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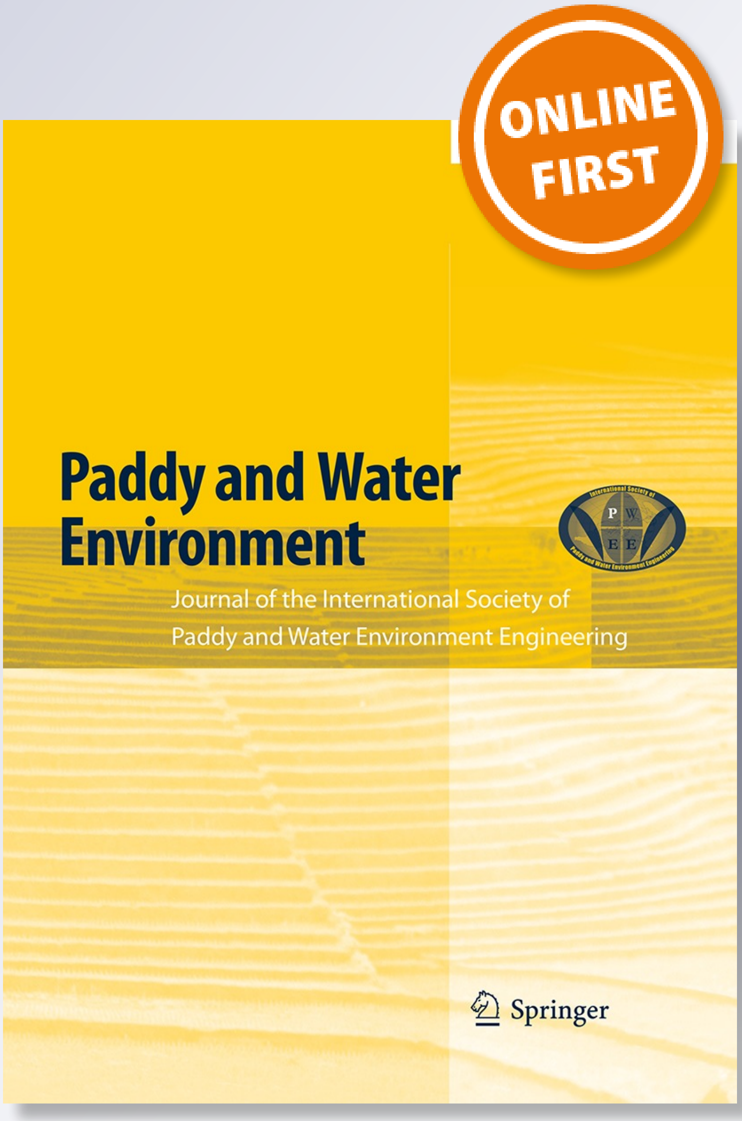

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ARTICLE

Effects of various organic amendments on organic carbon pools and water stable aggregates under a scented rice–potato–onion cropping system

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Abstract Pools of organic carbon are quantified from the soil samples under scented rice crop from different soil layers (0–10, 10–20, and 20–30 cm) under 9 years' long-term trials with five treatments in scented rice–potato–onion cropping system. These treatments were 100 % NPK (NPK), 50 % recommended NPK through mineral fertilizers + 50 % N as FYM (NPK + FYM), FYM + vermicompost (VC) + neem cake (NC) each equivalent to one-third of recommended N (FYM + VC + NC), 50 % N as FYM + biofertilizer for N + bone meal to substitute phosphorus requirement of crops + phosphate solubilizing bacteria (FYM + BFN + BM + PSB), FYM + vermicompost + neem cake each equivalent to 1/3rd of recommended N + PSB (FYM + VC + NC + PSB). SMBC (479 mg kg^{-1}), HWEOC (373 mg kg^{-1}), CWSCHO (235 mg kg^{-1}), HWSCHO (839 mg kg^{-1}), and ASCHO (180 mg kg^{-1}) were found to be the highest in the soil treated with FYM + VC + NC + PSB and the lowest with NPK. The quantity of hot water-extractable carbohydrate content is highest amongst cold water, dilute acid and hot water extractable carbohydrate that decreases with the soil depth irrespective of treatments, except CWEOC. Soil microbial biomass carbon (SMBC) shows significant correlation with CWEOC ($r = 0.60^{**}$), HWEOC ($r = 0.94^{**}$), CWSCHO ($r = 0.75^{**}$), HWSCHO ($r = 0.83^{**}$), and ASCHO ($r = 0.83^{**}$) that primed for better aggregate stability irrespective of soil layers up to 30 cm depth. This indicates that labile carbon pools, most specifically water-soluble carbon, carbohydrate, microbial biomass, could be a suitable indicator for evaluation of soil quality, particularly in relation to soil aggregation.

