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Research Article

Evaluation of organic nutrient-management practices in rice (*Oryza sativa*)–tomato (*Lycopersicum esculentum*)–okra (*Abelmoschus esculentus*) system under irrigated conditions

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ABSTRACT

A field experiment was conducted during 2005–06 to 2012–13 on organic nutrient management in rice (*Oryza sativa* L.)–tomato (*Lycopersicum esculentum* L.)–okra (*Abelmoschus esculentus* L.) cropping system under irrigated conditions in a sandy loam soil having *p*H 5.9 and organic carbon 0.76% at Chiplima, Odisha. Eight treatments comprising 5 organic, 2 integrated and 1 inorganic approach of nutrient management were evaluated with 3 replications. Organic source of nutrient supply reduced the system yield by 5.5–12.7% compared to the inorganic source in the first year. However, the mean system yield of 'conversion period' (first 3 cropping system cycles) with organic treatment comprising supply of one-third N each through farmyard manure (FYM), green manuring of *dhaincha* (*Sesbania cannabina*) or vermicompost and neem oilcake + *Azospirillum* or *Azotobacter* + phosphorus solubilizing bacteria (PSB) was at par with inorganic and integrated approach. The mean system yield from fourth to eighth cropping system cycles ('after conversion period') with organic source of nutrient supply, i.e. FYM + green manuring or vermicompost + neem oilcake + *Azospirillum* or *Azotobacter* + PSB was significantly higher (12%) than that of with inorganic source of nutrient supply, i.e. 100% NPK + $ZnSO_4$ @ 25 kg/ha to rice and 100% NPK + gypsum @ 110 kg/ha + borax @ 10 kg/ha + ammonium molybdate @ 0.8 kg/ha to both tomato and okra. The organic nutrient-management package increased the soil organic carbon and available N, P and K at the end of eighth cropping system cycle over the initial and the buildup was maximum in the soil applied with one-third N each through FYM, *dhaincha*/vermicompost and neem oilcake + *Azospirillum*/ *Azotobacter* + PSB. The microbial population in terms of colony-forming units increased in a higher rate in soils with organic nutrient-supply system (bacteria 32.4 to 37.1%, fungi 30.2 to 34.4% and actinomycetes 29.3 to 35.9%) compared to the inorganic source of nutrient supply system (bacteria 11.2%, fungi 5.5% and actinomycetes 11.3%) after eighth cropping system cycle over initial status. The microbial biomass carbon of the soils with organic sources of nutrient supply was enhanced considerably (53.4% to 61.8%) over the initial level (104.7 to 118.2 μg C/g).

Key words : Cropping system, Microbial biomass carbon, Organic sources of nutrient supply, Soil microbial population, Sustainable yield index, System yield

Rice–rice is the predominant cropping system in the Hirakud command area of western Odisha. Cropping systems involving cereal after cereal for years had led to mining of nutrients from the soil which resulted in deterioration of soil health (Porpavai *et al*., 2011). Inclusion of vegetables in the cropping system was more beneficial than cereals after cereals (Sharma *et al*., 2007), as it increased system productivity and sustained the soil health. A few farmers prefer vegetables during winter (*rabi*) and summer seasons in canal tail-ends where summer rice could experience water scarcity towards the late growth period. Thus, crop diversification during *rabi* and summer seasons plays a significant role in augmenting the farm income per unit area by integrating small duration high value crops with high water and nutrient-use efficiency (Pramanik and Ravisankar, 2007). Rice–tomato–okra has been identified as one of the most productive and profitable cropping systems for the Hirakud command area (OUAT, 2005). Cropping systems involving vegetable crops remove considerable quantum of nutrients from the soil.

