Soil Organic Carbon and Soil Physico-chemical Properties as Affected by Long Term Organic Cropping Systems in Indian Punjab

UNDER PEER REVIEW

ABSTRACT

Organic farming in five cropping systems viz. Poplar + turmeric, sugarcane + bottle gourd - broccoli, basmati - wheat, sugarcane fodder and maize + summer moong - wheat is practiced since 15 years at *Bhagat* Puran Singh Natural Agriculture Farm and Research Centre, Dherekot, Jandiala Guru, Amritsar, Punjab. The depth wise soil samples from these cropping systems were collected after rabi (2018-19) and kharif (2019) seasons. Poplar + turmeric cropping system has significantly higher soil organic carbon, soil carbon stock, aggregate associated carbon in macro aggregates, total water stable aggregates and mean weight diameter than sugarcane + bottle gourd - broccoli, basmati - wheat, sugarcane fodder and maize + summer moong - wheat cropping systems. Sugarcane fodder cropping system has significantly higher pH than other cropping systems. Basmati - wheat cropping system has significantly lower electrical conductivity and higher soil bulk density compared to other cropping systems. In the surface soil (0-7.5 and 7.5-15 cm depths) soil organic carbon, soil carbon stock, aggregate associated carbon, electrical conductivity, total soil aggregates and mean weight diameter were significantly higher than subsurface layers (15-22.5 cm and 22.5-30 cm depth) whereas soil pH and bulk density were significantly lower in surface soil than subsurface soil.

Keywords: *Soil organic carbon, soil carbon stock, aggregate associated carbon, soil pH, soil electrical conductivity, total soil aggregates, mean weight diameter, bulk density.*

1. INTRODUCTION

The advent of high yielding nutrient responsive varieties and increased area under assured irrigation led to a major shift from organic based nutrient application to use of chemical fertilizers. Consequently, excess use of high analysis fertilizers in an unbalanced manner resulted in additional problems of multiple secondary and micro nutrient deficiencies in soils. Indiscriminate use of chemical fertilizers without additions of organic materials to soils has led to gradual decline in soil quality (Biswas *et al.,* 2014). Now with the increasing awareness and demand for quality foods, the organic farming has gained momentum compared to conventional chemical farming. Cultivated area under certified organic farming has grown almost 17 fold in last one decade. Organic farming emphasizes increasing soil organic carbon (SOC) an indicator of good soil quality through application of organic manures and compost (Olesen *et al.,* 2007), growing of leguminous green manures in crop rotation, mulching and recycling of crop residues and intercropping of legumes in main crops (Purakayastha *et al*., 2008). Soil quality cannot be measured directly, but is inferred from static or dynamic soil quality indicators or measurable soil attributes like SOC levels, aggregate stability, aggregate associated carbon, pH, electrical conductivity (EC), bulk density and water holding capacity (Malik *et al.,* 2014). There is thus a need to improve the understanding of how the management measures in organic farming contribute to changes in these soil quality indicators. Data from long-term experiments with variation in cropping systems and crop management practices may provide valuable insights by providing information on changes in SOC storage and soil physical quality. Quantification of soil carbon cycling as influenced by management practices is needed for C sequestration and soil quality improvement. In some cases, the organic carbon fraction of a particular material may be of greater value than its total nutrient content because of the beneficial effect of organic carbon on soil physical properties and soil productivity (Nayak *et al.,* 2012). Cropping systems that maintain and/or improve levels of SOC may also improve soil properties. Therefore, the present study was conducted to study the changes in soil properties and organic carbon under long term use of organics in different cropping systems.

