Journal of Root Crops, 2013, Vol. 39 No. 1, pp. 48-55
Indian Society for Root Crops
ISSN 0378-2409

Impact of INM on Soil Quality, Yield, Proximate Composition and Nutrient Uptake of Sweet Potato in Alfisols

K. Laxminarayana

Regional Centre of Central Tuber Crops Research Institute, Dumduma, Bhubaneswar 751 019, Odisha, India
Corresponding author: K. Laxminarayana, e-mail: klnarayana69@rediffmail.com
Received: 25 February 2013; Accepted: 28 June 2013

Abstract

A field experiment was conducted for five consecutive *kharif* seasons during 2006-2011 to study the effect of integrated use of lime, mycorrhiza, inorganic and organic manures on soil quality and performance of sweet potato in an Alfisol. Application of 50, 100 and 150% NPK significantly increased the mean tuber yield by 44, 106 and 130% over control. Green manuring along with ½ NPK showed higher yield response (32 %) over that of inorganics. Significantly the highest mean tuber yield (13.69 t ha^{-1}) was obtained due to integrated application of lime, FYM, NPK and $MgSO_4$ with an increase of 19% over FYM + NPK. Inoculation of vesicular arbuscular mycorrhiza (VAM) along with lime + FYM + NPK resulted in a significant yield response of 10% over FYM + NPK. Addition of lime along with ½ NPK and organics (FYM, neem cake and green manure) resulted in 12, 10, and 13% greater tuber yield over the inorganic and organic sources without lime. Integrated use of organics (FYM, neem cake, green manure) along with ½ NPK and lime increased the nutrient use efficiency, apparent nutrient recovery and available nutrient status of the soil in comparison to inorganics and organic manures. Addition of 1½ NPK resulted in the highest dehydrogenase activity of soil (1.88 µg TPF g^{-1} h^{-1}). Highest fluorescein diacetate activity (FDA) (2.02 µg g^{-1} h^{-1}) was observed due to integrated application of lime, FYM, NPK and $MgSO_4$. Mycorrhizal application combined with NPK, FYM and lime resulted in the highest acid and alkaline phosphatase activities of the soil (84.19 and 64.03 µg PNP g^{-1} h^{-1}).

Key words: Organic manures, NPK, tuber yield, nutrient uptake, nutrient use efficiency, apparent nutrient recovery, soil chemical properties, soil biological activity

Introduction

Sweet potato has a long history as a famine relief crop, especially as a cheap source of energy. China accounts to more than 72% of world sweet potato production and 44% acreage with a productivity of 21.65 t ha^{-1}. According to the estimates of 2010-2011, in India sweet potato is grown in an area of 1.132 lakh ha with a production of 10.47 lakh tonnes (FAOSTAT, 2011). Among the Indian states, Odisha occupies 0.44 lakh ha with a production of 4.10 lakh tonnes and a productivity of 9.30 t ha^{-1} as against the world and all India average of 13.11 and 9.25 t ha^{-1}, respectively and its cultivation is mostly confined to plains and hilly areas.

Low fertilizer consumption coupled with low efficiency of applied nutrients and non adoption of improved technologies results in low crop productivity of sweet potato. The high cost of fertilizers and unsustainable crop production warrants the use of locally available low cost organic sources viz., cattle/poultry manures, green manures, biofertilizers etc. along with inorganics in a synergistic manner for sustainable production and to maintain soil quality. The supplementary use of organic manures and inorganic fertilizers augments the efficiency of both the nutrient sources to maintain a high level of soil productivity (Ayoola and Adeniyan, 2006). Keeping this in view, the present investigation was carried out to monitor the long term effect of integrated application of lime, mycorrhiza, organic manures and inorganic fertilizers on yield, proximate composition and nutrient uptake of sweet potato and their residual effect on soil fertility in acid Alfisols.