With growing concern about the human health, soil

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quality and environmental safety, need has been felt to rethink over the existing agricultural practices, especially the nutrient management (Singh and Chandra, 2011). Thus, organic source of nutrient supply to the vegetable-based cropping systems is being viewed as farming practice with distinct advantages of sustainability of crop production. However, availability of huge quantity of organic manure from an external source is often considered as a problem for the farmers. In this context, practices such as green manuring, recycling crop residues and animal manure and use of vermicompost and biofertilizers are important (Paikaray *et al*., 2002) in cropping systems. Though positive role of these practices on soils and crops has been well documented (Rupela *et al*., 2006), an information on organic package for location-specific cropping system is very meagre to understand the role of organic farming on soil health, production, profitability and sustainability. It is a common belief that yields of several crops are reduced during the initial years under organic farming, but many experiments were conducted only for 3 or 4 years consecutively and often only with a specific crop; rather than in a well-defined high productive cropping system (Dubey *et al*., 2014; Rao *et al*., 2014).

Keeping the above facts in mind, an experiment was designed on rice–tomato–okra system with various organic and integrated nutrient-management practices and tested for consecutive 8 years to study and compare the overall productivity of the system to find out the impact of various nutrient-management practices on system productivity and soil properties.

MATERIALS AND METHODS

A long-term (8 years) field experiment was conducted from 2005–06 to 2012–13 in Hirakud command irrigated condition at Regional Research and Technology Transfer Station, Orissa University of Agriculture and Technology, Chiplima, Odisha (21°38' N, 83°90' E, 144 m above mean sea-level). Hirakud command area belongs to Typic Haplustalfs. It has a hot humid climate with mean annual rainfall of 1,496 mm. The mean maximum and minimum temperature were 33.8 and 22.0°C respectively. The soil was sandy loam, having *p*H 5.9, organic carbon 0.76%, available N, P and K of 294.2, 10.1 and 121.4 kg/ha respectively. The experiment was laid out in randomized block design with eight treatments (as detailed in Table 1), replicated thrice.

The organic sources of nutrients used in the experiments were FYM (N, P, K 0.58, 0.29, 0.66%), vermicompost (N, P, K 1.67, 1.04, 1.59%), neem (*Azadirachta indica*) oilcake (N, P, K 4.38, 0.89, 1.35%), green manuring of *dhaincha* (*Sesbania cannabina*) (N, P, K 2.86, 0.59, 1.21%) and biofertilizers such as *Azotobacter*, *Azospirillum* and phosphate-solubilizing bacteria (PSB). The inorganic sources were N, P and K containing fertilizers such as urea, single superphosphate and muriate of potash, respectively, zinc sulphate (21% Zn), gypsum (21% Ca, 17% S), borax (10% B) and ammonium molybdate (52% Mo). Soil samples were drawn at initial and at the end of each cropping system cycle (up to eighth cropping system cycle) from a depth of 0–15 cm from each treatment and soil organic carbon (SOC), N, P and K content were analysed using standard procedures (Jackson, 1973). A portion of fresh soil samples were passed through a 2-mm sieve and stored at 4°C for determination of microbial population (Dhingra and Sinclair, 1993) and soil microbial biomass carbon (MBC) (Vance *et al*., 1987). The MBC was estimated from the equation, MBC = 2.64 Ec, where Ec is the difference between organic carbon extracted from the K_2SO_4 extract of fumigated and non-fumigated soils.

In case of organic nutrient management, all manures were applied before final land preparation for transplanting of rice and at planting of tomato and okra. In case of inorganic nutrient management, full quantity of P and K were applied basal in all the crops and N was applied in split doses. In rice, 25% of N was applied basal, 50% of N was top-dressed at tillering and rest 25% of N at panicle-initiation stages. In tomato and okra, 50% of N was applied basal and remaining N was applied in 2 equal split doses–25 and 45 days after planting. Standard agronomic management practices were followed for all the crops. The test varieties for rice, tomato and okra were 'Khandagiri', 'Utkal Kumari' and 'Utkal Gaurav' respectively.

Crop yields were recorded at the end of each season and rice equivalent yield (REY) was computed at the end of each cropping system cycle. System yield was obtained by adding REY of component crops and prices were used from eighth cycle for all the years.

