Environment & Ecology 35 (2) : 717—723, April—June 2017
Website: environmentandecology.com ISSN 0970-0420

Soil Microbial Properties as Affected by Short-Term Contrasting Tillages and Cropping Systems in a Rainfed Agro-Ecosystem of Northern Odisha

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Received 27 May 2016; Accepted 29 June 2016; Published online 15 July 2016

Abstract Conservation agriculture (CA) has been proposed as a portential system for improving soil organic matter and microbial attributes in the rainfed agro-ecosystem under the hilly tracts of North Odisha and the impact was assessed after 3rd cropping cycle. The treatments comprised of conventional tillage (CT) and minimum tillage (MT) with sole maize (M) and inter crop maize + cowpea (M+C) in main-plots during wet season and horsegram (H), Toria mustard (T) and no cover crop (NCC) in sub-plots during dry season. Residue buildup and reduced soil disturbance in MT elevated the SOC (+27.9%, + 15.2%, MBC (+ 115.1%, + 66.5%), population of bacteria (+61.2%, + 23.0%), fungi (+36.8%, +28.2%) and actinomycetes (+34.6%, +25.3%) over the initial status in the layers of 0—5 and 5—10 cm. The microbial quotient in MT soils (2.03%) was more than CT soils (1.53%) and solis under cover crops (1.83%) was higher than that of NCC (1.68%) in the surface layers (0—5 cm). The metabolic quotient in soils under MT was 37.9 and 21.4% lower than the soils under CT in top two layers indicating more efficient microbial community in MT soils. These soil microbial properties were shown to be sensitive indicators of long-term tillage management under rainfed agro-ecosystem.

Keywords Tillage, SOC, Microbial quotient, Basal respiration, qCO_2.

Introduction

The undulating hilly terrains under rainfed agro ecosystem on Northern Odisha are coarse textured, low in soil organic matter (SOM) and are highly susceptible to soil degradation. Growing monoculture of maize in intense tillage systems render the soils unproductive. Conservation agriculture (CA) with minimum tillage (MT) along with residue retention has been identified as an alternative to restore the SOM and consequently may cause a shift in the microbial community. A large and diverse soil microbial biomass pool and a high biological activity are fundamental for sustainable agricultural management [1]. The

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Table 1. Effect of tillage methods and cropping systems on soil organic carbon (SOC) and microbial biomass carbon (MBC). CT: Conventional tillage, MT: Minimum tillage, M: Maize, C: Cowpea, NCC: No cover crop, H: Horsegram, T: Mustard.

	SOC (g kg^{-1})			MBC (µg C g^{-1} soil)		
Treatments	0–5 cm	5–10 cm	10–20 cm	0–5 cm	5–10 cm	10–20 cm
Main plot						
CT-M	5.78	5.21	4.67	86.9	83.4	78.0
CT-M+C	6.51	5.64	4.80	101.2	91.2	80.9
MT-M	8.36	7.09	4.84	162.3	124.9	72.5
MT-M+C	9.08	7.74	5.08	191.7	136.9	76.5
LSD (0.05)	0.48	0.47	NS	10.98	10.68	NS
Sub plot						
NCC	6.88	6.04	4.76	118.5	99.6	74.5
H	7.99	6.70	4.93	150.5	116.1	78.6
T	7.43	6.52	4.86	137.6	111.6	77.8
LSD (0.05)	0.32	0.27	NS	9.32	4.44	NS
Initial	6.82	6.44	4.72	82.3	78.6	74.7

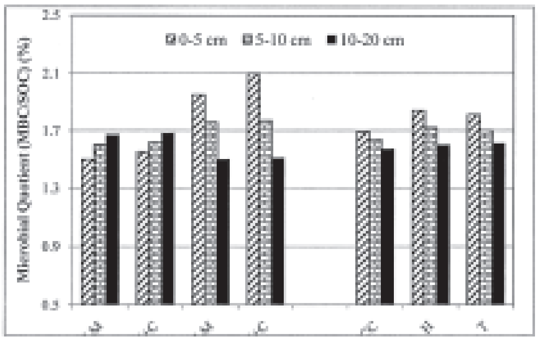

Fig. 1. Effect of tillage methods and cropping systems on microbial quotient.

