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Soil oxidisable carbon stocks, nutrient availability and enzyme activity in surface and subsurface soil layers as influenced by twelve years of organic farming

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Abstract
A study was conducted for 12 years on permanent plots from 2003-04 to 2014-15 at the College of Agriculture, Rajendranagar, PJTSAU to evaluate the impact of organic nutrient management (ONM) practices *vis a vis* chemical nutrient management (CNM) and Integrated nutrient management (INM) on soil quality and performance of crops using maize-onion as test crop sequence. Changes in Soil organic carbon (SOC) stocks, nutrient availability and biological activity in soil and depth influence of various nutrient management practices was evaluated at the end of 12th year. Soil bulk density was lower in all the depths under organic nutrient management though differences were nonsignificant. SOC stocks in 0-15 cm layer ranged between 21.45 to 25.40 Mg C ha^{-1} in organically managed plots and 21.69 Mg C ha^{-1} in INM and 16.60 Mg C ha^{-1} in chemical nutrient management plots. Superiority of ONM in terms of soil organic carbon stock was evident up to lower soil layers of 15-30 cm, 30-45 cm. But in deeper layers of 45-60 cm and 60-75 cm SOC stocks in all the treatments were on par. Availability of phosphorus after 12 years of experimentation in the surface layer was more under INM followed by ONM while CNM plots registered lowest amount of available P. In subsequent depths of 15-30 cm and 30-45 cm similar superiority of INM and ONM was observed over CNM. Similarly buildup of available potassium with ONM and INM was seen upto 30-45 cm soil depth. Soil enzyme activity was found to be influenced evidently only in the surface 0-15 cm and 15-30 cm soil layers. Activity of dehydrogenase was three fold higher in the surface 0-15 cm soil layer than 15-30 cm layer. Similarly two fold increased activity of acid and alkaline phosphotase enzymes activity was registered in surface layer when compared lower layer. Soil enzymatic activity in the lower layers was found to be not influenced by the nutrient management practices.

Keywords: Soil SOC stocks, Nutrient availability, Dehydrogenase activity, Phophotases activity, Organic farming

Introduction
With increase in cost of production inputs, inorganic fertilisers became increasingly more expensive. Another great concern was the sustainability of soil productivity as land began to be intensively tilled to produce higher yields under multiple and intensive cropping systems. Long term field experiments have made clear the negative impact of continuous use of chemical fertilizers on soil health (Yadav, 2003) [13]. The occurrence of multi nutrient deficiencies and overall decline in the productive capacity of the soil due to non-judicious fertiliser use, have been widely reported. In addition, crop production based on the use of organic manures rather than chemical fertilizers is assumed to be a more sustainable type of agriculture. Therefore, in recent years the application of organics has received great attention from environmentalists, agriculturists and consumers alike. Soil organic matter affects crop growth and yield, directly by supplying nutrients and indirectly by modifying the soil physical, chemical and biological properties, thereby improving the root environment and, thus, stimulating plant growth.

Material and methods
A long term experiment with different nutrient management practices for maize-onion cropping system was conducted for 12 years on permanent plots at the college farm of College of Agriculture, Rajendranagar, Hyderabad, from 2003-04 to 2014-15. The site is situated at 18^0.59’ N latitude, 78^0.55’E longitude and 534 m altitude.

The experimental soil is a sandy loam (Udic Ustochrept) with 61.9% sand, 23.8% silt and 12.5% clay. The experimental soil had an initial pH of 7.6, organic C of 0.36%, Olsen's P of 24.0 kg ha^{-1} and exchangeable K of 293 kg ha^{-1} respectively. The experiment was laid out on large plots of 300 sq.m with seven treatments viz., 50% Recommended NPK + 50% N as FYM (T1), FYM + Vermicompost + Neem cake each equivalent to 1/3rd Rec. N (T2), T2+Inter crop of radish in kharif & carrot in rabi (T3), T2 + Agronomic practices for weed and pest control (T4), 50% N as FYM + Bio-fertilizer for N + Rock phosphate for P + PSB (T5), T2 + Biofertilizer containing N and P carrier (T6) and 100% NPK (T7). The recommended dose of fertilizers (RDF) for maize and onion were 180:60:40 and 150:60:60 kg NPK ha^{-1} respectively. Farmyard manure, vermicompost and neem cake were applied on N equivalent basis. Years of experimentation were considered as replications for statistical analysis of the data.

