



Soil organic carbon stocks and carbon dynamics under organic and conventional farming systems in Indo-Gangetic Plains

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ABSTRACT

The long-term effect of organic farming practices were evaluated on soil organic carbon stocks (SCS) and its fractions in texturally divergent soils of Haryana. Surface (0-15 cm) soil samples were collected from 25 organic farms and adjoining conventional farms from 11 districts of Haryana. Soil samples were analyzed for pH, EC, calcium carbonate (CaCO_3), soil organic carbon (SOC) and its fractions, viz. light fraction C (LOC), particulate organic C (POC) and mineral associated C (MOC). Results revealed that shifting from conventional to organic farming had no effect on soil pH and EC but reduced the CaCO_3 significantly ($P < 0.05$). Soil under organic farming exhibited a significant increase in the SOC from 5.1 to 6.2 g/kg and SCS from 11.2 to 13.3 Mg/ha as compared to soils under conventional farming. The light fraction C was most sensitive to management practices, followed by POC and MOC fraction. The magnitude of increase in LOC, POC and MOC under organic soils was 48.9, 23.6 and 14.7%, respectively as compared to conventionally managed soils. Different organic carbon pools in various fractions followed the order $\text{MOC} > \text{POC} > \text{LOC}$. The study concluded that shift from conventional to organic farming could be adopted or promoted for sustainable management of soil organic C stocks.

Key words: Carbon fractions, Carbon stocks, Farming practices, Soil organic carbon

The major challenge for Indian agriculture in the coming era will be to meet the ever increasing demands for food, fibre and energy, while maintaining or sustainings oil fertility and productivity (Gopalasundaram *et al.* 2012). Adoption of different farming systems could either have positive or negative effects on the accumulation of carbon by influencing the amount and type of residues incorporated to the soil (Campbell *et al.* 2000) and the rate of decomposition of plant residues and organic matter. Though with the introduction of high nutrient responsive dwarf varieties and increased use of chemicals fertilizers coupled with better irrigation facilities, the area along with the production and productivity of crops increased significantly in the Indo-Gangetic plains (IGPs) between 1960s and 1990s (Kataki *et al.* 2001) but now there are reports of declining or stagnating crop yields (Ladha *et al.* 2003) and thus sustainability of the different farming systems is now under threat. The fundamental reasons for turning down or stagnation of crop yields are not specifically identified, but it can be attributed to changes in quality and quantity of organic matter (SOM) content in soil (Benbi *et al.* 2012a, 2015) and a steady decline in the nutrient supplying capacity of soils, causing widespread macro

and micro nutrient deficiencies and imbalances (Ladha *et al.* 2003). While some reports on changes in soil organic carbon (SOC) content as a result of continuous intensive farming practices in the IGPs are available (Swarup *et al.* 2000). Generally, SOM is characterized by differentiating it in different pools, i.e. physical, chemical and biological pools (Benbi *et al.* 2016) and it is well established fact that physical fractionation of SOM according to their size and density provides a sound platform for the study of its utility and turnover in soil (Nieder and Benbi 2008). Density fractionation is one of the physical fractionation method which allows the separation of various C pools in soil, including the light fraction, occluded light fraction and heavy fraction (Von Luetzow *et al.* 2007). Therefore, understanding the SOC dynamics and its different fractions in soil is a key element to manage soil organic matter in the present era of intensive cropping system coupled with poor land management practices (Singh and Benbi 2018). The input of C in soil through adoption of management practices like organic farming with addition of organic manures, crop residues, green manuring and other sources of nutrients returns a good amount of carbon to soil. When organic amendments are added to the soil, a very small portion of them are stabilized against microbial attacks as soil organic C and then distributed into different carbon fractions. The real picture of overall sustainability in organic management practices, however, continues to face

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many challenges. Keeping in view the above concerns, the present study was planned with the objective to assess the changes in SOC, its fractions and thereby quantifying the carbon stocks in soils under organic management practices in Haryana, India.

MATERIALS AND METHODS

Organic farms under different cropping systems, vegetables and horticultural, and their adjoining conventional farms were identified in 11 districts of Haryana, viz. Sirsa, Fatehabad, Hisar, Jind, Kaithal, Karnal, Kurukshetra, Ambala, Panchkula, Yamunanagar and Panipat. The soil samples were collected from the experimental sites and analyzed for different soil properties. Total 150 (42-vegetables, 84- field crops and 24- horticultural crops) soil samples (three replications) of 0-15 cm depth were collected from the two types of farming systems, which were pooled to make 50 composite samples and analysed for pH, EC, calcium carbonate (CaCO_3) content, soil organic C and its fractions, i.e. light fraction organic C (LFC), particulate organic C (POC) and mineral associated organic C fractions (MOC) and finally C stocks were estimated. The texture of soils varied from sand to clay loam, representing almost