2. MATERIAL AND METHODS

The research work was conducted at *Bhagat* Puran Singh Natural Agriculture Farm and Research Centre, Dherekot, Jandiala Guru, Amritsar (31^0 34' 24″ N, 75^0 03' 58″E) situated at an altitude of 230 m above mean sea level. The total area of the organic farm is 12 ha. The impact of long term five organic cropping systems viz. poplar + turmeric (CS_1), sugarcane + bottle gourd – broccoli (CS_2), basmati – wheat (CS_3), sugarcane fodder (CS_4) and maize + moong – wheat (CS_5) was studied on soil physico-chemical properties and build up of soil organic carbon. The poplar + turmeric cropping system (CS_1) is practiced from last 4 years with spacing of 28' (East-West) × 20' (North-South) having 200 plants/ha. In the third year (2018), 200 plants were grown in between the rows and now in 2020 eighty plants of 4th year age were harvested. This cycle of growing and harvesting of the poplar is in operation since fifteen years. Every year turmeric is being sown as inter crop in the poplar during the month of April and harvested by the end of December. Two rows of turmeric were sown on 37.5 cm wide beds with plant to plant spacing of 18 cm. Paddy straw mulch was applied @ 9 t ha^{-1} after the first irrigation. No other chemical fertilizer was added to this cropping system. Irrigation was applied through flooding in the rows as and when required. In sugarcane + (bottle gourd – broccoli) cropping system (CS_2), sugarcane (Co J 85 var.) was sown as two rows (in 4') and 12' inter row spacing in the North-South direction. The inter row spacing (12') was used for sowing of vegetables since 15 years. Within 12' space of sugarcane, bottle gourd was sown during the month of March and harvested in the months of September. Broccoli was transplanted in the month of October after bottle gourd and harvested in the months of December-February. Only organic manures (added through compost @ 5 t ha^{-1} + *Jeeva Amrita*) were used to raise vegetables and sugarcane. In basmati-wheat cropping system (CS_3), basmati (Pusa Basmati 1121 var.) was transplanted in the month of July and harvested in October. After incorporation of basmati straw, wheat (Sona Moti var) was sown as 8 rows on 120 cm beds and furrows of 30 cm. In maize + moong – wheat cropping system (CS_5), maize (var. local) was sown in the month of April after harvesting of wheat at a 60 cm row to row spacing and two rows of summer moong (SML 668 var.) were sown as intercrop in maize during April every year. After maize, black wheat was sown in October as 8 rows on the beds (120 cm width and 30 cm furrow). In sugarcane fodder cropping system (CS_4), sugarcane fodder (KRFo93-1 var.) was sown on beds (75cm) at 75 cm plant to plant spacing during 2016 and it was a 3 year ratoon crop during 2019.

In all these cropping systems, cultivation of crops was done without chemical fertilizers, herbicides and pesticides. Different crops were grown with the application of locally prepared compost, jivamrita*/jeevamrutha, bijamrita and acchadana-mulching* to supply nutrients. Other important principles for crop growth were intercropping of legumes and use of local species of earthworms. The pest management was taken care of through the use of *agniastra*, the *brahmastra* and the *neemastra* (Badwal *et al.,* 2019). Irrigation water used was a mixer of cow urine and constructed wetland water (containing natural bacteria, fungi etc). Sprinkler system was used for irrigation at different time intervals as and when required.

The soil samples were taken from four sites and four depths (0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm) under each cropping system following the grid sampling technique using the dutch auger. Under the poplar, the samples were collected after clearing the land surface of the accumulated leaf litter. The samples were taken after the harvest of *rabi* crops on May 22-23, 2019 and after harvesting of *kharif* crops in October 21-22 and December 21, 2019. The collected soil samples were dried, grounded and passed through 2-mm sieve for analysis in the soil testing laboratory of Department of Agriculture, Khalsa College Amritsar, Punjab, India. The soil pH was determined from 1:2 soil:water suspension with Elico-glass electrode pH meter (Jackson, 1967) after equilibrating soil with distilled water for half an hour. The electrical conductivity of 1:2 soil:water suspension soil samples was recorded using conductivity meter (Richards, 1954). Soil organic carbon (SOC) and carbon associated different sized dried soil aggregates after wet sieving (Yoder, 1936) was estimated by Walkley and Black's (1934) rapid titration method. The SOC was converted to SOC stock (Mg ha^{-1}) as

$$\text{SOC stock (Mg ha}^{-1}\text{)} = \text{(SOC/100)} \times \text{Bulk density (Mg m}^{-3}\text{)} \times 10{,}000 \text{ m}^2 \times \text{soil depth (m)}$$

Soil bulk density (Mg m^{-3}) was measured using metallic cores having inner diameter of 6.8 cm and height of 7.5 cm as per procedure described by Blake and Hartge (1986). Different size soil aggregates (percent) were determined using wet sieving method proposed by Yoder (1936).