Depth wise soil samples from each plot in three locations at every 15 cm interval from 0 to 75 cm were collected every year and at the end of 12th cropping cycle (*rabi*, 2014-15) after clearing the surface litter. Soil physical parameters like bulk density and water holding capacity were estimated using soil core and pressure plate apparatus methods. Soil organic carbon was determined by the Walkley–Black method (Nelson and Sommers, 1982) [9], available N by Alkaline permanganate method (Subbaiah and Asija, 1956) [11], available P Olsen's extractant method (Olsen *et al*., 1954) [10] and available K by extracting with neutral normal ammonium acetate and using Flame photometer (Jackson, 1967) [6]. Dehydrogenase [DHA, Enzyme Commission (EC) number 1.1.1.] activity was assayed using 2, 3, 5-triphenyltetrazolium chloride as the substrate (Casida *et al*., 1964) [3] and was expressed as micrograms of Tripheny Formazone released per gram of soil per day (mg TPF g^{-1} day $^{-1}$). Phosphatase (EC 3.1.3.2) activity was estimated using modified universal buffer at pH 4.5 (Acid phosphatase) and 11.0 (Alkaline phosphotase) and p-nitrophenyl phosphate as the substrate (Tabatabai and Bremner, 1969) [12] and expressed in micrograms of para-nitrophenol released per gram of soil per hour (ug PNP g^{-1} h^{-1})

Results and discussion

Soil Physical properties

In all the treatments, decrease in bulk density (Table 1) was noticed in the surface layer when compared to initial (1.47 Mg m^{-3}) with 1.37 to 1.41 Mg m^{-3} under organically managed plots, 1.40 Mg m^{-3} under INM and 1.42 Mg m^{-3} in the plots which received only inorganic fertilizers. Soil bulk density was lower in all the depths under organic nutrient management and was ranging from 1.44 to 1.47 in 15-30 cm layer, 1.45 to 1.52 in subsequent 30-45 cm depth, 1.43 to 1.53 in further 45-60 cm layer and 1.47-1.61 in 60-75 cm deep soil layer. In all the depths or soil layers, chemical or integrated nutrient management treatments recorded higher bulk density. Continuous addition of organic matter might be the major component that stimulated the formation and stabilization of granular and crumb type of aggregates (Brady, 1996) [2]. Decomposition of organic residues releases organic acids, sugars, mucilaginous substances, and other viscous microbial by-products are evolved, which, along with associated fungi and bacteria, encourage the crumb formation and net effect of these activities will decrease bulk density and increase porosity (Loganathan, 1990) [8]. Similar beneficial effects of reduced bulk density by addition of organic sources have been reported by Kumpawat (2004) [7]. Available water content at field capacity and permanent wilting point in 0-15 cm layer also showed significant variation with application of organics nutrition. Higher organic matter addition could increase organic carbon content of the soil and in turn in increased water holding capacity of the soil. The humus can absorb water two to six times its own weight. Soil organic matter is responsible to a great extent, directly or indirectly for making the physical environment of the soil suitable by improving soil aggregation, porosity, soil structure, water infiltration, moisture conservation, drainage, aeration, temperature, and microbial activities in turn for the growth of crops.