Materials and Methods

A long term field experiment was conducted in a Typic Haplustalf at the farm of the Regional Centre of Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India for five consecutive *kharif* (rainy) seasons during 2006-2011 to study the effect of integrated use of lime, mycorrhiza, inorganic and organic sources on yield, proximate composition, soil fertility and nutrient uptake of sweet potato. The soil of the experimental site was sandy loam, acidic (pH 5.51), non saline (0.58 dS m^{-1}) with 0.33% organic C, 0.075% total N, 141.8, 12.32 and 217.8 kg ha^{-1} of available N, P and K, respectively. The experiment was laid out with 20 treatments replicated thrice in a randomized block design. The treatments included:

1. Control
2. ½ NPK (NPK@37.5:11:31.25 kg ha^{-1})
3. NPK (NPK@75:22:62.5 kg ha^{-1})
4. 1 ½ NPK (NPK@112.5:33:93.75 kg ha^{-1})
5. Lime @ 0.5 t ha^{-1} + NPK
6. FYM @ 10 t ha^{-1} + ½ NPK
7. FYM @ 10 t ha^{-1} + NPK
8. Lime @ 0.5 t ha^{-1} + FYM @ 10 t ha^{-1} + ½ NPK
9. Neem cake @ 0.5 t ha^{-1} + ½ NPK
10. Lime @ 0.5 t ha^{-1} + neem cake @ 0.5 t ha^{-1} + ½ NPK
11. Green manure + ½ NPK
12. Lime @ 0.5 t ha^{-1} + green manure + ½ NPK
13. FYM @ 10 t ha^{-1} + NPK + $ZnSO_4$ @ 10 kg ha^{-1}
14. Lime @ 0.5 t ha^{-1} + FYM @ 10 t ha^{-1} + NPK + $ZnSO_4$ @ 10 kg ha^{-1}
15. FYM @ 10 t ha^{-1} + NPK + B @ 2.5 kg ha^{-1}
16. Lime @ 0.5 t ha^{-1} + FYM @ 10 t ha^{-1} + NPK + B @ 2.5 kg ha^{-1}
17. FYM @ 10 t ha^{-1} + NPK + $MgSO_4$ @ 25 kg ha^{-1}
18. Lime @ 0.5 t ha^{-1} + FYM @ 10 t ha^{-1} + NPK + $MgSO_4$ @ 25 kg ha^{-1}
19. FYM @ 10 t ha^{-1} + NPK + vesicular arbuscular mycorrhiza (VAM) @ 5 kg ha^{-1}
20. Lime @ 0.5 t ha^{-1} + FYM @ 10 t ha^{-1} + NPK + VAM @ 5 kg ha^{-1}

Well decomposed farmyard manure (FYM) @ 4 t ha^{-1} on dry weight basis, neem cake @ 0.50 t ha^{-1} and lime @ 0.5 t ha^{-1} were applied one month before planting of the cuttings. Cowpea (cv. SB-2) fresh biomass (1.5 t ha^{-1} on dry weight basis) was incorporated in the respective treatments 10 days before planting. Mycorrhizal fungal (*Glomus microcarpum* var. *microcarpum*) culture was mixed with fine sand, broadcasted on the raised bed, thoroughly mixed with the soil and the vine cuttings were planted as per treatments. Neem cake, FYM and green manure contained 2.15, 1.16, 1.32; 0.46, 0.28, 0.54; 1.72, 0.46, 1.28 % N, P, and K, respectively. Sweet potato (cv. Kalinga) was grown up to physiological maturity and the yield parameters were recorded.

Post harvest soil samples were analyzed for physico-chemical properties. Dehydrogenase activity in the soil was determined by the method described by Casida et al. (1964). Fluorescein diacetate (FDA) hydrolysis assay in the soil was determined by the method of Green et al. (2006). Phosphomonoesterases activity in the soil was determined by the method developed by Tabatabai and Bremner (1969). Total sugars in the tubers were estimated in the alcohol filtrate and the starch was determined in the residue. Tuber and vine samples were analyzed for N, P and K contents and its uptake was computed.