The mean weight diameter (MWD) of the soil samples (Youker and McGuinness, 1956) was computed as:

$$MWD = \sum^{n}_{i=1} d_i \times w_i / \sum^{n}_{i=1} w_i$$

Where, di, is mean diameter of i^{th} size fraction in mm, n is number of size ranges, w_i is the weight of aggregates of size fraction in g .

The least significant difference among means was calculated as per procedure of Gomez and Gomez (1984) for completely randomized design using computer programme of CPCS1 (Cheema and Singh, 1991).

3. RESULTS AND DISCUSSION

3.1 Soil organic carbon

The data of soil organic carbon of both the seasons was pooled and presented in Table 1. Irrespective of depths, CS_1 has significantly higher SOC than CS_2, CS_3, CS_4 and CS_5. However no significant differences in soil organic carbon were observed in CS_2, CS_3 and CS_5 but these have significantly higher SOC than CS_4. Higher SOC in CS_1 could be due to the higher biomass addition by mulching of paddy straw in turmeric and addition of leaf litter of poplar during winter months particularly in the surface soil layers. Similar results have been reported by Barreto *et al.* (2011) and Benbi *et al.* (2012) where total organic carbon (TOC) was higher in soils under agroforestry systems. The lower soil carbon in CS_4 may be due to less addition of organic manures in *ratoon* sugarcane fodder compared to other cropping systems having more number of crops per season which can sequester more carbon in the top 30 cm soil (West and Post, 2002).

Irrespective of cropping systems SOC generally decreases with soil depth (Table 1). In 0-7.5 cm and 7.5-15 cm depths SOC was significantly higher than 22.5-30 cm depth. Significant difference in SOC was also observed in 0-7.5 cm and 15-22.5 cm layer. However no significant difference in SOC was observed in 7.5-15 cm and 15-22.5 cm depth. The higher SOC in surface layers was because of additions of organic manures on the surface and more root biomass in the surface layers compared to lower depths (Rasool *et al.,* 2008).

Table 1. Effect of different organic cropping systems on soil organic carbon (g kg^{-1})

Soil depths (cm)	**Cropping systems**					**Mean***
	CS_1	**CS_2**	**CS_3**	**CS_4**	**CS_5**	
0-7.5	10.3	8.7	7.5	6.0	7.7	8.1^{a}
7.5-15	9.4	7.8	6.7	5.2	7.2	7.3^{ab}
15-22.5	8.4	6.9	5.9	4.8	6.6	6.5^{b}
22.5-30	7.0	5.8	5.2	3.6	5.7	5.5^{c}
Mean*	8.8^{a}	7.3^{b}	6.3^{c}	4.9^{d}	6.8^{bc}	

*Dissimilar letters are significantly different at 5 percent level of significance

3.2 Soil organic carbon stock

Irrespective of depths, CS_1 has significantly higher SCS than CS_2, CS_3, CS_4 and CS_5 (Table 2). No any significant difference in SCS was observed among CS_2, CS_3 and CS_5 but these have significantly higher SCS than CS_4. Irrespective of cropping systems, SCS of 0-7.5, 7.5-15 and 15-22.5 cm depths were significantly higher than 22.5-30 cm layer. However, no significant difference in SCS was observed in 0-7.5, 7.5-15 and 15-22.5 cm depths. Higher SCS in agroforestry systems has also been reported by Benbi *et al.* (2012).

UNDER PEER REVIEW

Table 2. Effect of different cropping systems on soil carbon stock (Mg ha^{-1})

Soil depths (cm)	Cropping systems					Mean*
	CS$_1$	**CS$_2$**	**CS$_3$**	**CS$_4$**	**CS$_5$**	
0-7.5	11.70	10.08	9.22	7.03	8.94	9.40^{a}
7.5-15	11.22	9.51	8.74	6.81	8.81	9.02^{a}
15-22.5	10.90	9.20	8.16	6.39	8.70	8.67^{a}
22.5-30	9.13	7.71	6.97	4.85	7.60	7.25^{b}
Mean*	10.74^{a}	9.12^{b}	8.27^{b}	6.27^{c}	8.51^{b}	

*Dissimilar letters are significantly different at 5 percent level of significance