The first 3 cropping system cycles were taken as 'conversion period' and the next 5 years' yields were taken as 'after conversion period' and the mean yields of 'conversion period' and 'after conversion period' were calculated. Overall mean yield was also calculated taking yields of all the 8 years. The treatment with recommended dose of inorganic nutrients (100% NPK + $ZnSO_4$ @ 25 kg/ha to rice and 100% NPK + gypsum @ 110 kg/ha + borax @ 10 kg/ha + ammonium molybdate @ 0.8 kg/ha to both tomato and okra) was taken as reference treatment and increase or decrease in system yield was calculated for the 'conversion period', 'after conversion period' and 'overall mean' over this treatment for comparison. Economic efficiency in terms of ₹/ha/day was worked out by net returns of the system divided by 365 days. For economic analysis (cost of cultivation and gross return) cost of inputs and price of outputs were used from eighth cycle (2012–13) for all the years. Sustainable-yield index (SYI) for each treatment was also calculated using standard procedure. Statistical analyses were carried out using standard methodology of randomized block design.

RESULTS AND DISCUSSION

Crop yields and system yield

The individual crop yields and system yield in terms of rice-equivalent yield (REY) in the first cropping system cycle were highest with 50% of the RDF + 50% of N as FYM, which was closely followed by the recommended dose of fertilizers (RDF) including secondary and micronutrients (zinc sulphate to rice, gypsum, borax and ammonium molybdate to tomato and okra) (Table 2). Application of 50% N as FYM + *Azospirillum* + rock phosphate (RP) + PSB recorded the lowest yield during the first year and the reduction in system yield was 12.7% compared to inorganic sources. Even supplementing the RDF with crop residue recycling could not improve the yield of the crops; rather it reduced the system yield by 4.9%. However, reduction in yields due to replacement of chemical fertilizers with organics decreased after the first year and in the 'conversion period'. After the first 3 cropping system cycles, the mean system yield with FYM + green manuring or vermicompost + neem oilcake + *Azospirillum* or *Azotobacter* + PSB was on par with inorganic treatment. Integrated approach of 50% RDF + 50% of N as FYM increased the mean system yield by 2.4% over the inorganic treatment; however, the other organic treatments without rock phosphate and biofertilizers gave low yields. Dubey *et al*. (2014) observed the similar results in rice–potato–okra system.

After conversion period (fourth to eighth cropping system cycles), all the organic nutrient-management practices except one (50% N as FYM + *Azospirillum* + RP + PSB) increased the individual mean crop yields and mean system yields over the inorganic treatment (Table 2). The increase in mean system yield of fourth to eighth cropping system cycles in the treatment with FYM + green manuring or vermicompost + neem oilcake + *Azospirillum* or *Azotobacter* + PSB was the highest (11.9%). The trend was also same for the overall mean yield (first to eighth cropping system cycle).

The lower yield under organic treatment during conversion period might be related to the still continuing phase of

Table 1. Details of organic nutrient management treatments in rice–tomato–okra system

Treatment	*Kharif* (rice)	*Rabi* (tomato)	Summer (Okra)
T_1	50% N as RDF + 50% N as FYM (8 t/ha)	50% RDF + 50% N as FYM (10 t/ha)	50% RDF + 50% N as FYM (8 t/ha)
T_2	Different organic sources equivalent to 1/3 of recommended N (1/3 N as FYM @ 5.5 t/ha, 1/3 N as *dhaincha*, 1/3 N as neem	Different organic sources equivalent to 1/3 of recommended N (1/3 N as FYM @ 6.7 t/ha, 1/3 N as vermicompost, 1/3 N as neem oilcake)	Different organic sources equivalent to 1/3 of recommended N(1/3 N as FYM @ 5.5 t/ha, 1/3 N as vermicompost, 1/3 N as neem oilcake)
T_3	Same as T_2	Same as T_2	T_2+ cowpea (*Vigna sinensis*) as a trap crop (1:1) in additive series
T_4	T_2 + manual weed control + biopesticides (neem oil and pot manure*)	T_2 + manual weed control + biopesticides (neem oil and pot manure*)	T_2 + manual weed control + biopesticides (neem oil and pot manure*)
T_5	50% N as FYM + *Azospirillum* + RP + PSB (soil application)	50% N as FYM + *Azotobacter* + RP + PSB (soil application)	50% N as FYM + *Azotobacter* + RP + PSB (soil application)
T_6	T_2 +*Azospirillum* + PSB	T_2 + *Azotobacter* + PSB	T_2 + *Azotobacter* + PSB
T_7	100% NPK + $ZnSO_4$ @ 25 kg/ha	100% NPK + gypsum @ 110 kg/ha + borax @ 10 kg/ha + ammonium molybdate @ 0.8 kg/ha	100% NPK + gypsum @ 110 kg/ha + borax @ 10 kg/ha + ammonium molybdate @ 0.8 kg/ha
T_8	T_7 + crop residue recycling**	T_7 + crop residue recycling**	T_7 + crop residue recycling**