Results and Discussion

Tuber yield and quality

The tuber yield increased significantly with increasing doses of NPK and the increase in tuber yield was found to be 44, 106 and 130% with respect to 50, 100 and 150% NPK over control (Table 1). Addition of lime along with 100% NPK showed an increase of 109% in tuber yield over control. The vine yield also increased significantly with the increase in NPK doses and lime addition further enhanced the vine yield. Sweet potato is a heavy consumer of nutrients and the tuber and vine yields increased considerably due to application of excess doses of NPK fertilizers in low and marginal soils, where it is being extensively cultivated (Halavatau et al., 1998).

Significantly highest mean tuber yield (13.69 t ha^{-1}) was produced with the application of lime + FYM + NPK + $MgSO_4$ with a yield response of 40 and 19% over that of NPK and FYM + NPK, respectively (Table 1). Incorporation of organic manure (FYM) provides conducive physical environment which helps in better root growth and absorption of nutrients from the native as well as applied sources. Highest nutrient absorption resulted in higher tuber and vine yields of sweet potato. These results are in conformity with the findings of Singh et al. (2002). The mean yield response was highest with addition of $MgSO_4$ (7.5%) followed by $ZnSO_4$ (6.8%) and borax (2.9 %). Addition of lime along with FYM, 100% NPK and micronutrients showed a significant rise in tuber yields over that of unlimed plots and the response between limed and unlimed treatments was highest in respect of Mg (10.5 %) followed by Zn (9.7 %) and B (4.9 %). Significantly highest mean vine yield (13.4 t ha^{-1}) was observed due to integrated application of lime + FYM + NPK + $MgSO_4$, which was on par with lime + FYM + NPK + $ZnSO_4$ (13.1 t ha^{-1}) application. Liming and addition of $MgSO_4$ in acidic soils contributed to neutralization of soil acidity and greater absorption of all the essential nutrients both from native as well as applied sources, which eventually increased vine and tuber yields.

Green manuring along with the application of lime and ½ NPK resulted in almost equivalent yield response in comparison to 1½ NPK. This might be due to greater retention and availability of all the essential nutrients as well as improvement in soil physical and biological properties. However, lime addition resulted in further increase of 19, 6 and 13% tuber yield due to green manure + ½ NPK, FYM + ½ NPK and neem cake + ½ NPK, respectively over that of unlimed plots. The results emphasized that lime had profound influence when it is applied in combination with organic sources in comparison to inorganic chemical fertilizers and this might have enhanced nutrient transformations and improvement in soil physical properties that attributed to higher crop yields (Ossom and Rhykerd, 2008).

Application of VAM along with optimum doses of NPK and FYM resulted in a mean tuber yield of 11.67 t ha^{-1} with an increase of 19.0% over that of NPK. Integrated use of FYM + NPK + VAM has shown an yield increase of 6.7% compared to 1½ NPK. Liming further enhanced the tuber yields by 9.0% over that of FYM + NPK + VAM. Application of VAM along with lime had a greater impact on tuberization, resulted in higher tuber yields over that of FYM + NPK. Inoculation with *Glomus microcarpum* enhances the root length density and volume with root hairs, whereas VAM colonization releases organic acids, facilitates mineralization of organic P and solubilization of insoluble inorganic P fractions. This ultimately contributed to higher absorption of P including Fe, Cu, Mn and Zn. These results are in agreement with the findings of O′ Keefe and Sylvia (1993).

Significantly highest tuber dry matter content (34.6%) was observed due to the integrated application of lime + FYM + NPK + B (Table 1) followed by lime + FYM + NPK + $MgSO_4$ (34.0%). Significantly highest starch content (26.64%) was observed due to the integrated use of lime + FYM + NPK + $MgSO_4$. Green manure along with lime + FYM + ½ NPK resulted in higher starch (25.72%) and dry matter (32.6%) than neem cake or FYM in combination with lime + ½ NPK. Total sugars ranged from 2.87 to 3.38% while the highest was due to the application of lime + FYM + NPK + $MgSO_4$. Total sugars also significantly increased with the addition of lime and organic manures over the inorganic sources.