3.3 Aggregate associated carbon

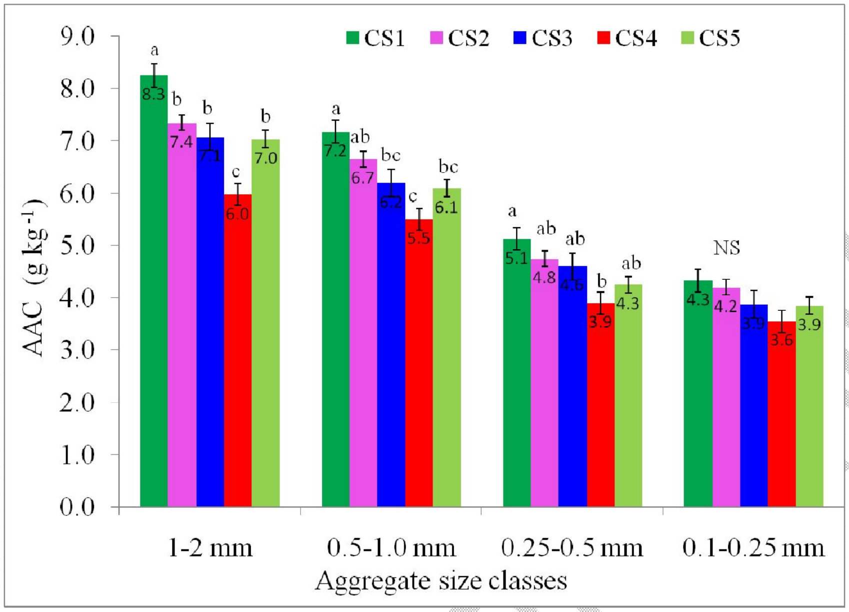
Carbon fraction associated with different size aggregates under different cropping systems and depths is presented in Fig. 1 in which it can be easily seen that macro-aggregates (0.5-1 mm) act as main carrier of organic carbon. It was observed that irrespective of cropping systems, highest aggregate associated carbon (AAC) was observed in case of 1-2 mm size aggregates. Highest C content was recorded in 1-2 mm size aggregates followed by 0.5-1.0 mm, 0.25-0.5 mm and 0.10-0.25 mm. The carbon content decreased as aggregates become smaller than 1-2 mm size. Irrespective of soil depths, poplar + turmeric cropping system (CS$_1$) has significantly higher AAC in size fraction of 1-2 mm compared to CS$_2$, CS$_3$, CS$_4$ and CS$_5$. However no significant difference in AAC was observed in CS$_2$, CS$_3$ and CS$_5$ but these have significantly higher AAC than CS$_4$. In size fraction of 0.5-1.0 mm, CS$_1$ has significantly higher AAC than CS$_3$, CS$_4$ and CS$_5$ but AAC in CS$_3$, CS$_4$ and CS$_5$ were at par. In size fraction 0.25-0.5 mm CS$_1$ has significantly higher AAC than CS$_4$ and cropping systems CS$_1$, CS$_2$, CS$_3$ and CS$_5$ were at par. In micro aggregates (0.1-0.25 mm size) AAC was at par in all cropping.

Irrespective of cropping systems, depth wise AAC decreased in all size aggregates. In size fractions of 1-2, 0.5-1 and 0.25-0.5 mm size AAC was significantly higher in 0-7.5 cm depth compared to 7.5-15, 15-22.5 and 22.5-30 cm depths. In all size fractions, no significant difference in AAC was observed in 7.5-15, 15-22.5 and 22.5-30 cm depths. However in micro aggregates (0.1-0.25 mm size) AAC in 0-7.5 and 7.5-15 cm depth was at par but these have significantly higher AAC than 15-22.5 and 22.5-30 cm depths.

Macro-aggregates were found to be main carrier of organic carbon which is also favoured by the results of Li *et al.* (2007). In most of the cases it was observed that highest amount of C was associated with the 1-2 mm sized aggregate which is in conformity with the findings of many other researchers (Saha *et al.*, 2011; Sodhi *et al.,* 2009). Organic matter helped in an increased accumulation of OC in different sized aggregates in which the most pronounced effect was found in case of macro-aggregates as compared to micro-aggregates. This can be attributed to the concept of aggregate hierarchy (Tisdall and Oades, 1982) which states that C content increases with increase in aggregate size as larger aggregates are composed of smaller aggregates plus organic binding materials (Elliot, 1986). Another explanation could be that macro-aggregates provide physical protection to OC from decomposition (Benbi and Senapati, 2010). Improved AAC can be seen in CS$_1$ (poplar+ turmeric) as compared to other cropping systems due to higher input of carbon by leaf litter of poplar during winter months and mulching of paddy straw in turmeric. The lowest AAC in CS$_4$ (ratoon sugarcane fodder) may be due to less addition of organic carbon.