RDF, recommended dose of fertilizers; FYM, farmyard manure; RP, rock phosphate; PSB, phosphate-solubulizing bacteria
RDF (in kg N-P-K kg/ha): rice, 80–17.5–33; tomato, 100–33–33; okra, 80–17.5–33
*Pot manure or *handi khata* as locally called is prepared with karanja leaves (*Pongamia pinnata*) 0.5 kg, bel (*Aegle marmelos*) leaves 0.5 kg, *arakha* leaves (*Calotropis* sp.) 1 kg, neem (*Azadirachta indica*) leaves 1 kg, jaggery 0.2 kg, cow urine 2 litres and fresh cow dung 1 kg. All the materials and chopped leaves are kept inside an earthen pot and thoroughly mixed. Then the mouth of pot is covered and kept under shade. After a week, another 2 litres of cow urine is poured inside the pot. In 3 weeks, the manure is ready to use in crop fields. The liquid extract is diluted with water and sprayed on the plants; **after harvesting the total quantity of plant residues was incorporated in the soil of the respective plots. On an average, rice straw 3.8 t, tomato haulm 3.0 t and okra plant residue 4.2 t/ha were available for recycling. Average nutrient content, rice straw N 0.43, P 0.24, K 1.33%, tomato haulm N 1.76, P 0.09, K 1.09% and okra plant residue N 1.89, P 0.38, K 2.09%

transition from conventional to organic agriculture (Surekha and Satishkumar, 2014) and relatively slow release of nutrients from organics. However, presence of organic matter after conversion period improved the physico-chemical properties of soil (Table 5) and reduced nutrient loss from the soil which might have resulted in increased productivity by increasing availability of plant nutrients (Chaudhary and Thakur, 2007). Further, organic matter also maintained regular supply of macro- and micronutrients in optimal congruence with crop demand which might have improved its yield attributes and yield.

Sustainable-yield index

Application of one-third N each through FYM, green manuring of *dhaincha* and neem oilcake + *Azospirillum* + PSB to rice followed by FYM + vermicompost + neem oilcake + *Azotobacter* + PSB to both tomato and okra recorded the highest sustainable yield index of 0.83. Application of 50% N as FYM + *Azospirillum* + RP + PSB to rice and 50% N as FYM + *Azotobacter* + RP + PSB to both tomato and okra recorded the lowest sustainable yield index of 0.75 (Table 2).

System economics

Application of one-third N each through FYM, green manuring of *dhaincha* and neem oilcake + *Azospirillum* + PSB to rice followed by FYM + vermicompost + neem oilcake + *Azotobacter* + PSB to both tomato and okra recorded the highest mean (first to eighth cropping system cycles) gross return ₹259,483/ha (Table 3). However, the highest system net returns ₹1,00,679 with highest benefit: cost ratio and economic efficiency were realized with application of 100% NPK + $ZnSO_4$ @ 25 kg/ha to rice and 100% NPK + gypsum @ 110 kg/ha + borax @ 10 kg/ha + ammonium molybdate @ 0.8 kg/ha to tomato and okra. This was due to higher cost of cultivation in case of organic treatment which also include transportation cost of huge quantity of organic manure. Organic treatment incurred about ₹35,000/ha more cost than the inorganic treatment which restricted the net return/ha.