Keywords Soil microbial biomass carbon · Water-extractable organic carbon · Carbohydrate fractions · Aggregate stability

Introduction

"Organic agriculture- A future conventional production system" had become a key issue for debate since last two decades. Central concept of the debate was whether organic agriculture can produce sufficient food to sustain global food security. Organic farming is believed to be a unique food production system with minimal harm to ecology and environment. It is a nonsynthetic input-based production system, where crop production relies on closed nutrient recycling through returning plant residues and manures from livestock back to the land (Niggli et al. 2009).

India is one of the world's largest producers of cereals, which contributes 3.3 M ha of land under organic management (FiBL and IFOAM 2015), and the second largest producer in Asia where rice is the major staple food followed by wheat. Rice-based cropping systems are fertilizer-responsive cropping system. Indiscriminate use of mineral fertilizer causes harm to soil ecosystem. Organic amendments augment the organic carbon in soil and provide invaluable insight in improving the soil quality and health for sustainable agriculture. It is considered as a critical segment added in soil for its high contribution to soil productivity. The impact of organic amendments in soil health (Doran and Parkin 1994; Masto et al. 2008) and carbon retention (Aoyama et al. 1999a, b; Rudrappa et al.

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2006) in conjunction with mineral fertilizer in rice-based cropping system was studied by several workers, but its sole impact was not enlightened in the past, particularly in nutrient-exhaustive cropping system. Soil microbes are the living part of the soil that contribute to several dynamic microbial transformations. Soil organic matter is the primary energy and carbon source for microbes. The basic understanding of organic amendments application is to maintain microbial activity and organic carbon in soil. Microbial activity is greatly influenced by the dynamics and stability of soil organic matter (Smith and Paul 1990). Three-pool model describes the persistence of soil organic carbon into "active" pool, "slow" pool, and "resistant" (Parton et al. 1988). This "active" pool is greatly influenced by the agronomic practices and other disturbances (Powlson et al. 1987; Lundquist et al. 1999; Tu et al. 2006).

Soil microbial biomass (SMB) represents the total mass of microorganisms present in the soil (Brookes 1995) which has been suggested to be a sensitive indicator of changing soil condition and than total organic carbon content (Powlson and Jenkinson 1976) and water-soluble carbon which includes soluble carbohydrate and their derivatives and small amount of carbon (C) derived from microbial cells (van Ginkel et al. 1994) that acts as carbon source for soil microbes. These fractions are considered as labile/active organic carbon pool (Ghani et al. 1999, 2003; Choudhary et al. 2013). SMBC is considered as a very sensitive index to describe the biological activity whereas water-soluble (cold and hot water) carbon fraction is often used as a sensitive tool for estimating the decomposable SOM in soils (Schulz 2004). Water-soluble (cold and hot water) carbon includes mostly carbohydrates that play major role in increasing the supply of nutrient and improving soil aggregation (Cheshire 1979; Yousefi et al. 2008). The present study focuses on long-term dynamics of carbon in the scented rice–potato–onion cropping system under humid subtropical climate. Our hypothesis of the study is that organic farming would have higher labile SOC pools and improved aggregation than integrated nutrient management and balanced fertilization. Considering all these facts, the work has been carried out to study the effect of organic amendments on organic carbon pools and aggregate stability and to find out suitable indicator for soil quality in a silt loam textured soil.

Materials and methods

This study was carried out as a part of the network project research program entitled "Development of organic farming package for system based high value crops" of Project Directorate of Farming System Research, Modipuram (Now Indian Institute of Farming System Research) under scented rice–potato–onion cropping system initiated during the period 2004–2005 at Bihar Agricultural College Research Farm (24°13′N, 87°3′E and 12 m above mean sea level), Sabour. Sabour is situated at Bhagalpur district of Bihar in Eastern India under subtropical region of temperate zone with humid subtropical climate. Initially, soil was of silt loam texture (Sand 35.6 %, silt 53.1 % and clay 11.3 %), alkaline in nature (pH 8.1), and medium in soil organic carbon (5 g kg^{-1}) with low available nitrogen (153.4 kg N ha^{-1}), high available phosphorus (26.9 kg P_2O_5 ha^{-1}) and medium available potassium (122 kg K_2O ha^{-1}).