UNDER PEER REVIEW

a)



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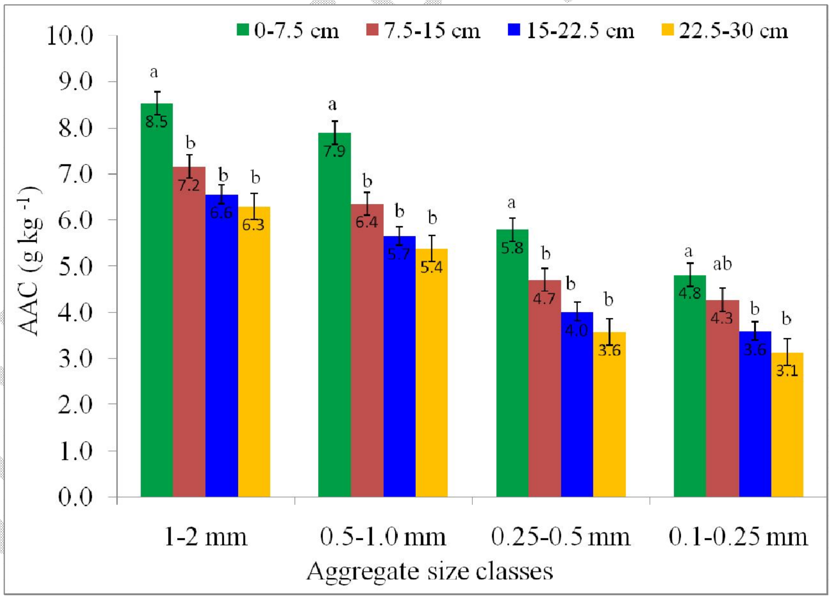


*Vertical bars and dissimilar letters indicate standard errors of means and significant differences at 5% level of significance respectively

Fig. 1 Aggregate associated carbon (g kg^{-1}) in relation to different cropping systems (a) and soil depths (b).

UNDER PEER REVIEW

3.4 Soil pH

Among cropping systems significant difference in pH was observed (Table 3). Irrespective of depths the data in the table shows that CS_4 has significantly higher pH value than CS_1, CS_2, CS_3 and CS_5. No any significant difference in pH was observed between CS_1 and CS_5. Soil pH of CS_3 was significantly lower than all other cropping systems. Lowering of soil pH of alkaline soil in Basmati-wheat cropping system may be attributed to effect of puddling (Fageria *et al.,* 2011) and submergence (Sharma *et al.,* 2015) compared to poplar based cropping system. Irrespective of cropping systems pH generally increased with soil depth. In 15-22.5 cm and 22.5-30 cm depths pH was significantly higher than 0-7.5 cm depth. In 0-7.5 cm and 15-22.5 cm depth significant difference in pH was also observed. However no significant difference in pH was observed in 15-22.5 cm and 22.5-30 cm depths. The higher pH of lower soil layers is ascribed to downward leaching of soluble salts with percolating water (Singh *et al.,* 2009).

Table 3. Effect of different cropping systems on soil pH

Soil depth (cm)	**Cropping systems**					**Mean***
	CS_1	**CS_2**	**CS_3**	**CS_4**	**CS_5**	
0-7.5	7.59	7.80	7.24	8.05	7.63	7.66^{a}
7.5-15	7.70	7.86	7.41	8.08	7.72	7.76^{ab}
15-22.5	7.81	7.95	7.63	8.20	7.75	7.87^{bc}
22.5-30	7.94	8.07	7.75	8.21	7.89	7.97^{c}
Mean*	7.77^{a}	7.92^{b}	7.51^{c}	8.13^{d}	7.75^{a}	

*****Dissimilar letters are significantly different at 5 percent level of significance

3.5 Soil Electrical Conductivity

Irrespective of depths, CS_3 has significantly lower EC than CS_1, CS_2, CS_4 and CS_5 (Table 4). No any significant difference in EC was observed among CS_1, CS_2, CS_4 and CS_5. The increase in soil electrical conductivity as impacted by manure addition might be due to the amount of dissolved salts in the manures (Ozlu and Kumar, 2018). Irrespective of cropping systems, EC was maximum in 0-7.5 cm and it significantly decreased with depth. All soil depths are significantly different from each other. Similar results were reported by Sharma *et al.* (2015) where EC decreased with soil depth.