Soil Oxidisable carbon (SOC) stocks

The content of organic carbon in 0-15 cm soil layer at the end of 12th cycle was higher with 0.78%, 0.75% and 0.50% with organic, integrated and chemical treatments when compared to initial status (0.36%). Average improvement in organic carbon with organic nutrient management was 66-93% when compared to initial status and compared to conventional inorganic nutrient management, integrated nutrient management had 19.8% higher organic carbon and organic nutrient management had 18.7 to 38.2% higher organic carbon. Increase in the soil organic carbon content status in soil due to addition of organic matter through organic manures for supply of major and micro nutrient content in soil can be assigned as possible cause for variation of initially soil fertility status to post harvest the crops (Choudhary and Sinha, 2001) [4]. The increase in organic carbon with the application of manures was attributed to greater input of root biomass due to better crop productivity. The carbon content for each layer is expressed as carbon stock (Mg ha^{-1}) by multiplying carbon concentration (in fraction g/g) with bulk density (Mg m^{-3}) of each layer, thickness of the layer (in m) and the area of a hectare (in m^2). The summation for each layer in a profile depth will give total carbon (in Mg ha^{-1}). The treatment differences were also significant and demonstrate that manures were more effective in enhancing the SOC (Table.2). Soil organic carbon stock in 0-15 cm layer ranged between 21.45 to 25.40 Mg C ha^{-1} in organically managed plots and 21.69 Mg C ha^{-1} in INM and 16.60 Mg C ha^{-1} in chemical nutrient management plots. Superiority of ONM in terms of soil organic carbon stock was evident up to lower soil layers of 15-30 cm, 30-45 cm. But in deeper layers of 45-60 cm and 60-75 cm SOC stocks in all the treatments were on par. On the whole, in 0-75 cm soil layer a total carbon stock of 50.6 to 71.7 Mg C ha^{-1} was recorded in ONM plots and 54.2 Mg C ha^{-1} in INM and 42.7 Mg C ha^{-1} in CNM plots. SOC stock under ONM was 25.8 to 68.1 % higher in 50% recommended dose of nitrogen fertilizers applied as FYM and 100% recommended dose of nitrogen applied through FYM + vermicompost + neemcake each. The increased level of carbon stock is a good indication of better carbon sequestration in soil by reducing the amount of CO_2 released to the atmosphere.

Nutrient availability

Organic matter addition significantly enhanced the nutrient availability of the soil. The status of available N, P and K were increased in organic manure treated plots. The process of aminization, amonification, and oxidative deaminisation brought about by microbially mediated enzyme systems that are active in vermi compost and other organic amendments, thus contributed to more of soluble N. However, build-up of available nitrogen was not much by nutrient management practices in the surface and deeper layers and the status was close to initial status.

Availability of phosphorus after 12 years of experimentation in the surface layer was more under INM (66.9 kg ha^{-1}) followed by ONM (31.0 kg ha^{-1} in T5 to 61.5 in kg ha^{-1} in T6) and CNM plots (42.6 kg ha^{-1}) registered lowest amount of available P (table 3).Compared to initial, average build-up of available phosphorus observed over the twelve year period was by 46% in chemical farming, 61% under INM and 49 to 85% under different organic nutrient management practices. The high microbial activity and enhanced mineralization of soil P coupled with high phosphatase activity might be the reasons for high extractable P. In subsequent depths of 15-30 cm and 35-40 cm similar superiority of INM and ONM was observed over CNM. However, in further lower (45-60 cm and 60-75 cm) soil layers the differences in availability of phosphorus were non-significant.

Available potassium in the surface layer also registered an average increase of 9.3% with application of fertilizes alone and 15.9 to 44.0% with various organic nutrient management practices and 28.9% under INM. Similarly build-up of available potassium with ONM and INM was seen upto 30-45 cm soil depth. In subsequent soil layers of 45-60 cm and 60-75 cm available soil potassium was almost similar in all the treatments (table 4). K^+ ions from edge, wedge, or inter layer sites within clay minerals, could possibly be replaced by NH_4 ions of similar ionic radius, so the concentration of might have increased in the presence of vermin compost.