The study was conducted in a field experiment comprising 5 different combinations of treatments having plot size of 264 m^2 (22 m × 12 m). Each plot was divided into four quadrants considering each quadrant as a replication in a randomized block design. The five different combinations of treatments were NPK(100 % NPK + secondary and micronutrients based on soil test); NPK + FYM (50 % recommended NPK through mineral fertilizers + 50 % N as FYM + inorganic sources of micronutrient as per soil testing values); FYM + VC + NC [different organic sources each equivalent to one-third of recommended N (FYM + vermicompost + neem cake)]; FYM + BFN + BM + PSB [50 % N as FYM + biofertilizer for N + bone meal to substitute P requirement of crops + phosphate solubilizing bacteria (PSB)]; and FYM + VC + NC + PSB [different organic sources each equivalent to one-third of recommended N (FYM + vermicompost + neem cake) + biofertilizer containing N and P carrier (PSB)] (Table 1). The NPK content of the organics used in the experiment is given in Table 2. The recommended doses of scented rice, potato, and onion are 100 kg N + 40 kg P_2O_5 + 20 kg K_2O ha^{-1}; 150 kg N + 90 kg P_2O_5 + 100 kg K_2O ha^{-1}, and 100 kg N + 80 kg P_2O_5 + 80 kg K_2O ha^{-1}, respectively.

Soil samples were collected from all the quadrants in every plots at three different depths (0–10, 10–20, and 20–30 cm) after the harvesting of scented rice crop in October, 2013. Soil organic carbon was determined by the dichromate digestion method (Walkley and Black 1934), mean weight diameter was determined by wet aggregate stability method (Yoder 1936; Kamper and Rosenau 1986), and total soil organic carbon was estimated by trapping evoluted CO_2 after wet oxidation (Snyder and Trofymow 1984). Field soil samples were stored in a refrigerator (4 °C) and used for analyzing water-extractable carbon pools and soil microbial biomass carbon (SMBC).

Soil microbial biomass carbon was estimated by chloroform-fumigation extraction method (Vance et al. 1987). Cold water-extractable organic carbon was determined by shaking soil and distilled water in 1:5 ratio for 30 min and then centrifuging for 10 min at 5000 rpm (Ghosh 2003). Hot water-extractable organic carbon was determined by heating soil and water in a 1:5 ratio up to moderate boiling

Table 1 Treatment details

Notation	Treatment details	Remarks
NPK	100 % NPK + secondary and micronutrients based on soil test	Balanced fertilization
NPK + FYM	50 % recommended NPK + 50 % N as FYM + inorganic sources of micronutrients as per soil test	Integrated nutrient management
FYM + VC + NC	Different organic sources each equivalent to 1/3 of recommended N (FYM + Vermicompost + Neem cake)	Organic farming
FYM + BFN + BM + PSB	50 % N as FYM + biofertilizer for N + bone meal to substitute P requirement of crops + phosphate solubilizing bacterial (PSB) culture	
FYM + VC + NC + PSB	T_3 + biofertilizer containing N and P carriers (PSB)	

Table 2 Nutrient content in organic sources used

Organic sources	N %	P	K
Farm yard manure (FYM)	0.50	0.30	0.40
Vermicompost (VC)	1.20	1.80	0.50
Neem cake (NC)	5.40	1.10	1.50
Bone meal (BM)	–	23.0	–

for 1 h under reflux condensers (Schulz 2004). The water extractable (cold and hot water) organic carbon (WEOC) in the supernatant was measured by the dichromate digestion method (Walkley and Black 1934).

The carbohydrate fractions were determined in three types of soil extracts, viz. cold water soluble, hot water soluble, and dilute acid soluble by mixing soil with cold distilled water (at 25 °C and shaking for 16 h), hot distilled water (at 85 °C and heated for 2.5 h), and H_2SO_4 (0.25 M and shaking for 16 h), respectively, in 1:10 ratio. All the three types of soil suspension were centrifuged at 3000 rpm for 30 min. After centrifugation, supernatant solution was used to determine carbohydrate concentration using phenol–sulfuric acid method (Dubois et al. 1956; Yousefi et al. 2008) using glucose standard.