Table 4 Effect of different cropping systems on soil electrical conductivity (dS m^{-1})

Soil depth (cm)	**Cropping systems**					**Mean***
	CS_1	**CS_2**	**CS_3**	**CS_4**	**CS_5**	
0-7.5	0.2125	0.2020	0.1511	0.1724	0.1678	0.1812^{a}
7.5-15	0.1772	0.1824	0.1191	0.1699	0.1708	0.1638^{b}
15-22.5	0.1550	0.1582	0.1104	0.1521	0.1503	0.1452^{c}
22.5-30	0.1256	0.1384	0.1051	0.1304	0.1329	0.1265^{d}
Mean*	0.1676^{a}	0.1703^{a}	0.1214^{b}	0.1562^{a}	0.1554^{a}	

*****Dissimilar letters are significantly different at 5 percent level of significance

3.6 Soil aggregation

The data pertaining to total soil aggregates in different cropping systems at different depths and seasons is presented in Table 5. Irrespective of depths, CS_1 has significantly higher TSA than CS_2, CS_3, CS_4 and CS_5. However, no significant difference in TSA was observed among CS_2, CS_3 and CS_5 but these have significantly higher TSA than CS_4. The order of decrease in TSA with different cropping systems is $CS_1 > CS_2 > CS_3 > CS_5 > CS_4$. Irrespective of cropping systems, the TSA were significantly different among soil depths and were maximum in the surface layer compared to lower depths and the trend was 0-7.5>7.5-15>15-22.5>22.5-30 cm depths.

UNDER PEER REVIEW

Table 5 Effect of different cropping systems on total soil aggregates (percent)

Soil depth (cm)	**Cropping systems**					**Mean***
	CS$_1$	**CS$_2$**	**CS$_3$**	**CS$_4$**	**CS$_5$**	
0-7.5	81.5	74.7	71.3	63.2	70.5	72.2^{a}
7.5-15	76.1	68.3	62.8	56.7	62.7	65.3^{b}
15-22.5	65.3	60.6	58.2	44.2	52.4	56.1^{c}
22.5-30	57.2	51.8	49.8	39.4	43.4	48.3^{d}
Mean*	70.0^{a}	63.8^{b}	60.5^{b}	50.9^{c}	57.2^{bd}	

*****Dissimilar letters are significantly different at 5 percent level of significance

When the overall pooled analysis of different cropping systems and depths was done, it was observed that the largest proportion of total WSA was in 0.1-0.25 mm size fraction among all sized aggregates and 1-2 mm sized fraction constituted least proportion (Fig. 2a). Similar results were observed by Chen *et al.* (2009). The aggregates of size 1-2, 0.5-1 and 0.25-0.5 mm were significantly higher in CS$_1$ whereas in the size fraction of 0.1-0.25 mm, CS$_3$ has significantly higher percent aggregates than all other cropping systems indicating that higher proportion of macro-aggregates were found CS$_1$. This may be attributed to higher amount of organic carbon (Table 1) which affected the activity of soil fauna and also soil aggregation (Mandal *et al.,* 2020). Macro-aggregate formation is linearly correlated with SOC content (Benbi and Senapati, 2010). The macro-aggregates, i.e. 1-2, 0.5-1 and 0.25-0.5 mm sized aggregates followed the order CS$_1$ > CS$_2$ > CS$_5$ > CS$_3$=CS$_4$ but the micro-aggregate, i.e. 0.1-0.25 mm sized aggregate followed a different trend of CS$_3$ > CS$_4$ > CS$_5$ ≥ CS$_2$ = CS$_1$. Higher amount of micro-aggregate in CS$_3$ may be due to mechanical breakdown of macro-aggregates during puddling and other cultivation practices (Gupta-Choudhuri *et a1.,* 2008). Among all, lower water stable aggregates in CS$_4$ may be due lower SOC (Table 1) as compared to other cropping systems. Soil organic matter that is responsible for binding of micro-aggregates to form macro-aggregates is generally a labile fraction of soil C which is sensitive to cropping system change and cultivation (Ashagrie *et a1.,* 2005).