Soil Enzyme Activity

Microbial and biochemical soil properties have been suggested as early and sensitive indicators of changes in soil quality as they manifest themselves over shorter timescales and are central to the ecological function of a soil (Bandick and Dick 1999) [1]. Soil enzyme activities in particular are increasingly used as indicators of soil quality because of their relationship to decomposition and nutrient cycling, ease of measurement, and rapid response to changes in soil management (Dick 1994). The enzyme assay also indicated the significance of organic nutrition over inorganic. Enzymes respond to soil management changes long before other soil quality indicator changes are detectable. Nutrient management through chemical fertilizers recorded lowest dehydrogenase activity. Highest activity of alkaline phosphatase was noticed in treatment wherein along with organic nutrient management agronomic practices like incorporation of weeds were practiced. However, the influence of ONM on soil biological activity was evident only in the surface 0-15 cm and 15-30 cm soil layers with three fold higher activity of dehydrogenase and two fold increased activity of acid and alkaline phosphotase enzymes in the surface 0-15 cm soil layer than 15-30 cm layer. In the lower layers soil enzymatic activity was found to be not influenced by the nutrient management practices. The higher dehydrogenase and phosphatases activity in the surface soils might be due to the availability of a higher quantity of biodegradable and mineralizable substrates for improvement in microbial activity.

Conclusion

The study clearly demonstrated the beneficial effect organic farming on soil physical, chemical and biological environment which in turn will be reflected in terms of productivity and ecological sustainability. However the depth of influence of 12 years of organic nutrient management was prominent up to 30 cm of soil depth

Table 1: Changes in soil physical properties of the soil under organic farming for 12 crop cycles

Treatment	Bulk Density (Mg m^{-3})					Field Capacity (%)	Wilting Point (%)	Available Water (%)	Porosity (%)
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm
T1: 50% NPK + 50% N as FYM	1.40	1.55	1.69	1.67	1.70	14.38	6.88	7.50	49.8
T2: FYM + VC + NC (1/3rd rec.N).	1.37	1.44	1.52	1.63	1.69	17.40	7.99	9.41	51.3
T3: T2+ Inter Crop(carror/radish)	1.41	1.47	1.55	1.64	1.67	16.30	7.12	9.18	50.8
T4: T2 + Agronomic practices for weed and pest control.	1.40	1.51	1.59	1.70	1.74	17.23	7.66	9.56	52.1
T5: 50% N as FYM + bio-fertilizers for N + Rock Phosphate for P + PSB	1.39	1.54	1.68	1.63	1.67	15.54	6.74	8.80	55.1
T6 : T2+ biofertilizers containing N & P carrier.	1.37	1.47	1.58	1.63	1.64	16.76	7.77	8.99	53.6
T7: 100% NPK	1.42	1.57	1.73	1.67	1.71	11.62	5.75	5.87	48.3
CD @ 5%	NS	NS	NS	NS	NS				
Initial	1.47					11.08	5.85	5.23	46.4

Table 2: Changes in soil oxidisable carbon (SOC) stocks of the soil under organic farming for 12 crop cycles

Treatment	Initial 2003-04 SOC (%)	SOC (%)		% Increase / Decrease over initial		Average increase over T7		Depth wise changes in SOC stocks (Mg C ha^{-1}) after 12 crop cycles					
		Average after 12 Cycles	2014-15	Average after 12 Cycles	2014-15	Average after 12 Cycles	2014-15	0-15 cm	15-30 cm	30-45 cm	0-75 cm	60-75 cm	Total 0-75 cm
T1: 50% RDF + 50% N FYM	0.36	0.60	0.75	67.8	108.3	19.8	48.8	21.69	13.32	7.64	5.79	5.72	54.2
T2: FYM+VC+ NC(1/3 N each)	0.36	0.70	0.78	93.5	116.7	38.2	51.4	25.40	20.56	13.12	5.54	7.09	71.7
T3: T2 + Inter Crop (radish)	0.36	0.67	0.63	85.6	75.3	32.6	28.6	24.36	18.99	13.41	5.57	6.73	69.1
T4: T2 + Agron. Practices	0.36	0.68	0.73	87.7	102.8	34.0	49.0	24.10	19.10	13.06	5.18	6.48	67.92
T5: 50% + Azospirillum + RP + PSB	0.36	0.60	0.73	66.2	102.8	18.7	49.0	21.45	12.46	7.47	4.16	5.10	50.6
T6: T2 + Azospirillum + PSB	0.36	0.65	0.72	81.3	100.0	29.4	46.9	23.71	19.04	13.26	5.48	5.77	67.3
T7: 100% RDF and S	0.36	0.50	0.50	40.0	36.1			16.60	13.26	4.11	5.24	3.43	42.7
Range		0.50-0.70	0.50-0.78	40.0-93.5	38.1-116.7	19.8-38.2	27.0-56.9						
CD@ 5%			0.16										