accumulation of organic matter in soil, proceeding from organic amendments and/or crop litter, stimulates microbial and fungal communities and has a positive effect on the physico-chemical properties of the soil matrix [2]. Increased soil organic matter content associated with conservation tillage practices not only improves soil structure and water retention, but also serves as a nutrient reservoir for plant growth as well as a substrate for soil microorganisms [3]. In conventional agriculture, tillage has generally the greatest impact on biological properties since physical disturbance changes soil water content, temperature, aeration, and the degree of mixing of crop residues within the soil matrix [4]. Conservation agriculture constitutes the most important change in soil management in modern agriculture and soil under CA also showed higher microbial activities and better physical properties compared with corresponding soils under traditional tillage [5]. Microbial biomass measurements can detecttillage and crop rotation effects on soil earlier than total organic C or N measurements in soil [6]. Biological indicators, especially those related to soil microbial communities, are increasingly used to assess the changes due to soil management due to their quick response, high sensitivity, ecological relevance, and capacity to provide information that integrates many environmental factors [7, 8].

Little is known about the rate at which soil microbiological properties change following the introduction of a new agricultural management practice. The objective of the present study is to assess the impact of contrasting tillage practices on soil organic carbon (SOC), microbial biomass carbon (MBC), microbial quotient, metabolic quotient and microbial population for soils in a rainfed agro ecosystem under North central plateau zone of Odisha after three successive years.

(The authors are grateful to the research project SMARTS (Sustainable Management of Agro-ecological Resources for Tribal Societies), an Orissa University of Agriculture and Technology (Odisha, India) and University of Hawaii, Manoa (USA) collaborative program for logistics and technical support provided during the research).

Materials and Methods

A field experiment was conducted from 2011 at Regional Research and Technology Transfer Station of Orissa University of Agriculture and Technology, Kendujhar (20°50´E, 85°34´N, and 499 m above mean sea level), Odisha, India. The climate of the location is hot, moist sub humid with mean annual rainfall of 1527 mm, 75% of which, is received in the months from July to September. The landscape of the study area is a piedmont plain and the soil formed from colluvial alluvial deposits belongs to Fluventic

Table 2. Impact of tillage methods and cropping systems on bacteria and fungal population. CT: Conventional tillage, MT: Minimum tillage, M: Maize, C: Cowpea, NCC: No cover crop, H: Horsegram, T: Mustard.

Treatments	Bacteria ($\times 10^6$ cfu g^{-1}) 0–5 cm	0–5 cm	0–5 cm	Fungi ($\times 10^4$ cfu g^{-1}) 0–5 cm	5–10 cm	10–20 cm
Main plot						
CT-M	19.56	19.56	19.56	12.73	9.88	8.52
CT-M+C	23.56	23.56	23.56	13.62	10.44	9.16
MT-M	26.67	26.67	26.67	15.67	11.49	9.21
MT-M+C	30.00	30.00	30.00	16.53	12.63	9.89
LSD (0.05)	1.68	1.68	1.68	1.15	1.40	NS
Sub plot						
NCC	21.75	21.75	21.75	13.29	10.21	8.86
H	27.25	27.25	27.25	15.63	11.68	9.42
T	25.83	25.83	25.83	15.00	11.44	9.31
LSD (0.05)	1.31	1.31	1.31	1.31	0.56	NS
Initial	17.56	17.56	17.56	11.77	9.44	8.37

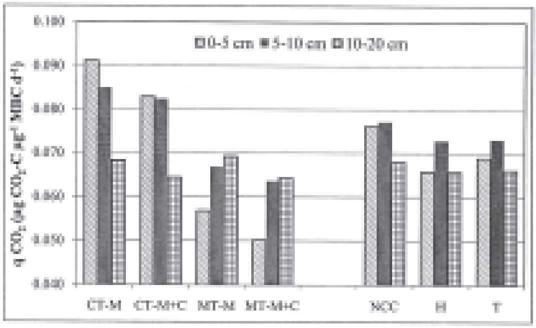

Fig. 2. Metabolic quotient (q CO_2) as influenced by tillage methods and cropping systems.

