‘r’ values were found to be 0.74** and 0.55** in respect of pH and organic C. Organic matter is the store house of various groups of microbes and hence improvement in organic matter had significant role in accumulation of micro-flora and various groups of enzymes involved in different bio-chemical processes in the soil.

Decrease of soil acidity had higher significant relationship with alkaline phosphatase activity (r = 0.75**) rather than acid phosphatase activity (r = 0.73*). Available P in the soil showed significant relationship with acid phosphatase activity (r = 0.67**) rather than alkaline phosphatase activity (r = 0.66**), whereas the relationship was relatively higher in respect of acid phosphatase due to increase in available N & K content of the soil (r = 0.63* & 0.64*) in comparison to alkaline phosphatase activity (r = 0.61* & 0.62*).

Relationship between microbial activities with yield and proximate composition

Positive and significant relationship was observed between corm yield and bio-chemical constituents of elephant foot yam with total actinomycetes rather than other microbes (Table 8). Dehydrogenase activity showed significant relationship with starch (r = 0.53*) and dry matter (r = 0.48*) of elephant foot yam. Thus, the results indicating that long term application of soil amendments, organic and inorganic chemical fertilizers at balanced proportion not only helps to augment the crop yields but also enhances the microbial activity. Positive and significant relationship was recorded between grain & haulm yields with actinomycetes and fungi, whereas phosphatase activities showed significant relationship with biometric characteristics of black gram. The soil microbial variables had non significant relationship with crude protein content of black gram. Soils receiving inputs of organic residues through amendments, or with higher levels of plant residues, showed greater FDA hydrolytic, dehydrogenase, and acid phosphatase activities than soils received inorganics alone or no source of nutrients. These results are in concurrent with the findings of Kremer and Jianmei Li (2003). Organic amendments and associated plant residues may supply additional sources of labile C and P to soil, which can stimulate microbial growth and biochemical activity (Carpenter-Boggs *et al*., 2000).

In conclusion, application of soil test based fertilizers in combination with lime, organic manure and secondary/ micro nutrients sustain the soil quality, enhances the productivity of elephant foot yam – black gram cropping system and improve the proximate composition of the crops in acid Alfisols. Addition of lime is customary for nutrient availability and microbial activities in the acid soils. Incorporation of organic manure, optimum doses of NPK fertilizers along with secondary/ micro nutrients improve the microbial activities, which helps in nutrient transformations and availability to the crops. 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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