Nutrient uptake

The pattern of total nutrient uptake (Table 4) almost followed the trend of the system yield. In the first year, the maximum nutrient uptake was obtained in the integrated nutrient-management treatment closely followed by inorganic treatment. On the other hand, the crops under organic treatment involving FYM + green manuring or vermicompost + neem oilcake + *Azospirillum/Azotobacter* + PSB removed the maximum nutrients when averaged over the 8 cropping system cycles. The same treatment also recorded the highest increase in system-nutrient up-

Table 2. Effect of nutrient-management practices on crop yields (t/ha) in rice–tomato–okra cropping system

Treatment	Initial yield level (first year)				Mean yield of 'conversion period' (first–third cropping system cycles)				Mean yield of 'after conversion period' (fourth–eighth cropping system cycles)				Overall mean yield (first–eighth cropping system cycles)				SYI
	Kharif	*Rabi*	Summer	REY	*Kharif*	*Rabi*	Summer	REY	*Kharif*	*Rabi*	Summer	REY	*Kharif*	*Rabi*	Summer	REY	
T_1	5.61	13.88	4.80	20.07	5.20	13.91	5.37	20.20	4.45	15.69	6.08	21.39	4.73	15.02	5.82	20.95	0.82
T_2	4.85	12.30	5.00	18.35	5.06	13.10	5.32	19.43	4.34	15.78	5.60	20.91	4.61	14.78	5.50	20.36	0.81
T_3	4.99	12.52	4.88	18.52	5.37	13.23	5.11	19.64	4.60	16.06	5.63	21.40	4.89	15.00	5.44	20.74	0.82
T_4	4.78	12.44	5.05	18.42	4.80	13.33	5.28	19.29	4.47	16.01	5.62	21.22	4.59	15.00	5.49	20.50	0.80
T_5	4.79	11.75	4.55	17.48	4.71	12.72	4.77	18.30	4.18	14.76	5.34	19.76	4.38	14.00	5.12	19.21	0.75
T_6	4.80	13.08	5.05	18.90	5.14	13.50	5.47	19.93	4.68	16.90	6.76	23.11	4.85	15.62	6.28	21.92	0.83
T_7	5.82	13.30	4.96	20.01	5.10	13.54	5.26	19.73	4.17	15.56	5.69	20.66	4.52	14.80	5.53	20.31	0.81
T_8	5.43	13.27	4.35	19.03	5.20	13.48	5.16	19.69	4.31	15.52	5.71	20.79	4.64	14.76	5.50	20.37	0.80
SEm±	0.16	0.26	0.10	0.33	0.08	0.13	0.08	0.22	0.07	0.23	0.16	0.36	0.06	0.17	0.13	0.29	–
CD (P=0.05)	0.47	0.76	0.30	0.98	0.24	0.38	0.24	0.65	0.21	0.68	0.47	1.06	0.19	0.50	0.39	0.85	–

Details of treatments are given in Table 1; REY, rice equivalent yield; SYI, sustainable yield index take (14.4, 12.6 and 19.6% higher for N, P and K, respectively) at end of the eighth cropping system cycle over the first cropping system cycle. Higher availability of nutrients under organic sources might have improved the physiological and metabolic activities in crops leading to higher biomass production and higher uptake (Shalini Pilai *et al*., 2007).

Soil organic carbon

The initial status of soil organic carbon (SOC) of the experimental site was medium to high (0.74 to 0.79%). Addition of organic inputs over the years resulted in positive changes in the SOC contents (Table 5) at the end of the eighth cropping system cycle and the increase was 17.9–22.8% over the initial. Continuous addition of inorganic fertilizers, however registered reduction by 10.9% in SOC over the initial status. The higher buildup of SOC in the organic sources applied plots may be attributed to slower breakdown rate (less and constant mineralization rate) and increased above- and below-ground organic residues due to enhanced crop growth (Moharana *et al*., 2012).