Nutrient uptake, nutrient use efficiency and apparent nutrient recovery

Significantly highest total uptake of N (77.69 kg ha^{-1}) was obtained due to integrated application of lime + FYM + NPK + $MgSO_4$ with an uptake response of 178% over control (Table 1). The total uptake of P was the highest due to combined application of lime + FYM + NPK + VAM (36.04 kg ha^{-1}) with an uptake response of 48 % over that of optimum doses of NPK. Combined application of lime + FYM + NPK + $ZnSO_4$ resulted in highest total uptake of K (94.0 kg ha^{-1}). Green manuring showed higher NPK uptake response both in tubers and vines followed by FYM. The uptake of N, P and K in both tubers and vines significantly increased with increase in doses of NPK. Liming along with ½ NPK and organic manures further enhanced the uptake of N, P, and K in sweet potato.

Table 1. Effect of lime, inorganic, biological and organic sources on yield, proximate composition and nutrient uptake of sweet potato (mean of five years)

Treatment	Yield (t ha^{-1})		Proximate composition (%)			Nutrient uptake (kg ha^{-1})								
	Tuber	Vine	Starch*	Total sugars*	Dry matter	Tubers			Vines			Total uptake		
						N	P	K	N	P	K	N	P	K
Control	4.76	5.23	21.84	2.87	29.04	10.21	7.50	16.23	17.74	5.61	14.78	27.96	13.10	31.02
½ NPK	6.86	7.11	23.23	3.15	30.04	12.75	9.88	21.13	24.62	7.97	20.62	37.38	17.85	41.74
NPK	9.81	8.96	23.92	3.29	31.84	18.75	13.64	30.62	32.22	10.68	31.24	50.97	24.32	61.86
1½ NPK	10.94	11.24	24.51	3.31	33.23	22.17	16.12	36.38	43.52	14.18	41.15	65.69	30.31	77.53
Lime + NPK	9.94	9.55	24.44	3.17	32.46	19.93	14.27	32.17	36.54	11.23	34.62	56.47	25.50	66.79
FYM + ½ NPK	8.58	8.74	24.51	3.19	31.26	16.64	12.31	27.69	31.73	9.75	26.37	48.36	22.06	53.72
FYM + NPK	11.53	10.93	24.96	3.36	33.53	22.43	16.31	36.63	41.18	13.37	42.62	63.61	29.68	79.26
Lime + FYM + ½ NPK	9.07	8.90	24.29	3.17	32.32	18.83	13.63	28.93	33.08	10.38	30.90	51.91	24.01	59.82
Neem cake + ½ NPK	7.70	7.85	23.75	3.21	30.78	15.04	11.09	24.65	28.19	8.60	27.12	43.23	19.69	51.77
Lime + neem cake + ½ NPK	8.72	8.99	24.09	3.29	31.67	16.99	13.03	28.06	32.14	9.83	33.48	49.12	22.86	61.53
Green manure (GM) + ½ NPK	9.08	9.57	24.17	3.13	31.51	18.49	13.92	29.26	37.18	10.36	34.27	55.67	24.27	63.52
Lime + GM + ½ NPK	10.82	10.38	25.72	3.22	32.59	22.32	16.59	33.94	41.85	11.85	38.52	64.17	28.44	72.46
FYM + NPK + $ZnSO_4$	12.31	11.75	24.48	3.22	33.02	23.19	16.81	40.05	44.17	10.87	44.02	67.36	27.68	84.06
Lime + FYM + NPK + $ZnSO_4$	13.51	13.14	25.79	3.35	33.48	25.72	19.11	44.06	48.07	12.37	49.95	73.79	31.48	94.01
FYM + NPK + B	11.63	11.09	24.63	3.30	33.14	22.01	16.67	38.24	41.55	12.59	43.40	63.56	29.25	81.64
Lime + FYM + NPK + B	12.20	12.09	25.38	3.37	34.61	23.57	19.03	41.84	43.41	13.83	45.00	66.97	32.85	86.84
FYM + NPK + $MgSO_4$	12.39	11.54	24.41	3.25	33.50	24.38	17.46	41.56	42.98	13.55	46.43	67.36	31.01	87.98
Lime + FYM + NPK + $MgSO_4$	13.69	13.41	26.64	3.38	33.99	28.13	20.48	45.96	49.56	15.02	47.52	77.69	35.51	93.48
FYM + NPK + VAM	11.67	11.55	24.96	3.29	32.97	23.31	17.70	39.07	43.43	14.32	43.86	66.74	32.02	82.93
Lime + FYM + NPK + VAM	12.72	12.61	25.75	3.37	33.68	25.68	19.88	43.20	46.17	16.15	48.12	71.85	36.04	91.33
CD (0.05)	0.53	0.59	1.46	0.11	0.60	1.17	0.89	2.11	2.07	0.72	2.55	2.64	1.21	3.67