haplustepts. The surface texture is sandy clay loam surface texture. The treatments are conventional tillage (CT) and minimum tillage (MT) with sole maize (M) and maize + cowpea intercrop (M+C) in main plots during dry season and fallow (NCC), horsegram (H) and toria mustard (T) in subplots during dry season, resulting a total of 12 treatment combinations. The experiment was designed in split plots with three replications. The CT is characterized by three mould board ploughing to a depth of 20–25 cm without residue and the MT involves one shallow disking up to a depth of 10 cm with addition of chopped main crop (maize, cowpea) and cover crop (horsegram, toria mustard) biomass as surface residues. The soil samples from individual experimental plots drawn from depth of 0–5, 5–10 and 10–20 cm after the end of 3rd cropping cycle (2014) were placed in plastic bags and brought to the laboratory immediately for analysis. A portion of fresh soil samples were sieved through a 2 mm sieve and stored at 4°C for determination of microbial population [9] and MBC. The MBC was measured by determining the organic carbon in chloroform fumigated and non-fumigated soils by dichromate digestion or described by Vance et al. [10]. 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. Soil respiration was measured as CO_2 evolution according to Alef [11]. Soil samples were placed in 300 ml glass containers closed with rubber stoppers, moistened at 60% of the maximum water holding capacity and incubated for 7 day sat 25°C. Glass vials holding 10 ml of 0.5 N NaOH to trap the evolved CO_2 were placed in the above containers. On day 7 after the incubation, the glass vials were removed and the CO_2 trapped in NaOH was determined by titration. The metabolic quotient (qCO_2) was obtained by dividing the basal respiration by the microbial biomass C. Another portion of the sieved soils were air dried (2–3 days) and used for determination of organic carbon [12].

Results and Discussion

Soil organic carbon

The soils under MT exhibited significantly higher SOC (+27.9% and +15.2%) in the top layers of 0–5 and 5–10 cm over the initial status at the end of 3rd cropping cycle (Table 1). The corresponding decrease of SOC for the same layers under CT was in the tune of -9.8% and 15.7%. Growing of cover crops also elevated the SOC pool over NCC by +13.0% in 0–5 cm layer and +2.6% in 5–10 cm layer. The soils in the deeper layer of 10–20 cm did not show any significant variation in SOC irrespective of different tillage methods and cropping systems.

The increase of SOC in the MT with cropping

Table 3. Actionomycetes and soil basal respiration as influenced by tillage methods and cropping systems. CT: Conventional tillage, MT: Minimum tillage, M: Maize, C: Cowpea, NCC: No cover crop, H: Horsegram, T: Mustard.

Treatments	Actinomycetes ($\times 10^6$ cfu g^{-1}) 0–5 cm	5–10 cm	10–20 cm	Soil basal respiration ($\mu g\ CO_2$-C g^{-1} day^{-1}) 0–5 cm	5–10 cm	10–20 cm
Main plot						
CT-M	13.73	11.26	9.50	7.87	7.08	5.33
CT-M+C	14.48	11.82	9.96	8.37	7.51	5.21
MT-M	16.69	13.23	10.15	9.19	8.39	5.02
MT-M+C	17.14	13.83	10.53	9.50	8.68	4.92
LSD (0.05)	1.07	1.88	NS	0.44	0.41	NS
Sub plot						
NCC	14.35	11.91	9.75	8.40	7.54	5.06
H	16.25	12.95	10.27	9.05	8.20	5.16
T	15.94	12.76	10.10	8.75	7.94	5.14
LSD (0.05)	0.93	0.62	NS	0.20	0.18	NS
Initial	12.56	10.77	9.43	7.83	7.12	5.18

systems is due to greater surface accumulation of residue in puts and less oxidation of *in situ* organic matter due to the absence of tillage and absence of soil redistribution. Elevated SOC concentration due to absence of soil inversion was also reported by Jemai et al. [13] and Choudhury et al. [14]. The soils under CT, in contrast, exhibited higher degradation of macro-aggregate induced by intense soil disturbances exposing the formerly incorporated SOC stocks to microbial decomposition [15] in the top layers.