all the soil types of the State (Table 1), pH and EC were determined in 1:2 :: soil:water suspension using glass electrode (Jackson 1967) and systronics conductivity bridge (Richards 1954), respectively. Calcium carbonate of soil samples were determined by titrating the soil suspension with 0.5N H_2SO_4 in the presence of bromothymol blue and bromocresol green indicators using Puri's (1930) method. Organic C was determined by rapid titration method (Walkley and Black 1934). LFC was isolated as per the method described by Janzen *et al.* (1992). Soil (25 g) was put in a 250 ml plastic bottle and 40 ml of NaI solution was added to it (specific gravity- 1.72) and the suspension was gently shaken for 30 min on shaker. The sample was then transferred to 100 ml beaker. The beakers were covered and the suspension was allowed to equilibrate for 48 h at room temperature. The floating and suspended material (LOC) was aspirated and transferred to a suction filtration unit. The LOC was then washed under suction with 3 successive aliquots of 0.01M CaCl_2 and 3 aliquots of distilled water. After drying overnight at 50°C, the LOC was weighed. The dried LOC were ground and analyzed for total C by dichromate digestion of modified Walkley and Black's rapid titration method as described by Nelson and Sommers (1996).

POC and MOC were estimated as per the method described by Cambardella and Elliott (1992) and Hassink (1995). Soil (50 g) was dispersed in 150 ml of 0.5% sodium hexametaphosphate solution by shaking for 15 h on a reciprocal shaker. The dispersed soil sample was passed through a set of 250 and 53 μm sieves. The material retained on the 53 μm sieve consisted of particulate organic C (53-250 μm size). After rinsing several times with water, the material retained on the sieves was dried at 50°C in a hot-air oven. The slurry that passed through 53 μm sieve comprising silt and clay particles i.e. mineral associated organic C (MOC) was centrifuged and the solution was decanted. The mineral matter was dried at 50°C, weighed and labeled as mineral associated organic C (<53 μm). The dried mineral matter were ground and analyzed for total C by dichromate digestion following modified Walkley and Black's rapid titration method as described by Nelson and Sommers (1996). The soil organic C stocks were calculated using the following equation:

Soil organic C stocks (Mg/ha) = Organic C (%) $\times$ bulk density (Mg/m) $\times$ depth (m) $\times$ 100

The significance of treatment effects was analyzed using two factorial RBD analysis with OP Stat, CCS HAU Hisar software (Sheoran *et al.* 1998). Spatial variability graphs were prepared by using ArcGIS software.

RESULTS AND DISCUSSION

Physico-chemical Properties: Perusal of data on pH, EC and CaCO_3 of soils under organic and conventional farming systems (Table 2) clearly indicated that shifting from conventional to organic farming had no effect on pH and EC, but CaCO_3 content reduced significantly. The pH of soils varied from 8.0 to 8.7 at different locations under both

Table 1 Soil texture at different locations under conventional and organic farming systems

Location	District	Village	Soil texture
L1	Panchkula	Billa	Sand
L2	Sirsa	Mamad Khera	Sand
L3	Panipat	Kurad	Loamy sand
L4	Panchkula	Tabar	Loamy sand
L5	Sirsa	Kharian	Loamy sand
L6	Fatehabad	Zandli Kalan	Loamy sand
L7	Fatehabad	Hasinga	Loamy sand
L8	Hisar	Shahpur	Loamy sand
L9	Hisar	Biyana Khera	Sandy loam
L10	Panipat	Bahuapur	Sandy loam
L11	Jind	Ikkas	Sandy loam
L12	Yamunanagar	Amadapur	Sandy loam
L13	Jind	Balerkha	Loam
L14	Kaithal	Kailram	Loam
L15	Kurukshetra	Mangoli Jattan	Loam
L16	Kaithal	Hajwana	Loam
L17	Hisar	Ramayan Daderi	Loam
L18	Panipat	Sink	Silt loam
L19	Yamunanagar	Kandroli	Silt loam
L20	Fatehabad	GillaKhera	Silt loam
L21	Sirsa	Shahpur Begu	Sandy clay loam
L22	Kaithal	Sikanderpurkheri	Sandy clay loam
L23	Jind	Palwan	Clay loam
L24	Karnal	Kachhwa	Clay loam
L25	Ambala	Sherpur Sulkhani	Clay loam

Table 2 Soil pH, EC and CaCO₃ content under conventional and organic farming systems at different location