Irrespective of cropping systems, aggregates of 1-2, 0.5-1 and 0.25-0.5 mm size were significantly higher in 0-7.5 cm depth compared to 15-22.5 and 22.5-30 cm depths (Fig. 2b). Aggregates of size 1-2, 0.5-1 mm were also significantly higher in 0-7.5 cm depth compared to 7.5-15 cm depth. However, no significant difference in percent aggregates was observed in 0-7.5 and 7.5-15 cm depths in 0.25-0.5 mm size fraction. No significant difference in micro aggregates was observed among all soil depths.

3.7 Mean weight diameter of soil aggregates

Irrespective of depths, CS$_1$ has significantly higher MWD than CS$_2$, CS$_3$, CS$_4$ and CS$_5$ (Table 6). However no significant difference in MWD was observed in CS$_3$ and CS$_5$ but MWD in these cropping systems was significantly higher than CS$_4$. The order of decrease in MWD with different cropping systems is CS$_1$>CS$_2$>CS$_5$>CS$_3$>CS$_4$. Irrespective of cropping systems, maximum MWD was in 0-7.5 cm depth which significantly decreases with soil depths. Significantly higher MWD was observed in both 0-7.5 and 7.5-15 cm depths compared to 15-22.5 and 22.5-30 cm depths.

Table 6. Effect of different cropping systems on mean weight diameter of soil aggregates (mm)

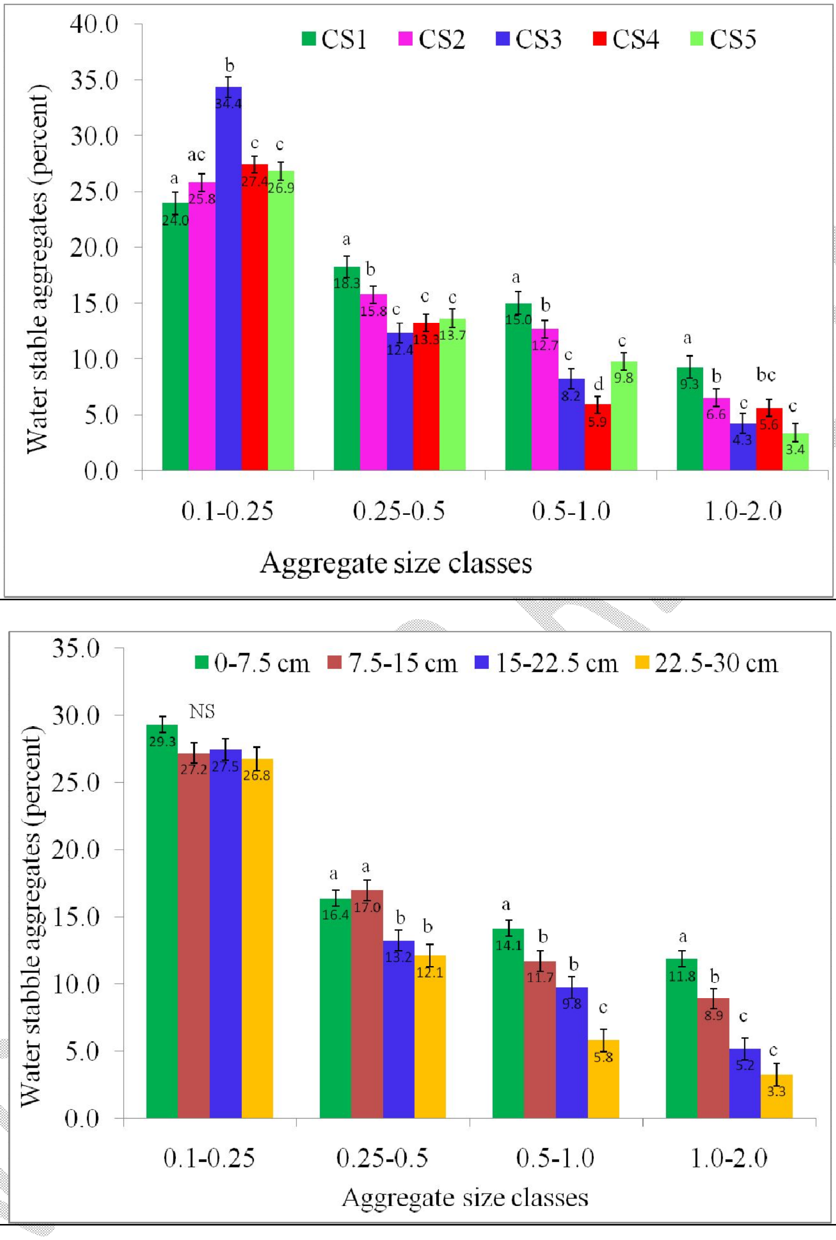
Soil depth (cm)	**Cropping systems**					**Mean***
	CS$_1$	**CS$_2$**	**CS$_3$**	**CS$_4$**	**CS$_5$**	
0-7.5	0.568	0.443	0.337	0.275	0.374	0.399^{a}
7.5-15	0.473	0.365	0.276	0.248	0.316	0.336^{b}
15-22.5	0.333	0.301	0.231	0.161	0.232	0.252^{c}
22.5-30	0.272	0.236	0.146	0.125	0.156	0.187^{d}
Mean*	0.412^{a}	0.337^{b}	0.247^{c}	0.202^{d}	0.269^{c}	