*Results expressed on fresh weight basis

Table 2. Effect of integrated use of lime, inorganic, biological and organic sources on nutrient use efficiency and apparent nutrient recovery (mean of five years)

Treatment	Nutrient use efficiency (kg kg^{-1})			Apparent nutrient recovery (%)		
	N	P	K	N	P	K
½ NPK	56.0	84.0	56.0	25.1	19.0	28.6
NPK	67.3	101.0	67.3	30.7	22.4	41.1
1½ NPK	54.9	82.4	54.9	33.5	22.9	41.3
Lime + NPK	69.1	103.6	69.1	38.0	24.8	37.0
FYM + NPK	72.5 (93.5)	110.6 (153.6)	70.1 (79.6)	47.5 (68.7)	27.1 (47.9)	49.9 (80.5)
Lime + FYM + ½ NPK	77.1 (120.1)	119.1 (197.3)	72.9 (102.3)	42.8 (79.0)	30.1 (55.0)	48.7 (83.7)
Lime + neem cake + ½ NPK	82.1 (173.0)	128.6 (320.7)	89.8 (281.8)	43.9 (109.2)	31.7 (86.4)	69.2 (299.8)
Lime + green manure + ½ NPK	95.7 (153.5)	190.0 (573.9)	106.9 (206.3)	57.2 (103.8)	48.1 (153.5)	73.1 (160.0)
Lime + FYM + NPK + $ZnSO_4$	93.7 (201.1)	143.0 (330.4)	90.6 (171.3)	49.1 (124.0)	30.0 (63.9)	65.2 (148.8)
Lime + FYM + NPK + B	79.7 (129.9)	121.6 (213.4)	77.0 (110.6)	41.8 (87.0)	32.3 (76.2)	57.8 (115.6)
Lime + FYM + NPK + $MgSO_4$	95.6 (210.9)	145.9 (346.4)	92.4 (179.6)	53.2 (145.2)	36.6 (99.9)	64.7 (146.4)
Lime + FYM + NPK + VAM	85.2 (158.2)	130.1 (259.8)	82.4 (134.7)	47.0 (113.5)	37.5 (104.6)	62.4 (136.4)

Figures in parentheses indicate the contribution of the organic sources over inorganic fertilizers

Application of optimum doses of NPK resulted in the highest efficiency of N, P and K (67, 101 and 67 kg tubers kg^{-1} of N, P, and K, respectively), whereas it considerably decreased due to the application of sub-optimal and super-optimal doses of NPK over that of optimum doses of NPK (Table 2). Liming in combination with optimum doses of NPK showed greater N, P and K use efficiency over that of NPK alone. Incorporation of green manure along with lime and ½ NPK resulted in highest nutrient use efficiency for N, P and K (96, 190 and 107 kg tubers kg^{-1} fertilizer N, P and K, respectively). Integrated use of lime, organic manures and inorganic fertilizers not only enhances sweet potato productivity but also increases nutrient use efficiency by countering the acidity and exchangeable Al content in the soil (Hartemink, 2003).