Location (L)	pH(1:2)			EC(1:2) (dS/m)			Calcium carbonate (%)		
	Conventional	Organic	Mean	Conventional	Organic	Mean	Conventional	Organic	Mean
L1	8.5	8.5	8.5	0.24	0.14	0.19	2.4	2.5	2.4
L2	8.3	8.2	8.2	0.16	0.12	0.14	3.0	4.6	3.8
L3	8.7	8.7	8.7	0.29	0.23	0.26	3.0	1.9	2.4
L4	8.4	8.5	8.4	0.32	0.46	0.39	2.2	2.3	2.2
L5	8.2	8.3	8.2	0.55	0.72	0.63	5.0	4.6	4.8
L6	8.1	8.2	8.1	0.10	0.08	0.09	2.5	1.3	1.9
L7	8.2	8.1	8.1	0.12	0.07	0.09	4.0	3.0	3.5
L8	8.1	8.2	8.1	0.09	0.10	0.09	1.8	1.6	1.7
L9	8.1	8.1	8.1	0.07	0.10	0.08	0.0	0.0	0.0
L10	8.5	8.6	8.6	0.35	0.15	0.25	0.0	0.0	0.0
L11	8.4	8.4	8.4	0.10	0.24	0.17	0.0	0.0	0.0
L12	8.1	8.1	8.1	0.21	0.09	0.15	2.7	2.0	2.3
L13	8.5	8.3	8.4	0.28	0.36	0.32	3.0	3.2	3.1
L14	8.4	8.3	8.3	0.26	0.28	0.27	3.0	2.6	2.8
L15	8.2	8.3	8.2	0.10	0.32	0.21	2.3	2.7	2.5
L16	8.3	8.4	8.3	0.20	0.35	0.27	3.8	3.4	3.6
L17	8.2	8.0	8.1	0.25	0.20	0.22	0.0	0.0	0.0
L18	8.6	8.5	8.5	0.28	0.36	0.32	2.0	2.3	2.1
L19	8.2	8.2	8.2	0.08	0.12	0.10	2.4	3.6	3.0
L20	8.4	8.2	8.3	0.10	0.25	0.17	4.2	2.5	3.3
L21	8.0	8.2	8.1	0.68	0.25	0.46	0.0	0.0	0.0
L22	8.4	8.1	8.3	0.57	0.20	0.38	2.8	4.1	3.4
L23	8.5	8.5	8.5	0.26	0.23	0.24	0.0	0.0	0.0
L24	8.3	8.3	8.3	0.20	0.15	0.17	3.7	4.0	3.9
L25	8.2	8.3	8.3	0.20	0.23	0.21	3.0	3.2	3.1
Mean	8.3	8.3		0.24	0.23		2.3	2.2	
CD (P=00.5)	Location (L) = 0.2, Farming system (F) = NS, L × F = NS			Location (L) = 0.01, Farming system (F) = NS, L × F = 0.02			Location (L) = 0.08, Farming system (F) = 0.02, L × F = 0.12		

the systems. Although, a slight change in pH was observed upon adoption of organic farming practice but no definite trend was observed between the two systems at different locations. All the soils were non-saline as the EC at different location was less than the critical limit of 0.8 dS/m. The changes in EC of soils upon adoption of organic farming were nonsignificant, however, there was slight reduction from 0.24 to 0.23 dS/m under organic farming system. Data further revealed that the mean CaCO₃ content which was 2.3% under conventional farming system was reduced significantly to 2.2% under organic farming system. This may be due to high buffering capacity based on carbonate contents which resisted change in pH of soils during SOM decomposition under organic farming. Herencia *et al.* (2007) and Abu-Zahra and Tahboub (2008) also reported no difference in soil pH and EC among plots which were managed organically as well as conventionally. The organic acids released during decomposition of relatively higher amount of organic material application in organic farming

system may have solubilized the solid CaCO₃ present in the soils leading to decrease in its content (Thakare *et al.* 2017).

Soil organic C: Soil organic carbon (SOC) content at different locations under both organic and adjoining conventionally cultivated fields is presented in Table 3. Mean soil organic carbon content at different locations varied from 2.7 to 7.1 g/kg. Lowest soil organic carbon content was observed in sand at L₁ (2.7 g/kg) which increased with increase in fineness of soil texture, and maximum value 7.1 g/kg was observed in clay loam at L₂₅. At all the locations, organic farming resulted in a significant increase in SOC. The mean SOC of all the locations was observed to be 5.1 g/kg in conventional farming which increased significantly to 6.2 g/kg under organic farming practice. The interaction between location and farming system was found to be significant. The results of study on SOC support that long-term organic farming increases SOC quite significantly over the conventional system under different crops/cropping systems (Marriott and Wander 2006,

Table 3 Soil organic carbon content (g/kg) and carbon stocks (Mg/ha) under conventional and organic farming systems at different locations