The data were analyzed using analysis of variance (ANOVA) and are reported with Duncan's Multiple Range Test ($P < 0.05$) for comparing the means of the treatments. Correlation and regression analyses were also done to evaluate the relationships among the various parameters. Statistical analysis was performed by Microsoft Excel (Microsoft Corporation, USA) and SPSS window version 16.0 (SPSS Inc., Chicago, USA).

Results and discussion

Soil organic carbon

Long-term fertilization with different organic or inorganic amendments changes the Soil organic carbon (SOC) with respect to initial value. The amount of SOC was significantly increased in all the treatments over NPK irrespective of soil depths. The highest amount of SOC was obtained for FYM + VC + NC + PSB (7.5 g kg^{-1} at 0–10 cm soil depth) treatment and the lowest quantity for NPK (5.0 g kg^{-1} at 20–30 cm soil depth) treatment. At a soil depth of 0–10 cm, SOC increased by 17, 16, 12, and 11 %, with the application of FYM + VC + NC + PSB, FYM + VC + NC, FYM + BFN + BM + PSB, and NPK + FYM over the treatment NPK, respectively. Similar trend was observed in case of soil depth 10–20 cm in respect of the above-mentioned different treatments over the treatment NPK (Fig. 1). SOC was decreased with increase in soil depth as shown in Fig. 1. SOC was estimated to be more on surface soil compared to subsurface due to addition of root biomass, root exudates, and plant biomass by the different treatments (Padre et al. 2007; Brar et al. 2013).

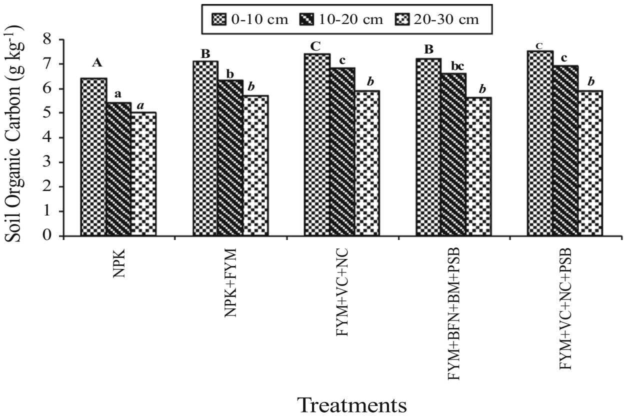

Fig. 1 Effects of long-term fertilization on soil organic carbon estimated by Walkley–Black method in different soil depths (0–10, 10–20, and 20–30 cm). **Bars* represent mean values with *the same letter* denoting that they are not significantly different at $P < 0.05$ using Duncan's Multiple Range Test

Mean weight diameter

Mean weight diameter (MWD) is an important structural index, whose higher value indicates better aggregation that imparts better soil quality. Long-term fertilization with different organic amendments significantly increases the MWD over the NPK treatment. The MWD of water stable aggregates was found to be highest in treatment FYM + VC + NC + PSB followed by FYM + VC + NC > NPK + FYM > FYM + BFN + BM + PSB > NPK (Fig. 2). The decrease in MWD with depth may be due to the low organic matter content, although it was applied in the surface soil. MWD of water stable aggregates increased by 51, 50, 31, and 25 % in the treatments FYM + VC + NC + PSB, FYM + VC + NC, NPK + FYM, and FYM + BFN + BM + PSB, respectively, over NPK in soil at surface layer (0–10 cm). Similar trend was found at subsurface layer (10–30 cm). MWD of water stable aggregates increased by 36, 34, 27, and 20 % and 30, 26, 12, and 4 percent at the depth of 10–20 and 20–30 cm respectively (Fig. 2).