Application of 1½ NPK resulted in the highest N recovery (33.5%), while lime + NPK enhanced the recovery of applied N over that of NPK (Table 2), which may be ascribed to higher biomass production and nutrient uptake due to balanced fertilization. Integrated application of lime + green manure + ½ NPK resulted in the highest N recovery (57.2%). Contribution of organics towards apparent N recovery was 104, 109 and 79% in respect of green manure, neem cake and FYM over that of ½ NPK. It was observed that the efficiency to applied P under optimum and super-optimal doses of NPK was 22.4 and 22.9%, respectively. Green manuring along with lime and ½ NPK resulted in the highest P recovery (48.1%). Inoculation of VAM in combination with lime + FYM + NPK resulted in the highest P recovery (37.5%) with a contribution of 104.6% from VAM towards P recovery. Application of optimum and super-optimal doses of NPK resulted in the highest K recovery (41.1 and 41.3%, respectively). Highest apparent K recovery (73.1%) was observed due to green manuring along with lime + FYM + ½ NPK with a contribution of 160% from green manure towards K recovery while considering the nutrient supply from both the sources.

Soil fertility

The pH of the soil increased to 5.92 due to long term application of lime + FYM + NPK + $MgSO_4$ from the initial level of 5.51 (Table 3). Addition of inorganic

Table 3. Effect of integrated use of lime, inorganic, biological and organic sources on soil properties (at the end of five years)

Treatment	pH	Organic	Total	Available major nutrients (kg ha^{-1})			Soil enzymes			
	(1:2)	C (%)	N (%)	N	P	K	Dehydrogenase (µg TPF g^{-1} h^{-1})	FDA (µg g^{-1} h^{-1})	Acid phosphatase (µg PNP g^{-1} h^{-1})	Alkaline phosphatase (µg PNP g^{-1} h^{-1})
Control	4.85	0.274	0.0683	195.7	56.2	175.5	0.786	0.627	37.29	30.85
½ NPK	4.84	0.382	0.0709	200.0	80.6	192.8	1.149	0.832	46.01	36.77
NPK	4.79	0.403	0.0763	228.0	92.3	212.4	1.361	1.014	53.68	39.20
1½ NPK	4.78	0.585	0.0892	255.9	107.5	248.2	1.882	1.548	58.67	46.61
Lime + NPK	5.22	0.415	0.0812	238.7	96.8	225.9	1.423	1.418	57.76	42.08
FYM + ½ NPK	5.02	0.388	0.0779	217.1	94.6	211.9	1.390	1.467	54.63	42.58
FYM + NPK	5.23	0.446	0.0825	240.4	101.0	239.8	1.571	1.622	59.92	46.63
Lime + FYM + ½ NPK	5.44	0.422	0.0804	233.4	97.8	222.6	1.493	1.525	57.94	46.01
Neem cake + ½ NPK	5.20	0.390	0.0762	215.7	86.6	208.0	1.325	1.381	52.12	39.74
Lime + neem cake + ½ NPK	5.36	0.429	0.0776	225.9	91.4	220.8	1.356	1.453	55.49	41.01
Green manure (GM) + ½ NPK	5.20	0.474	0.0808	232.5	92.3	218.9	1.475	1.543	60.57	45.33
Lime + green manure + ½ NPK	5.37	0.541	0.0826	242.1	105.3	229.9	1.606	1.641	63.97	50.95
FYM + NPK + $ZnSO_4$	5.31	0.532	0.0831	251.9	92.1	256.6	1.619	1.732	65.62	48.74
Lime + FYM + NPK + $ZnSO_4$	5.45	0.655	0.0856	265.9	101.6	272.9	1.642	1.804	68.57	52.59
FYM + NPK + B	5.25	0.462	0.0837	243.4	102.7	246.1	1.510	1.687	68.08	53.23
Lime + FYM + NPK + B	5.42	0.518	0.0842	254.1	105.2	255.8	1.531	1.730	72.98	55.29
FYM + NPK + $MgSO_4$	5.54	0.610	0.0854	260.5	103.8	263.2	1.784	1.819	70.74	57.01
Lime + FYM + NPK + $MgSO_4$	5.92	0.730	0.0866	274.9	112.0	286.9	1.853	2.019	76.28	61.36
FYM + NPK + VAM	5.35	0.582	0.0840	249.8	108.5	254.2	1.719	1.764	78.18	61.26
Lime + FYM + NPK + VAM	5.50	0.651	0.0852	260.3	127.6	264.4	1.809	1.886	84.19	64.03
CD (0.05)	0.17	0.023	0.004	3.67	7.53	4.75	-	-	-	-
Initial	5.51	0.328	0.0746	141.8	22.3	217.8	0.814	0.630	41.20	32.86