Location (L)	Organic carbon (g/kg)			Soil organic C stocks (Mg/ha)		
	Conven-tional	Organic	Mean	Conven-tional	Organic	Mean
L1	2.4	3.0	2.7	5.9	7.3	6.6
L2	2.5	3.4	3.0	6.1	8.2	7.1
L3	4.2	4.8	4.5	9.8	11.0	10.4
L4	4.3	5.5	4.9	10.2	12.9	11.5
L5	3.8	4.6	4.2	8.8	10.7	9.8
L6	4.2	5.4	4.8	9.8	12.4	11.1
L7	3.9	4.8	4.4	9.2	11.0	10.1
L8	4.0	5.3	4.7	9.1	12.0	10.5
L9	5.5	6.4	6.0	12.2	14.1	13.2
L10	5.2	6.7	6.0	11.3	14.4	12.8
L11	5.2	6.1	5.7	11.6	13.6	12.6
L12	5.5	6.3	5.9	12.5	13.9	13.2
L13	5.9	6.7	6.3	12.0	13.5	12.8
L14	5.9	6.6	6.3	12.7	13.8	13.2
L15	4.9	6.5	5.7	10.4	13.7	12.0
L16	5.4	6.6	6.0	11.7	14.1	12.9
L17	6.1	6.7	6.4	12.9	14.0	13.4
L18	6.3	7.5	6.9	13.0	15.3	14.2
L19	6.5	7.2	6.9	13.6	15.0	14.3
L20	5.9	7.0	6.5	12.4	14.2	13.3
L21	5.6	6.7	6.2	12.0	14.0	13.0
L22	5.9	6.9	6.4	12.7	14.5	13.6
L23	6.3	7.9	7.1	13.1	16.5	14.8
L24	5.9	7.6	6.8	12.6	16.0	14.3
L25	6.4	7.8	7.1	13.8	16.4	15.1
Mean	5.1	6.2		11.2	13.3	
CD (P=00.5)	Location (L) = 0.02, Farming system (F) = 0.01, L×F = 0.04			Location (L) = 0.61, Farming system (F) = 0.17, L×F = 0.86		

Leifeld *et al.* 2009, Aher *et al.* 2015, Jadhav *et al.* 2016, Maharjan *et al.* 2017). Lowest SOC was observed in sand (2.7 g/kg) which increased with increase in fineness of soil texture, and maximum value of 7.1 g/kg was observed in clay loam. This may be due to the fact that SOC tends to increase with the increase in clay content of soil as bonds between clay particles and SOM retards the decomposition process and increase the potential for aggregate formation which physically protect organic matter from microbial attack. An increase in SOC under organic farming may be attributed to several factors but input of organic manures is the most important driver. Typically, organic farming received higher rates of organic manures than conventional system (Leifeld and Fuhrer 2010). Further, greater biomass production (Sihi *et al.* 2012, Munda *et al.* 2013) and higher

rhizode position of carbonaceous materials from the root and sloughed-off tissue have greater soil C sequestration potential under long-term fertilization (Zhao *et al.* 2016) and it can serve as a sustainable option for greenhouse gas mitigation in the agricultural sector (Lal 2004). The SOC content in conventional and organic farming at different locations (Fig 1) showing the variable response of organic farming in enhancing the SOC at individual location.

Soil organic C stocks: Soil organic carbon stocks (SCS) at different locations in both organic and adjoining conventional fields are presented in Table 3. The data revealed that mean soil organic carbon stock (SCS) was highest at location L₂₅ (15.1 Mg/ha C) in comparison with other locations and least at location L₁ (6.59 Mg/ha). Organic farming resulted in a significant increase in SCS from 11.17 to 13.29 Mg/ha over conventional farming. Apart from organic farming system, the texture of soil was also found to influence the SCS under different cropping systems (Fig 2) which increased with increase in clay content of the soil at different locations. The SCS was highest in clay loam soil (15.1 Mg/ha C) in comparison with other soil textures while it was least in sandy soils (6.59 Mg/ha). The possible reason for enhanced SCS under organic farming was possibly due the increased SOC in soil and further relative increase in SOC storage depending upon crop mediated C input, large supply of organic matter and the initial organic C content of soils (Banger *et al.* 2010, Malhi *et al.* 2011, Singh and Benbi 2018). In many other studies, the SOC stocks under organic and conventional systems of farming have been compared (Leifeld and Fuhrer 2010, Canqui *et al.* 2013) and found the organic farming to increase SOC stock. Converting cropland to organic production may thus provide significant GHG reduction opportunities in further by increasing the SCS (Kumar 2012). The relationship of SOC and SCS in soils under organic and conventional farming systems showed that organic farming is very helpful in increasing SOC ($y = 0.831x$) and SCS ($y = 0.842x$) over conventional system in Haryana.

Soil organic carbon fractions: At all the locations, the organic C fractions were significantly affected by the farming systems (Table 4). Adoption of organic farming resulted in significant improvement in LOC from 396 to 590 mg/kg, POC from 1109 to 1371 mg/kg and, MOC pool from 2469 to 2833 mg/kg. The LOC, POC and MOC fractions varied from 163 to 770 mg/kg, 631 to 1717 mg/kg and 1397 to 3413 mg/kg, respectively, at different locations. The magnitude of increase in LOC, POC and MOC fraction was to the tune of 48.9, 23.6 and 14.7 %, respectively, however, the amount in different fractions followed the order MOC > POC > LOC.