Microbial biomass
carbon (MBC)

MT system significantly enhanced the MBC of soils by 115.1% and 66.5% over the intitial status of 82.3 and 78.6 μg C g^{-1} in the layers of 0–5 cm and 5–10 cm, respectively and the corresponding increase in these layers over CT system were 88.1% and 49.9% (Table 1). Accumulation of crop residues through cover crops elevated the MBC of soils by 21.5% and 14.3% as compared to NCC treatments (118.5 and 99.6 μg C g^{-1}) in the top two layers (0–5 and 5–10 cm). The MBC of soils under different treatments decreased from surface to downwards and at 10–20 cm layer, no significant variation could be observed.

Accumulation of concentration C input in the top few centimeters results an increase in MBC near the soil surface and it increases much more readily due to changes in tillage system and residue supply [16]. Balota et al. [17] have reported that the fresh SOM at the surface moderates the soil temperature and moisture that is conducive to microbial activity and higher MBC. From the contrasting profiles of MBC observed in MT and CT systems, it may be deduced that the high SOC near the soil surface is maintained or that the enrichment will be even continued, whereas, in the deeper MT layers (10–20 cm), low MBC values indicate a decline in SOM contents. Similar relations of SOC with MBC in contrasting tillage systems were reported by Doran [18] and Carter [19]. The contribution of SOC to MBC is justified by their significant positive correlation (r=0.98** and 0.99**) in the layers of 0–5 and 5–10 cm.

Microbial population

Bacteria

The population of bacteria in different layers was enhanced as compared to the initial status irrespective of tillage methods and cropping systems (Table 2). In the surface layer (0–5 cm), an increase of 61.2% and 23.0% over the initial population of 17.6×10^6 cfu g^{-1} was observed in MT and CT treatments, respectively. Similar treand was also observed in the layer of 5–10 cm and no significant changes in bacterial population could be noticed among treatments below the depth of 10 cm. Higher amounts of organic matter in MT soils increased the bacterial abundance significantly to the tune of 31.0% and 25.5% over the CT soils in the top two layers (0–5cm and 5–10 cm). Again, practice of cover crops enhanced the bacterial proportion by 21.8% and 20.1% over no cover crop treatments (NCC) in the layers of 0–5 cm, and 5–10 cm, respectively.

Fungi

Differential status of organic matter among treatments influenced the population of fungi in the soil. The soils under MT registered the maximum fungal population and gain was of 36.8% and 28.2% over the initial values (11.8 and 9.4×10^4 cfu g^{-1}) in the layers of

0–5 cm and 5–10 cm, respectively (Table 2). The treatments under CT too exhibited an increase of 12.1% and 8.1% over the initial status (base year) in the top two layers. Cover cropping also enhanced the fungal population in the tune of 15.1% in 0–5 cm layer and 13.6% in 5–10 cm layer over NCC treatments. The fungal population in 10–20 cm layer did not show significant changes among various treatments.

Actinomycetes

Accumulation of residue inputs under MT treatments enhanced the actinomycetes population by 34.6% and 25.3% over the initial status (12.6 and 10.8×10^6 cfu g^{-1}) in the layers of 0–5 cm and 5–10 cm, respectively (Table 3). Soils of these two layers under MT treatments also registered significantly higher population of actinomycetes (19.6% and 17.4%) over CT treatments. Growing of follow-up cover crops enhanced the actinomysetes population in the tune of 12.2% and 8.3% over the NCC treatments (14.3 and 11.9×10^6 cfu g^{-1}) in the top two layers. No significant difference in the status of actinomycetes population could be observed among treatments in the bottom layer (10–20 cm).