*****Dissimilar letters are significantly different at 5 percent level of significance

UNDER PEER REVIEW

Significant difference in MWD was in the order of 0-7.5>7.5-15>15-22.5> 22.5-30 cm depths.

a)



*Vertical bars and dissimilar letters indicate standard errors of means and significant differences at 5% level of significance respectively

Fig. 2 Water stable aggregates (percent) in different size fractions in relation to cropping systems (a) and soil depths (b).

3.8 Soil bulk density

The pooled data of two cropping seasons pertaining to soil bulk density (BD) in different cropping systems at varying depths is presented in Table 7. Among cropping systems, CS_3 has significantly higher bulk density than CS_1, CS_2 and CS_5. However, no significant difference in BD was observed in CS_3 and CS_4

cropping systems. Among soil depths, BD was significantly lower in 0-7.5 cm depth compared to 7.5-15, 15-22.5 and 22.5-30 cm depths. Bulk density of 7.5-15 cm was also significantly lower than 15-22.5 and 22.5-30 cm depths. However, no significant difference in bulk density was observed in 15-22.5 and 22.5-30 cm depths. Higher bulk density in CS_3 (Basmati-wheat) cropping system may be attributed to compaction during puddling (Singh *et al.*, 2009). Lower bulk density in CS_1 (poplar+ turmeric) may be attributed to addition of more organic matter. Similarly Ramanandan and Jogan (2019) observed lower bulk density in organic farming compared to conventional farming. Higher bulk density of lower soil depths is in accordance with Singh *et al.* (2009) where higher subsoil bulk density was reported due to formation of subsoil compact plough pan.

Table 7 Effect of different cropping systems on bulk density of soil (Mg m^{-3})

Soil depth (cm)	**Cropping systems**					**Mean***
	CS_1	**CS_2**	**CS_3**	**CS_4**	**CS_5**	
0-7.5	1.51	1.54	1.64	1.56	1.51	1.55^a
7.5-15	1.59	1.63	1.74	1.73	1.59	1.65^b
15-22.5	1.74	1.79	1.85	1.76	1.76	1.78^c
22.5-30	1.74	1.77	1.79	1.80	1.79	1.78^c
Mean*	1.64^a	1.68^a	1.75^b	1.71^{ab}	1.66^a	

*****Dissimilar letters are significantly different at 5 percent level of significance

4. CONCLUSION

Conclusively, maximum carbon sequestration was observed in poplar + turmeric cropping system due to more carbon recycling through paddy straw mulching and leaf litter of poplar during autumn season every year which further resulted improvement in aggregate associated carbon, soil aggregation, mean weight diameter, bulk density, pH and electrical conductivity of soil. The improvement in soil physical properties in different cropping systems followed the trend of poplar + turmeric > sugarcane + bottle gourd – broccoli > maize + summer moong – wheat > basmati – wheat > sugarcane fodder. Favourable changes in soil properties were more in surface layers compared to sub surface soil layers. Thus, poplar + turmeric cropping system is promising for build-up of organic carbon and improvement in soil physico-chemical characteristics in the state of Punjab compared to the prevalent rice (basmati) – wheat cropping system.

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