Application of organic amendments in organic farming has a major influence on SOC and relative distribution among various C fractions. It was observed that LOC is most sensitive to farming practices, followed by POC and MOC fractions and thereby suggesting that these fractions may be considered as active, slow and passive fractions of soil organic carbon, respectively. The LOC fraction significantly improved from 396 to 590 mg/kg under organic farming

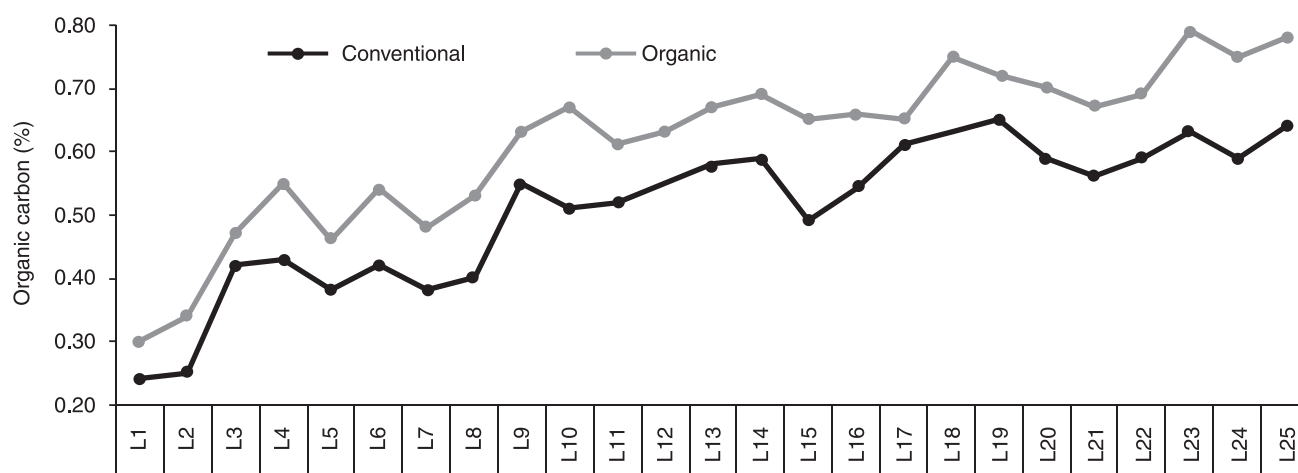


Fig 1 Soil organic C at different locations under conventional and organic farming systems

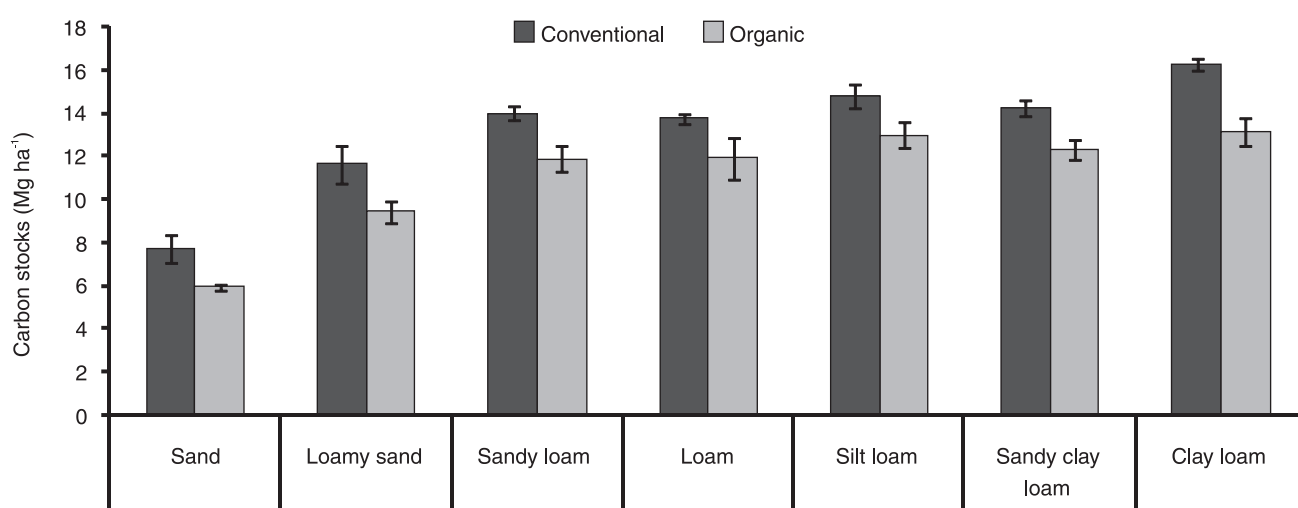


Fig 2 Soil C stocks in different textured soils under conventional and organic farming systems

as compared to conventional farming may be due to the application of organic manures which markedly increases light organic carbon fraction (Gong *et al.* 2009a, Ding *et al.* 2012, Liang *et al.* 2012). Organic manures directly contributes to the soil labile organic carbon fraction (LOC) and enhances microbial activities in organically managed soils thereby increasing the conversion of plant residue carbon into labile fraction of organic carbon (Benbi *et al.* 2012, 2016, Poirier *et al.* 2013, Whalen *et al.* 2014). The POC fraction was significantly increased from 1109 to 1371 mg/kg upon adoption of organic farming practices. The increase in POC fraction under organic farming may also be attributed to addition of organic material (partly or well decomposed), increased the root biomass and microbial biomass entities which are the main source of POC or greater biochemical recalcitrance of root litter (Puget and Drinkwater 2001). The continuous replacement of organic manure on the soil creates a favourable environment for the cycling of C and formation of macroaggregates. Furthermore, POC acts as a cementing agent to stabilize macroaggregates and protect intraaggregate C in the form of POC. Marriott and Wander