Microbial biomass carbon

Long-term fertilization significantly increases the soil microbial biomass carbon (SMBC) in various treatments supplied with organic amendments in comparison with NPK application in all the soil layers (Table 3). The SMBC in the of 0–10 cm soil layer was observed to be the highest in the treatment FYM + VC + NC + PSB (479 mg kg^{-1} soil), while in the soil layer of 20–30 cm it was observed to be the least in the NPK (183 mg kg^{-1} soil) treatment. Surface soils are mostly enriched with the leftover crop and root biomass, and hence have higher MBC (Gupta et al. 1994; Rudrappa et al. 2006). The soil amended with VC and NC like FYM + VC + NC and FYM + VC + NC + PSB has higher SMBC values in comparison with the soil amended with BM like FYM + BFN + BM + PSB. Therefore, the addition of VC and NC provides favorable condition than BM for microbial activity and in turn increase in biomass C. Addition of PSB improves the microbial activity and increases the biomass C and so the treatment FYM + VC + NC + PSB has higher SMBC compared to FYM + VC + NC. Overall, the treatments with organic amendments approximately show 1.5–2 times increase in SMBC values than NPK application. This is due to addition of organic amendments that improve the soil properties and create a favorable soil environment for improving biological and microbial activities (Rao et al. 2004; Choudhary et al. 2013) that resulted in increased SMBC.

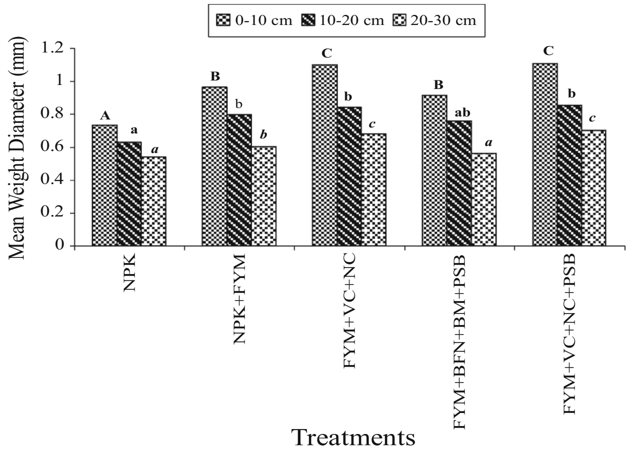

Fig. 2 Effects of long-term fertilization on mean weight diameter (mm) in different soil depths (0–10, 10–20, and 20–30 cm). **Bars* represent mean values with the *same letter* denoting that they are not significantly different at $P < 0.05$ using Duncan's Multiple Range Test

Table 3 Effects of long-term fertilization on soil microbial biomass carbon (SMBC) of the different soil depths

Treatments	SMBC (mg kg^{-1} soil) Soil depth (cm)		
	0–10	10–20	20–30
NPK	226a	230a	183a
NPK + FYM	316b	272a	237b
FYM + VC + NC	460d	388c	321c
FYM + BFN + BM + PSB	400c	334b	308c
FYM + VC + NC + PSB	479e	403c	338c

Values denoted with same letter are not significantly different at $P < 0.05$ using Duncan's Multiple Range Test

The SMBC decreases with increase in soil depth. Trend of SMBC in soil layers is 0–10 > 10–20 > 20–30 cm. The decline in SMBC on increase in soil depth was due to the deterioration in soil characteristics, viz. soil organic carbon, water holding capacity, bulk density, etc., that governs the microbial activities in the soil (Choudhary et al. 2013).

Water-extractable organic carbon (WEOC)

Treatments supplied with organic amendments increase the cold Water-extractable organic carbon (CWEOC) compared to sole inorganic fertilizer but the obtained value does not show a particular trend in different soil layers (Table 4) as cold water may be not a suitable extractant for estimating water-soluble carbon. The CWEOC in soil depth 0–10 cm was found to be the highest in case of treatment with FYM + BFN + BM + PSB (27.5 mg kg^{-1} soil) and the least in case of that with NPK application (20.7 mg kg^{-1} soil), while in the soil depth of 10–20 cm the CWEOC was observed to be the highest in the treatment FYM + BFN + BM + PSB (29.6 mg kg^{-1} soil) and the least in that of NPK (20.1 mg kg^{-1} soil).

Table 4 Effects of long-term fertilization on cold water-extractable organic carbon (CWEOC) and hot water-extractable organic carbon (HWEOC) of the different soil depths (0–10, 10–20 and 20–30 cm)

Treatments	Soil depth (cm)					
	CWEOC			HWEOC		
	0–10 (mg kg^{-1} soil)	10–20	20–30	0–10	10–20	20–30
NPK	20.7a	20.1a	18.4a	200a	183a	172a
NPK + FYM	21.3a	20.5a	19.8a	292b	212a	195b
FYM + VC + NC	23.8ab	26.1b	21.2a	355d	298b	235c
FYM + BFN + BM + PSB	27.5c	29.6c	18.2a	314c	202a	192b
FYM + VC + NC + PSB	26.6bc	31.7c	22.8a	373d	310c	246c