Soil microbial biomass, even though represents only a small proportion of overall SOM, it is more dynamic than total SOM and a better indicator of how tillage and cropping systems impact soil health and productivity. Increased soil organic matter content due to residue buildup and reduced soil disturbance enhanced the population of bacteria, fungi and actinomycetes up to a depth of 0–10 cm under MT, which could be related to availability of higher amounts of substrates for microorganisms (3. 20]. Higher microbial biomass and diversity because of residue retention under reduced tillage has also been reported by Govaerts et al. [21]. Deeper in the soil profiles (10–20 cm), the negligible difference between the tillage treatments is due to lower and even distribution of SOC in MT and CT, respectively. One explanation for the effect of MT on microbial biomass is that low-tilled soils provide a more favorable habitat for microorganisms [17]. The significant positive correlation of SOC with population of bacteria (r=0.91** and 0.77**), fungi (r=0.86** and 0.88**) and actinomycetes (r=0.87** and 0.86**) indicates the contribution of SOC on microbial density in the top soil layers (0–5 and 5–10 cm).

Microbial quotient

The microbial quotient is the ratio of MBC to SOC expressed as ratio or percentage and it is very often used as a measure of C availability to micro-organisms. The microbial quotients from the soils of different layers were presented in Fig. 1. In the surface layer (0–5 cm), the microbial quotient of MT soils was more (2.03%) than CT soils (1.53%) and soils under cover crops (1.83%) was more than that of NCC (1.68%). A similar trend was also observed in the layer of 5–10 cm. However, the soils of the bottom layer (10–20 cm) exhibited higher microbial quotient in CT (1.68%) as compared to MT (1.51%). In the top layers of 0–5 and 5–10 cm of MT, the MBC/SOC ratio is much higher, suggesting higher substrate availability through the accumulation of crop residues in the surface soil [22]. On the other hand, in deeper layers (10–20 cm) of MT, the microbial quotient is relatively low indicating on going decline in SOM concentration [16] and the increase of this ratio down the profile in CT may be related to an even distribution of SOC induced by tillage.

Soil basal respiration and metabolic quotient

Long-term tillage had a significant effect on soil basal respiration (BR), particularly in the 0–5 and 5–10 cm soil depths, where MT significantly ($p<0.05$) improved BR by 15 and 17% compared to CT in the top two layers (Table 3). Similarly, cover cropping with horsegram and toria in dry season enhanced the BR by 5.9% to 7% over falow (NCC) in the layers of 0–5 and 5–10 cm, respectively. In the 10–20 cm depth, there was no significant difference in BR between tillage methods and cropping systems. The higher BR in the surface layers under MT is related to more carbon availability in the biomass leading to greater biological activity [23]. Significantly higher BR in MT soils as a consequence of greater microbial biomass was observed by Costantini et al. [24]. Stimulation of elevated CO_2 release indicating better microbial activity with inputs and the maintenance of organic residues has also been reported by Bini et al. [25].

The metabolic quotient (qCO_2) is one of the most used soil stress/disturbance index and decrease in more stable systems [26]. The metabolic quotient, averaged across cropping systems varied from 0.084 to 0.087 under CT and from 0.054 to 0.066 μg CO_2-C μg^{-1} MBC d^{-1} under MT in the top two layers (Fig. 2). The metabolic quotient in soils under MT was 37.9 and 21.4% lower than the soils under CT in 0–5 and 5–10 cm, respectively. Similarly, the soils under cover crops exhibited 10.5 and 5.2% lower metabolic quotient over soils under fallow (NCC) in the top two layers. The efficiency of soil microbial populations in acquiring or utilizing SOC and the intensity of C mineralization are measured by qCO_2. Low values are related with more efficient utilization of C by the microbial community [27], and accordingly MT soils showed a more efficient microbial community than CT soils. A low q CO_2 in MT soils also suggests that soil microorganisms are expending relatively little energy for basic survival and therefore can devote greater resources to growth and such functions as litter decomposition and nutrient cycling [28].

Conclusion

The study show that changes in SOM and microbiological properties can occur within 3 years of a change in tillage and crop residue management practices. The practice of MT with cropping systems elevated the SOC, MBC, microbial population, microbial quotient and lower metabolic quotient up to a depth of 0–10 cm because of residue retention and lower physical soil disturbances. Redistribution of soils under CT, on the other hand, depleted the formerly incorporated SOM imparting negative effect on overall microbial attributes. Hence MT with maize cowpea intercrops and follow-up horse gram as cover crop confirms the benefits associated with the long-term application of this management system in the rainfed hilly agro-ecosystem of North Odisha.

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