(2006) investigated the perceptions about soil organic matter quantity in organically and conventionally managed soils by evaluating the responsiveness to organic management of particulate organic pool. The results revealed that organic management enriched the soil particulate organic carbon by relative to the conventional one 30-40% and the level of enhancement was two to four times greater than that in any other fraction. The effect of organic farming was also found to be prominent on MOC. The MOC fraction increased from 2469 to 2833 mg/kg upon conversion to organic from conventional system of farming. The MOC fraction is considered as passive pool of soil organic carbon as it is more resistant to decomposition by microbial attack and thus the increase was lower as compared to other carbon fractions. It can be implicit that the applied organic manures had different amounts of lignin and polyphenol constituents which are resistant to decomposition and application; these materials with higher contents of such constituents led to formation of stable soil organic complexes which are more resistant to the microbial decomposition than the other forms of soil organic matter (Majumder *et al.* 2008). Moreover,

Table 4 Soil light, particulate and mineral associated carbon fractions under conventional and organic farming systems

Location (L)	Light fraction organic C (mg/kg)			Particulate organic C (mg/kg)			Mineral associated organic C (mg/kg)		
	Conventional	Organic	Mean	Conventional	Organic	Mean	Conventional	Organic	Mean
L1	143	182	163	557	772	665	1425	1672	1549
L2	155	206	181	579	683	631	1284	1509	1397
L3	269	399	334	869	1024	947	2145	2432	2289
L4	300	489	395	967	1254	1110	2300	2756	2528
L5	272	419	345	809	1073	941	2097	2548	2323
L6	342	509	426	1103	1306	1205	2292	2678	2485
L7	286	438	362	923	1123	1023	2235	2667	2451
L8	251	402	327	876	1083	980	2060	2483	2272
L9	462	624	543	1283	1523	1403	2670	3017	2844
L10	435	684	559	1208	1668	1438	2398	2852	2625
L11	391	479	435	1086	1168	1127	2256	2339	2298
L12	355	561	458	1025	1369	1197	2444	2649	2547
L13	460	569	515	1179	1489	1334	2841	3018	2930
L14	378	655	516	1093	1522	1308	2670	3085	2878
L15	489	674	582	1219	1568	1393	2252	3179	2716
L16	348	597	473	1004	1389	1197	2661	3032	2847
L17	453	605	529	1243	1407	1325	2570	2895	2733
L18	509	722	615	1306	1503	1405	3087	3315	3201
L19	498	741	620	1278	1543	1411	2930	3290	3110
L20	466	683	575	1196	1423	1310	2774	3087	2931
L21	491	703	597	1259	1496	1378	2632	2885	2759
L22	502	778	640	1286	1588	1437	2670	3053	2861
L23	509	809	659	1438	1635	1537	2970	3394	3182
L24	547	868	708	1403	1753	1578	2775	3450	3112
L25	596	944	770	1528	1906	1717	3284	3542	3413
Mean	396	590		1109	1371		2469	2833	
CD (P=0.005)	Location (L) = 23.3, Farming system (F) = 6.5, L×F = 32.97			Location (L) = 37.1, Farming system (F) = 10.47, L×F = 52.3			Location (L) = 67.6, Farming system (F) = 19.1, L×F = 95.6		

Bird *et al.* (2002) showed that organic carbon from standing biomass is transferred to the coarse size fractions of the soil and then degraded over time with the residue progressively transferred into the more resistant finer particle sizes i.e. MOC. The relationship of LOC, POC and MOC of soils under organic and conventional farming showed that organic farming is very helpful in increasing LOC ($y = 0.667x$), POC ($y = 0.808x$) and MOC ($y = 0.871x$) over conventional system in Haryana.

The long-term effects of organic versus conventional farming on soil properties were studied. Shifting from conventional to organic farming had no effect on pH and EC but reduced the CaCO_3 significantly. However, adoption of organic farming enhanced the soil organic carbon and its fractions i.e. light fraction organic carbon (LOC), particulate (POC) and mineral associated carbon fractions (MOC) and overall soil organic carbon stocks were observed to be

significantly higher in organic soils over the conventionally managed soils. The results from the study indicate that the management practices have clear positive and significant effects on soil organic carbon and its fractions along with enhancing soil organic carbon stocks in different textured soils of Haryana.

REFERENCES

- Abu-Zahra T R and Tahboub A B. 2008. Effect of organic matter sources on chemical properties of the soil and yield of strawberry under organic farming conditions. *World Applied Sciences Journal* 5: 383–8.
- Aher S B, Lakaria B L, Kaleshananda S, Singh A B, Ramana S, Ramesh K and Thakur J K. 2015. Effect of organic farming practices on soil and performance of soybean (*Glycine max*) under semi-arid tropical conditions in Central India. *Journal of Applied and Natural Science* 7: 67–71.
- Banger K, Toor G S, Biswas A, Sidhu S S and Sudhir K. 2010.