Table 3: Changes in soil available phosphorus (kg ha^{-1}) of the soil under organic farming for 12 crop cycles

Treatments	Initial 2003-04 Avl.P (kg ha^{-1})	Available Phosphorus (kg ha^{-1})		% Increase / Decrease over initial		Average increase over T7		Depth wise changes in available phosphorus after 12 crop cycles (kg ha^{-1})				
		Average after 12 Cycles	2014-15	Average after 12 Cycles	2014-15	Average after 12 Cycles	2014-15	0-15 cm	15-30 cm	30-45 cm	0-75 cm	60-75 cm
T1: 50% RDF + 50% N FYM	24	38.7	66.9	61.1	178.8	10.6	57.0	66.9	27.6	22.3	5.3	3.0
T2: FYM+VC+ NC(1/3 N each)	24	40.8	55.7	70.2	132.1	16.8	30.8	55.7	45.7	28.4	4.8	2.6
T3: T2 + Inter Crop (radish)	24	38.4	45.2	60.0	88.3	9.8	6.1	45.2	46.5	31.9	4.9	2.5
T4: T2 + Agron. Practices	24	42.2	51.0	76.0	112.5	20.8	19.7	51.0	40.4	26.9	4.7	2.8
T5: 50% + Azospirillum + RP + PSB	24	35.8	31.0	49.0	29.2	2.3	-27.2	31.0	18.0	8.0	3.7	3.4
T6: T2 + Azospirillum + PSB	24	44.3	61.5	84.6	156.3	26.7	44.4	61.5	41.5	34.1	6.0	3.3
T7: 100% RDF and S	24	35.0	42.6	45.7	77.5			42.6	37.6	27.2	5.6	3.9
Range	24	35.0-44.3	31.0-66.9	45.7-84.6	29.2-178.8	2.3-20.8	(-)27.2- 57.0					
CD@ 5%			7.61					7.61	8.95	9.6	NS	NS

Table 4: Changes in soil enzyme activity under soil under organic farming for 12 crop cycles

Treatment	Dehydrogenase Activity (ug TPF g^{-1} day^{-1})				Acid Phosphatase (ug PNPg^{-1} hr^{-1})				Alkaline Phosphatase (ug PNPg^{-1} hr^{-1})			
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
T1: 50% NPK + 50% N as FYM	13.97	4.95	1.58	1.12	94.8	65.0	38.1	29.6	280.1	119.3	81.1	41.7
T2: FYM + VC + NC(1/3rd rec.N).	23.47	5.22	3.17	1.08	158.3	111.4	75.2	34.6	311.6	182.7	96.5	38.9
T3: T2+ Inter Crop	20.33	3.71	3.02	1.07	183.5	134.4	83.8	37.9	305.5	187.6	86.8	42.6
T4: T2 + Agron practices for weed and pest control.	18.61	4.12	2.78	1.11	181.6	140.1	80.6	40.8	351.7	142.2	100.1	37.1
T5: 50% N as FYM + bio-fert. for N + Rock Phosphate for P + PSB	13.35	4.44	2.30	1.21	86.0	43.3	38.5	41.0	320.1	150.4	96.0	38.9
T6 : T2+ biofert containing N & P carrier.	13.19	3.92	2.50	1.18	179.0	145.7	79.5	47.0	399.6	133.9	85.1	34.6
T7: 100% NPK	12.94	4.08	1.74	0.97	63.3	37.7	40.3	26.1	279.7	105.4	62.4	39.6
CD@5%	4.41	1.26	NS	NS	18.2	21.9	NS	NS	14.8	11.2	NS	NS

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