Available N, P and K

Significant increase in available N was observed in soils receiving organic nutrients over the initial status (Table 5). However, available N was decreased by 6.1% in the soils receiving nutrients through chemical fertilizers over the initial at the end of eighth cropping system cycle. The gain in available N due to application of organics over inorganic fertilizers was to the tune of 38.6–65.0 kg/ha. The increase in available N is attributed to the increase in SOC and might have been partially due to slow release of N from organics (Gami *et al*., 2001). The buildup of available P in soils receiving organics were 11.0–12.2 kg/ha and the increase was by 13.9–18.4% over the initial status. The increase in available P in soils treated with organics might be due to release of organically bound P during decomposition of organic matter. Continuous application of organics also reduced the activity of polyvalent cations

Table 3. Economics of rice–tomato–okra cropping system

Treatment	Eighth cropping system cycle					Mean of first to eighth cropping system cycles				
	Gross returns (×10³ ₹/ha)	Total cost (× 10³ ₹/ha)	Net returns (× 10³ ₹/ha)	Economic efficiency (₹/ha/day)	Benefit: cost ratio	Gross returns (× 10³ ₹/ha)	Total cost (× 10³ ₹/ha)	Net returns (× 10³ ₹/ha)	Economic efficiency (₹/ha/day)	Benefit: cost ratio
T_1	245.0	134.8	110.2	302	1.82	229.9	134.8	95.1	261	1.71
T_2	224.9	158.8	66.2	181	1.42	225.1	158.8	66.4	182	1.42
T_3	231.9	158.8	73.1	200	1.46	230.4	158.8	71.6	196	1.45
T_4	244.5	161.8	82.8	227	1.51	237.3	161.8	75.5	207	1.47
T_5	239.6	130.7	108.9	298	1.83	231.5	130.7	100.8	276	1.77
T_6	254.9	162.0	92.9	255	1.57	259.5	162.0	97.5	267	1.60
T_7	238.3	127.1	111.2	305	1.88	227.8	127.1	100.7	276	1.79
T_8	217.8	131.6	86.3	236	1.66	212.0	131.6	80.4	220	1.61

Details of treatments are given in Table 1; Sale Price (₹/t): rice grain, 11,000; rice straw, 1,000; tomato, 8,000; okra, 10,000

Table 4. System nutrient uptake (kg/ha) under various nutrient management practices in rice–tomato–okra cropping system

Treatment	System nutrient uptake by first cropping system cycle			System nutrient uptake by eighth cropping system cycle			Mean system nutrient uptake (first to eighth cropping system cycles)		
	N	P	K	N	P	K	N	P	K
T_1,	302.9	60.7	490.4	318.1	63.5	549.9	319.8	62.6	526.0
T_2,	279.2	55.7	464.0	305.7	59.5	537.8	304.0	57.7	511.9
T_3,	283.0	60.2	467.0	310.4	64.6	545.5	311.4	63.8	522.8
T_4,	286.2	58.7	467.5	318.3	63.3	550.4	314.4	61.3	521.6
T_5,	266.7	53.2	444.8	288.0	55.7	507.8	292.3	55.9	494.3
T_6,	282.1	56.3	475.8	322.7	63.4	568.8	342.5	71.5	568.7
T_7,	302.6	61.1	486.5	301.0	60.1	527.7	314.3	61.2	522.2
T_8,	284.9	56.4	470.0	306.2	59.5	540.4	308.2	58.6	516.1
SEm±	4.53	1.06	5.35	5.24	1.42	6.10	5.45	1.81	7.96
CD (P=0.05)	13.51	3.17	16.02	15.62	4.25	18.12	10.80	5.40	23.72

Details of treatments are given in Table 1 such as Ca, Fe and Al due to chelation thereby reducing the P-fixation (Gupta *et al*., 1988). Soils treated with organics exhibited an increase in available K (16.7–20.9%) over the initial (118.4–123.2 kg/ha), which can be attributed to the increased cation-exchange capacity due to elevated SOC.

Microbial population

The population of bacteria, fungi and actinomycetes in the soils receiving nutrients from various organic sources was increased by 30.2 to 34.4, 30.2 to 34.4 and 29.3 to 35.9% respectively, after eighth cropping system cycle over the initial status as against the respective increases of 11.2, 5.5 and 11.2% in the soils receiving nutrients through chemical fertilizers (Table 6). Increased organic carbon content of the soil due to application of various organic nutrients over the years served as a source of energy for biological activity thereby enhancing the density of microbes (Singh *et al*., 2008). Further, most of the soil microorganisms are chemo-autotrophs, which require organic source of carbon as food and oxidation of organic substances provides energy which might be the reason in improving microbial population in soils applied with organics (Ingle *et al*., 2014).