- Soil organic carbon fractions after 16-years of applications of fertilizers and organic manure in a TypicRhodalfs in semi arid tropics. *Nutrient Cycling in Agroecosystems* **86**: 391–9.
- Benbi D K, Brar K, Toor A S and Singh P. 2015. Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India. *Geoderma* **237–8**: 149–58.
- Benbi D K, Brar K, Toor A S, Singh P and Singh H. 2012. Soil carbon pools under poplar-based agroforestry, rice- wheat, and maize-wheat cropping systems in semi-arid India. *Nutrient Cycling in Agroecosystems* **92**: 107–18.
- Benbi D K, Sharma S, Toor A S, Brar K, Sodhi G P S and Garg A K. 2016. Differences in soil organic carbon pools and biological activity between organic and conventionally managed rice-wheat fields. *Organic Agriculture* **16**: 168–82.
- Benbi D K, Singh P, Toor A S and Verma G. 2016. Manure and fertilizer application effects on aggregate and mineral-associated organic carbon in a loamy soil under rice-wheat system. *Communications in Soil Science and Plant Analysis* **47**(15): 1828–44.
- Benbi D K, Toor A S and Kumar S. 2012. Management of organic amendments in rice-wheat cropping system determines the pool where carbon is sequestered. *Plant and Soil* **360**: 145–62.
- Bird M, Santrůkova H, Lloyd J and Lawson E. 2002. The isotopic composition of soil organic carbon on a north-south transect in western Canada. *European Journal of Soil Science* **53**: 393–403.
- Cambardella C A and Elliott E T. 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. *Soil Science Society of America Journal* **56**: 777–83.
- Campbell C A, Zentner R P, Selles F, Biederbeck V O, McConkey B G, Blomert B and Jefferson P G. 2000. Quantifying short-term effects of crop rotations on soil organic carbon in southwestern Saskatchewan. *Canadian Journal of Soil Science* **80**: 193–202.
- Canqui H B, Charles A, Francis L, Tomie D and Galusha. 2013. Does organic farming accumulate carbon in deeper soil profiles in the long term? *Geoderma* **288**: 213–21.
- Advances in soil science. *Climate Change and Tropical Ecosystems*. CRC Press, Boca Raton. pp 261–81.
- Ding X L, Han X Z, Liang Y, Qiao Y F, Li L J and Li N. 2012. Changes in soil organic carbon pools after 10 years of continuous manuring combined with chemical fertilizer in a Mollisol in China. *Soil and Tillage Research* **122**: 36–41.
- Gong W, Yan X Y, Wang J Y, Hu T X and Gong Y B. 2009. Long-term manuring and fertilization effects on soil organic carbon pools under a wheat–maize cropping system in North China Plain. *Plant and Soil* **314**: 67–76.
- Gopalasundaram P, Bhaskaran A and Rakkiyappan P. 2012. Integrated nutrient management in sugarcane. *Sugar Tech* **14**: 3–20.
- Hassink J. 1995. Density fractions of soil macro organic matter and microbial biomass as predictors of C and N mineralization. *Soil Biology and Biochemistry* **27**: 1099–1108.
- Herencia J F, Ruiz-porras J C, Melero S, Garcíagalavis P A, Morillo E and Maqueda C. 2007. Comparison between organic and mineral fertilization for soil fertility levels, crop macronutrient concentrations and yield. *Agronomy Journal* **99**: 973–83.
- Jackson M L. 1967. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.
- Jadhav A B, Kadlag A D and Amrutsagar V M. 2016. Soil enzyme activities, organic carbon and microbial population as influenced by integrated nitrogen management for Banana. *Journal of the Indian Society of Soil Science* **64**: 98–107.
- Janzen H H, Campbell C A, Brandt S A, Lafond G P and Smith L T. 1992. Light-fraction organic matter in soils from long-term crop rotations. *Soil Science Society of America Journal* **56**: 1799–1806.
- Kataki P K, Hobbs P and Adhikari B. 2001. The rice-wheat cropping system of South Asia: trends, constraints and productivity- A prologue. *Journal of Crop Production* **3**: 1–26.
- Ladha J K, Dawe D, Pathak H, Padre A T and Yadav R L. 2003. How extensive are yield declines in long-term rice-wheat experiments in Asia? *Field Crops Research* **81**: 159–80.
- Lal R. 2004. Soil carbon sequestration impacts on global climatechange and food security. *Science* **304**: 1623–7.
- Leifeld J, Reiser R and Oberholzer H R. 2009. Consequences of conventional versus organic farming on soil carbon: Results from a 27-Year Field Experiment. *Agronomy Journal* **101**: 204–1218.
- Leifeld J and Fuhrer J. 2010. Organic farming and soil carbon sequestration: what do we really know about the benefits? *Ambio* **39**: 585–99.
- Liang Q, Chen H Q, Gong Y S, Fan M S, Yang H F, Lal R and Kuzyako Y. 2012. Effects of 15 years of manure and inorganic fertilizers on soil organic carbon fractions in a wheat-maize system in the North China Plain. *Nutrient Cycling in Agroecosystems* **92**: 21–33.
- Maharjan M, Sanaullah M, Bahar S, Razavi and Kuzyakov Y. 2017. Effect of land use and management practices on microbial biomass and enzyme activities in subtropical top-and sub-soils. *Applied Soil Ecology* **113**: 22–8.
- Majumder B, Mandal B, Bandyopadhyay P K, Gangopadhyay A, Man P K, Kundu A L and Mazumdar D. 2008. Organic amendments influence soil organic carbon pools and rice-wheat productivity. *Soil Science Society of America Journal* **72**: 775–685.
- Malhi S S, Nyborg M, Solberg E D, McConkey B, Dyck M and Puurveen D. 2011. Long-term straw management and N fertilizer rate effects on quantity and quality of organic C and N and some chemical properties in two contrasting soils in western Canada. *Biology and Fertility of Soils* **47**: 785–800.
- Marriott E E and Wander M M 2006. Total and labile soil organic matter in organic and conventional farming systems. *Soil Science Society of America Journal* **70**: 950–9.
- Marriott E E and Wander M M. 2006. Total and labile soil organic matter in organic and conventional farming systems. *Soil Science Society of America Journal* **70**: 950–9.
- Munda S, Shivakumar B G, Gangaiah B, Rana D S, Manjaiah K M, Lakshman K and Layek J. 2013. Response of soybean (*Glycine max*) to phosphorus with or without biofertilizer. *Indian Journal of Agronomy* **58**: 86–90.
- Nelson D W and Sommers L E. 1996. Soil Science Society of America and American Society of Agronomy. 677 *Methods of Soil Analysis. Part 3. Chemical Methods-SSSA Book Series no. 5*. S. Segoe Rd., Madison, WI 53711, USA.
- Poirier V, Angers D A, Rochette P and Whalen J K. 2013. Initial soil organic carbon concentration influences the short-term retention of crop-residue carbon in the fine fraction of a heavy clay soil. *Biology and Fertility of Soils* **49**: 527–35.
- Puget P and Drinkwater L E. 2001. Short-term dynamics of root- and shoot-derived carbon from a leguminous green manure. *Soil Science Society of America Journal* **65**: 771–9.
- Puri A N. 1930. *A new method of estimating total carbonates in soils*. Pusa Bulletin, No. 73, Imperial Agriculture Research, New Delhi.