chemical fertilizers over a period of five years resulted in further increase in soil acidity. The soil pH was relatively higher under 100% NPK when applied in combination with lime or organic manure as compared to sole application of 100% NPK. Application of lime + ½ NPK + FYM increased pH of the soil rather than other organic sources, since organic matter has high cation exchange capacity (CEC) while it facilitated retention of exchangeable bases (Ossom and Rhykerd, 2008). Apart from yield gains, green manuring adds organic matter, improves soil physical properties and neutralizes soil pH (Hartemink and O'Sullivan, 2001). Highest organic C content was observed due to incorporation of lime + FYM + NPK + $MgSO_4$ (0.73%) with an increase of 123% of organic C over control. Total N content of the soil significantly increased with the integrated application of NPK and organic manures over NPK alone.

Significantly highest available N (275 kg ha^{-1}) was observed due to application of lime + FYM + NPK + $MgSO_4$. Incorporation of organics along with ½ NPK enhanced the available N content by 8.6, 7.9 and 16.3% due to FYM, neem cake and green manure, respectively over ½ NPK. The humus produced from the organic manures consequent to their decomposition, can supply almost all the essential nutrients slowly but steadily to the growing crops. Besides direct supply from the inorganic fertilizers contributed to the improvement of available nutrient status of the soil. The magnitude of increase in available P under 50, 100 and 150% NPK was 43, 64 and 91% over control. Integrated use of recommended doses of NPK and FYM resulted in significantly highest available P (101 kg ha^{-1}). Inoculation of VAM in combination with lime, FYM and optimum doses of NPK resulted in significantly highest available P (127.6 kg ha^{-1}). Highest available K content in the soil was observed due to integrated application of lime + FYM + NPK + $MgSO_4$ (287 kg ha^{-1}). The available K status of the soil sharply declined from the initial level due to addition of sub-optimal and optimal doses of NPK. It seems that the crop requirements for K were partly met from the added inorganic sources and also from the native soil. This resulted in depletion of available K in the soil. Supplementing the crop with inorganic fertilizers along with organic sources upon their decomposition released K and both the applied K and released K resulted in available K build up in the soil. Addition of lime in combination with reduced doses of NPK and organic manures increased the available K over that of inorganic and organic sources (Svotwa et al., 2007).

Soil enzyme activities

Incorporation of green manure along with lime and ½ NPK increased the dehydrogenase and fluorescein diacetate activities (1.641 µg TPF g^{-1} h^{-1} and 1.64 µg g^{-1} h^{-1}) in comparison to other organic sources (Table 3). Of the treatments, 1½ NPK increased the dehydrogenase activity (1.882 µg TPF $g^{-1}h^{-1}$), while the highest FDA (2.019 µg g^{-1} h^{-1}) was observed due to integrated application of lime + FYM + NPK + $MgSO_4$. Inoculation with VAM along with lime + FYM + NPK increased the dehydrogenase activity (1.809 µg TPF g^{-1} h^{-1}) over that of FYM + NPK (1.57 µg TPF g^{-1} h^{-1}). Addition of lime and organic matter enhanced the dehydrogenase activity rather than incorporation of organics alone. This may be due to the increased microbial population and enhanced biological activity. As the number of total actinomycetes was more in the soil, it can be presumed that actinomycetes contributed towards greater dehydrogenase activity in the soil.