Soil microbial biomass carbon

The microbial biomass carbon (MBC) in the soils under organic nutrient practices was enhanced considerably (53.4–61.8%) over the initial (104.7–118.2 μg C/g) (Table 6). The soils with inorganic fertilization on the other hand registered the minimum gain (8.7%) in soil microbial biomass carbon over the initial (107.7 μg C/g). The higher MBC in soils receiving organics is related to higher microbial population due to balanced supply of nutrients and carbon (Basak *et al*., 2012). The good quality organic inputs in the soil have a potential to augment soil-enzymatic activities and improve the microbial biomass carbon and organic carbon (Nath *et al*., 2012).

Table 5. Changes in physico-chemical properties under organic nutrient-management practices in rice–tomato–okra cropping system

Treatments	Initial						After eighth cropping system cycle					
	BD (g/cc)	WHC (%)	SOC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	BD (g/cc)	WHC (%)	SOC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
T_1	1.46	44.3	0.74	292.4	10.9	126.4	1.43	46.3	0.82	319.2	11.6	134.0
T_2	1.46	44.2	0.75	293.2	10.4	123.2	1.40	48.2	0.90	351.0	11.9	146.4
T_3	1.47	44.9	0.79	300.6	10.1	123.0	1.39	48.9	0.96	360.8	11.5	143.6
T_4	1.46	44.2	0.76	296.4	10.2	122.3	1.41	47.8	0.92	355.2	11.8	144.4
T_5	1.47	44.7	0.74	272.2	9.5	118.4	1.43	46.7	0.88	328.8	11.0	138.6
T_6	1.46	44.0	0.75	285.2	10.3	121.8	1.40	48.5	0.93	347.5	12.2	147.2
T_7	1.46	44.4	0.78	309.2	9.7	119.4	1.46	45.2	0.69	290.2	8.4	114.4
T_8	1.47	43.9	0.78	304.6	9.8	116.8	1.44	46.1	0.84	322.6	10.1	131.8

Details of treatments are given in Table 1; SOC, soil organic carbon; BD, bulk density; WHC, water-holding capacity

Table 6. Changes in microbial attributes under organic nutrient management practices in rice–tomato–okra system

Treatment	Initial				After eighth cropping system cycle			
	Microbial population in cfu/g dry soil			MBC (μg C/g)	Microbial population in cfu/g dry soil			MBC (μg C/g)
	Bacteria (×10⁷)	Fungi (×10⁴)	Actinomycetes (×10⁶)		Bacteria (×10⁷)	Fungi (×10⁴)	Actinomycetes (×10⁶)	
T_1	20.3	13.2	12.6	108.3	25.2	15.4	14.9	143.3
T_2	22.1	12.7	12.8	112.4	29.7	16.7	17.1	179.3
T_3	21.5	12.8	13.2	115.7	28.9	17.0	17.3	182.3
T_4	19.7	13.0	12.5	104.7	26.9	17.3	16.8	168.3
T_5	20.7	12.9	13.3	111.3	27.4	16.8	17.2	170.7
T_6	21.3	13.1	12.8	118.2	29.2	17.6	17.4	191.3
T_7	20.6	12.8	12.5	107.7	22.9	13.5	13.9	120.3
T_8	22.1	12.6	12.6	105.3	26.4	14.4	14.8	137.3
SEm±					1.37	0.58	0.50	4.70
CD (P=0.05)					4.16	2.30	1.51	14.26

Details of treatments are given in Table 1; MBC, microbial biomass carbon in soil; cfu, colony forming units

It can be concluded that application of one-third N each through FYM, green manuring of *dhaincha* and neem oilcake + *Azospirillum* + PSB to rice followed by FYM + vermicompost + neem oilcake + *Azotobacter* + PSB to both tomato and okra are essential for rice–tomato–okra system for improving soil health and crop productivity under organic management in Hirakud command areas.

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