- Richards L A. 1954. *Diagnosis and improvement of saline and alkaline soils*. USDA Handbook No. 60. Washington D. C. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA Circular 939.
- Sheoran, O P, Tonk D S, Kaushik L S, Hasija R C and Pannu R S. 1998. Statistical software package for agricultural research workers. Recent advances in information theory, Statistics & Computer applications. D S Hooda & R C Hasija (Ed). Department of Mathematics & Statistics, Chaudhary CharanSingh Haryana Agricultural University, Hisar. pp 139–43.
- Sihi D, Sharma D K, Pathak H, Singh Y V, Sharma O P, Nain N, Chaudhary A and Dari B 2012. Effect of organic farming on productivity and quality of basmati rice. *International Journal of Rice Research* **49**: 24–9.
- Singh P and Benbi D K. 2018. Nutrient management effects on organic carbon pools in a sandy loam soil under rice-wheat cropping. *Archives of Agronomy and Soil Sciences*. DOI: 10.1080/03650340.2018.1465564.
- Swarup A, Manna M C and Singh G B. 2000. Impact of land use and management practices on organic carbon dynamics in soils of India. (In). Lal R, Kimble J M and Stewart B A (Eds). Global Thakare R, Chaudhari R D and Zanje H B. 2017. Changes in soil chemical properties due to moisture regimes and sources of organic manures. *International Journal of Chemical Studies* **5**: 875–9.
- Von Luetzow M, Koegel-Knabner I, Ekschmitt K, Flessa H, Guggenberger G, Matzner E and Marschner B. 2007. SOM fractionation methods: Relevance to functional pools and to stabilization mechanisms. *Soil Biology and Biochemistry* **39**: 2183–207.
- Walkley A J and Black C A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Science* **37**: 29–38.
- Whalen J K, Gul S, Poirier V, Yanni S F, Simpson M J, Clemente J S, Feng X, Grayston S J, Barker J, Gregorich E G, Angers D A, Rochette P and Janzen H H. 2014. Transforming plant carbon into soil carbon: process-level controls on carbon sequestration. *Canadian Journal of Plant Science* **94**: 1065–73.
- Zhao Y, Zhang Y, Liu X, He X and Shi X. 2016. Carbon sequestration dynamic, trend and efficiency as affected by 22-year fertilization under a rice-wheat cropping system. *Journal of Plant Nutrition and Soil Science* **179**: 652–60.