Values denoted with same letter are not significantly different at $P < 0.05$ using Duncan's Multiple Range Test

Long-term fertilization with organic amendments significantly increases the mean hot water-extractable organic carbon (HWEOC) in various treatments over NPK fertilizer (Table 4). Among all the treatments, the HWEOC was observed to be the highest in the treatment with FYM + VC + NC + PSB (373 mg kg^{-1} soil, soil depth 0–10 cm) and the lowest in the treatment with NPK application (172 mg kg^{-1} soil, soil depth 20–30 cm). Numerous studies have explained that WEOC was observed to vary with the addition of organic amendments (Leinweber et al. 1995; Zsolnay and Gorlitz 1994; Marinari et al. 2010). According to Schulz et al. (2011), HWEOC forms a potential source of readily decomposable SOC. Körschens and Schulz (1999) proposed HWEOC classes based on the ratings of soil layer 0–10 cm: medium class (200–400 mg kg^{-1}) and low to medium (low 0–200, medium 200–400 mg kg^{-1}) in the deep layers of soil. HWEOC increased by 87, 78, 57, and 46 % in the treatment FYM + VC + NC + PSB, FYM + VC + NC, FYM + BFN + BM + PSB, and NPK + FYM, respectively, over NPK in a soil at a depth of 0–10 cm. Similarly, HWEOC increased by 69, 62, 16, and 10 % in the treatment FYM + VC + NC + PSB, FYM + VC + NC, NPK + FYM, and FYM + BFN + BM + PSB at a soil depth of 10–20 cm and 43, 37, 13, and 12 % in the treatment FYM + VC + NC + PSB, FYM + VC + NC, NPK + FYM, and FYM + BFN + BM + PSB, respectively, at a soil depth of 20–30 cm over NPK application. HWEOC continuously decreases in the soil depth in the order of 0–10 cm > 10–20 cm > 20–30 cm. The higher water-soluble carbon forms in surface layer might be due to the addition of plant residues and microbial activity. Similar results were reported by Brar et al. 2013.

The values of HWEOC are higher than those of CWEOC which is due to more labile carbon extracted by the hot water in comparison with cold water. The hot water extracts 10–15 times more labile carbon than the cold water. HWEOC represents a particular trend in comparison with CWEOC and thus serves as a stable soil lability indicator.

Carbohydrate

Cold water-soluble carbohydrate (CWSCHO) significantly increases in different organically amended treatments compared with sole inorganic fertilized soil but the obtained value does not show a particular trend in different soil layers (Table 5) as cold water does not dissolve carbohydrate carbon in a ideal way. The CWSCHO was found to be the highest in the soil treated with

Table 5 Effects of long-term fertilization on cold water-soluble carbohydrate (CWSCHO), hot water-soluble carbohydrate (HWSCHO), and acid-soluble carbohydrate (ASCHO) of the different soil depths (0–10, 10–20, and 20–30 cm)

Treatments	Soil depth (cm)								
	CWSCHO			HWSCHO			ASCHO		
	0–10 mg kg^{-1} soil	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30
NPK	114a	81a	97a	423a	227a	227a	149a	105a	93a
NPK + FYM	172b	154bc	116ab	497a	359b	301b	174bc	137b	96a
FYM + VC + NC	205cd	176c	152b	733c	400c	297b	166b	119ab	104a
FYM + BFN + BM + PSB	189c	154bc	150b	622b	366b	213a	156ab	121ab	95a
FYM + VC + NC + PSB	235d	131b	114ab	839d	486d	329b	180c	139b	106a

Values denoted with same letter are not significantly different at $P < 0.05$ using Duncan's Multiple Range Test

FYM + VC + NC + PSB in the 0–10 cm soil layer (235 mg kg^{-1} soil) and lowest in NPK (81 mg kg^{-1} soil) in the 10–20 cm soil layer.