Incorporation of green manure along with ½ NPK and liming increased the phosphatase activity (63.97 and 50.95 µg PNP g^{-1} h^{-1} in respect of acid and alkaline phosphatase). Combined application of lime + FYM + NPK + $MgSO_4$ relatively increased acid phosphatase (76.28 µg PNP g^{-1} h^{-1}) and alkaline phosphatase activity (61.36 µg PNP g^{-1} h^{-1}) in the soils. The increased microbial activity indicated by higher dehydrogenase, fluorescein diacetate and phosphatase activities under organic amendments in combination with chemical fertilizers and micronutrients might be due to greater availability of substrates that support such activities.

In conclusion, conjunctive use of organic manures and balanced doses of inorganic fertilizers not only enhanced the crop productivity but also improved the bio-chemical constituents of tubers and sustained the soil fertility. Application of Mg, Zn and B had profound influence on sustainable production of quality tubers in the acidic soils. Application of mycorrhiza had beneficial impact on tuber yield and soil fertility. Incorporation of organics in combination with limited doses of lime and inorganic chemical fertilizers was effective for sustainable sweet potato yields while maintaining soil health in acidic soils.

References

Ayoola, O.T. and Adeniyan, O.N. 2006. Influence of poultry manure and NPK fertilizer on yield and yield components of crops under different cropping systems in south west Nigeria. *African J. Biotech.*, **5**(15): 1386-1392.

Casida, L.E. Jr., Klein, D.A. and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci*., **98**: 371.

FAOSTAT. 2011. *Food and Agriculture Organization Statistics Database* (www. faostat.org).

Green, V.S., Stott, D.E. and Diack, M. 2006. Assay for fluorescein diacetate hydrolytic activity: Optimization for soil samples. *Soil Biol. Biochem.*, **38**: 693-701.

Halavatau, S.M., O'Sullivan, J.N., Asher, C.J. and Blamey, F.P. C. 1998. Better nutrition for the improvement of sweet potato and taro yields in the South Pacific. *Trop. Agric.*, **75**: 6-12.

Hartemink, A.E. 2003. Integrated nutrient management research with sweet potato in Papua New Guinea. *Outlook Agric.*, **32**(3): 173-182.

Hartemink, A.E. and O'Sullivan, J.N. 2001. Leaf litter decomposition of *Piper aduncum*, *Glyricidia sepium* and *Imperata cylindrica* in the humid lowlands of Papua New Guinea. *Pl. Soil*, **230**: 115-124.

O'Keefe, D. M. and Sylvia, D.M. 1993. Seasonal dynamics of the association between sweet potato and vesicular-arbuscular mycorrhizal fungi. *Mycorrhiza*, **3**(3): 115-122.

Ossom, E.M. and Rhykerd, R.L. 2008. Effects of lime on soil and tuber chemical properties and yield of sweet potato [*Ipomoea batatas* (L.) Lam.] in Swaziland. *Am. Eurasian J. Agron.*, **1**(1): 1-5.

Singh, S., Singh, R.N., Prasad, J. and Binod Kumar. 2002. Effect of green manuring, FYM and biofertilizer in relation to fertilizer nitrogen on yield and major nutrient uptake by upland rice. *J. Indian Soc. Soil Sci*., **50**(3): 313-314.

Svotwa, E., Baipai, R. and Jiyane, J. 2007. Organic farming in the small holder farming sector of Zimbabwe. *Electronic J. Environmental Agric. Food Chem.*, **6**(2): 1820-1827.

Tabatabai, M.A. and Bremner, J.M. 196). Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biol. Biochem*., **1**: 301–307.