Hot water-soluble carbohydrate (HWSCHO) significantly increased with combined application of organic amendments compared with NPK application irrespective of the soil depth. The concentration of HWSCHO increased by ~86, 61, 46, and 26 % in the treatment FYM + VC + NC + PSB, FYM + VC + NC, FYM + BFN + BM + PSB, and NPK + FYM, respectively, over NPK at a soil depth 0–30 cm. According to Haynes et al. (1991), hot water-extractable carbohydrate changes more rapidly than the organic C on adding organic manures. Here, it has been observed that hot water-extractable carbohydrate showed rapid increase in the different organic matter supplied treatment compared to SOC. The HWSCHO showed a decreasing trend in its content with increase in depth. This may be due to the decrease in organic matter content as well as microbial activity with increase in depth (Yousefi et al. 2008).

Trend of acid-soluble carbohydrate (ASCHO) is different from HWSCHO. The ASCHO was found to be the highest in the soil supplied with FYM + VC + NC + PSB (180 mg kg^{-1} soil, 0–10 cm) and lowest with NPK application (93 mg kg^{-1} soil, 20–30 cm). Treatment supplied with organic and inorganic fertilizer (NPK + FYM) showed higher acid extractable carbohydrate than the treatment supplied with FYM + VC + NC and FYM + BFN + BM + PSB. The ASCHO showed a decreasing trend in its content with increase in soil depth (Table 5).

The overall values of the different carbohydrates suggest that hot water extracts the highest carbohydrate followed by acid extracts and the lowest with cold water extracts. FYM + VC + NC + PSB is the best treatment in terms of carbohydrate content while NPK application as the lowest carbohydrate-containing treatment. This shows that adding organic manure and the higher return of crop residues in the soil increases the carbohydrate content in the different treatments supplied with organic amendments (Debosz et al. 2002; Xiao et al. 2006; Yousefi et al. 2008).

Table 6 presents the relationship among various organic carbon pools with one another in different soil depths. SMBC had a positive and highly significant correlation with CWEOC ($r = 0.60$**, $n = 15$), HWEOC ($r = 0.94$**), CWSCHO ($r = 0.75$**), HWSCHO ($r = 0.83$**), and ASCHO ($r = 0.83$**). These show that addition of organics to the soil increases microbial biomass and ultimately carbon and carbohydrate concentrations. Sparling et al. (1998) found a linear relationship and reasonable correlation between hot water-extractable C and microbial biomass C ($R^2 = 0.79$, $P < 0.001$). Thus, the combined application of organic manures triggered microbial activity,and hence more microbial biomass C and ultimately higher HWEOC. Guan et al. (1997) and Ghosh (2003) also reported a close relationship of SMBC with CWEOC and HWEOC. CWEOC had a positive and significantly correlated with HWEOC ($r = 0.53$*). This represents that on increase in organic amendments result into increase in quantity of CWEOC and HWEOC. The amount of carbon extracted by hot water also represents that fraction of labile carbon which can be extractable by cold water and acid. HWSCHO had a positive and highly significant correlation with CWSCHO ($r = 0.72$**) and ASCHO ($r = 0.90$**). The carbohydrate content increases on increase in organic matter and the hot water extract the maximum portion of the cold water and acid extractable carbohydrate.

In general, MWD was correlated with SOC, HWEOC, HWSCHO, ASCHO, and SMBC to assess the role of carbon and carbohydrate fractions in the aggregate stabilization of different soil layers. The results are presented in Table 7, showing that both carbon and carbohydrate fractions, typically hot water-soluble fraction, are correlated positively and highly significantly ($P < 0.01$) with MWD. The high correlation coefficient values mean that both carbon and carbohydrate fractions were contributing to aggregate stabilization of soil particles. Carbon and carbohydrate act as binding agents for soil aggregates and increases the macro aggregation in soil and in turn MWD (Haynes and Beare 1996; Yousefi et al. 2008). SMBC is

Table 6 Pearson's correlation matrix among soil microbial biomass carbon (SMBC), cold water-extractable organic carbon (CWEOC), hot water-extractable organic carbon (HWEOC), cold water-soluble carbohydrate (CWSCHO), hot water-soluble carbohydrate (HWSCHO), and acid-soluble carbohydrate (ASCHO)

	SMBC	CWEOC	HWEOC	CWSCHO	HWSCHO	ASCHO
SMBC	1					
CWEOC	0.60**	1				
HWEOC	0.94**	0.53*	1			
CWSCHO	0.75**	0.35	0.74**	1		
HWSCHO	0.83**	0.49*	0.91**	0.72**	1	
ASCHO	0.66**	0.41	0.79**	0.68**	0.90**	1

* Significance at $P < 0.05$; ** significance at $P < 0.01$

Table 7 Relationship between organic carbon pools and aggregate stability

Soil depths	Regression equations	R^2
0–10 cm	MWD = 2.934SOC − 1.1452	0.92**
	MWD = 0.0142CWEOC + 0.6304	0.35
	MWD = 0.0021HWEOC + 0.311	0.95**
	MWD = 0.0025CWSCHO + 0.5499	0.76*
	MWD = 0.0008HWSCHO + 0.4776	0.88**
	MWD = 0.009ASCHO − 0.5045	0.76*
	MWD = 0.0013SMBC + 0.4758	0.91**
10–20 cm	MWD = 1.3519SOC − 0.0942	0.94**
	MWD = 0.0078CWEOC + 0.5935	0.47
	MWD = 0.0012HWEOC + 0.4875	0.83*
	MWD = 0.002CWSCHO + 0.5026	0.81*
	MWD = 0.0009HWSCHO + 0.4512	0.94**
	MWD = 0.0048ASCHO + 0.1728	0.78*
	MWD = 0.001SMBC + 0.4513	0.85*
20–30 cm	MWD = 1.657SOC − 0.3103	0.84*
	MWD = 0.011CWEOC + 0.407	0.57
	MWD = 0.0023HWEOC + 0.1366	0.98**
	MWD = 0.0005CWSCHO + 0.5742	0.14
	MWD = 0.0014HWSCHO + 0.2524	0.89**
	MWD = 0.0127ASCHO − 0.6246	0.91**
	MWD = 0.0009SMBC + 0.3721	0.77*

MWD mean weight diameter, *SOC* soil organic carbon, *CWEOC* cold water-extractable organic carbon, *HWEOC* hot water-extractable organic carbon, *CWSCHO* cold water-soluble carbohydrate, *HWSCHO* hot water-soluble carbohydrate, *ASCHO* acid-soluble carbohydrate, *SMBC* soil microbial biomass carbon

* Significance at $P < 0.05$; ** significance at $P < 0.01$

enhanced with microbial activity and due to addition of more crop residue. This contributes in soil aggregate stability. The HWEOC, HWSCHO, ASCHO and SMBC can be used as an index of soil quality, particularly in relation to soil aggregation. Table 6 clearly represents that among all carbon and carbohydrate fractions, hot water-extractable forms are more closely correlated to aggregate stability in comparison with cold water-extractable and acid-soluble forms (Angers et al. 1993).

Contribution of various organic carbon pools towards TOC

Table 7 presents contribution of various organic carbon pools towards TOC. A perusal of data revealed that the application of organic amendments either in combination with other organics or with mineral fertilizer contributes more towards TOC except CWEOC, CWSCHO, and ASCHO because no particular trends appear on application with organics when extracted with cold water- and acid-soluble forms. Among all various pools, HWSCHO was found to be the highest contributor than other organic carbon pools, and also the treatment FYM + VC + NC + PSB had the maximum contribution among all treatments. The contribution of CWEOC towards TOC, however, did not vary much under different treatments. The trend of contribution towards depth is in decreasing order 0–10 > 10–20 > 20–30. This may be due to the decrease in the microbial activity as well as crop residue amount with increase in soil depth.

Conclusion

Long-term combined application of variable organic amendments made a positive influence on the different organic carbon pools in comparison with the integrated nutrient management and balanced fertilization. SMBC, CWEOC, and HWEOC in general increased with the increasing organic matter addition. Carbohydrate fractions such as CWSCHO, HWSCHO, and ASCHO also found to increase in soils treated with organic amendments. The quantity of carbohydrate fractions extracted increase in the order of cold water, dilute acid, and hot water extracts. All labile pools of carbons decrease with increase in soil depth irrespective of treatments, except CWEOC because of ease in solubility with percolating water. MWD is positively and highly significantly correlated to the SMBC, hot water, and acid extracts. There was significant variation found in the labile carbon pools under present best management practices, e.g., integrated nutrient management and balanced fertilization and future best management practice, i.e., organic farming. So, the labile pools of carbon, i.e., water-soluble carbon, carbohydrate, microbial biomass, could be a sensitive indicator to judge the effectiveness of any management practices in the light of soil quality. This study could be an insight for beneficial aspects of organic farming but before making this *conventional* other aspects of farming system like sustainability and impacts on yield, most importantly the availability of organic amendments to the farming community must be ensured.

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