Effect of Long-Term Organic Cropping Systems on Physico-Chemical Properties of the Soils of Indian Punjab

ABSTRACT

Organic farming is gaining momentum because of awareness among consumers for quality food. The long term effects of organic cropping systems on soil quality yet not have been studies in details. Therefore the present study the long term effect of five cropping systems viz. Poplar (*Populus deltoids)* + turmeric (*Curcuma longa)*, sugarcane *(Saccharum officinarum Linn)*+ bottle gourd *(Lagenaria siceraria)* - broccoli (*Brassica oleracea)*, basmati rice (*Oryza sativa*) - wheat (*Triticum aestivum*), sugarcane fodder and maize (*Zea mays*) + summer moong *(Vigna radiate)* - wheat on soil physico-chemical properties was studied at *Bhagat* Puran Singh Natural Agriculture Farm and Research Centre, Amritsar, Punjab (31.573^{0} N, 75.066^{0} E). 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(SOC), soil carbon stock(SOCS), soil aggregate associated carbon(AAC), water stable soil aggregates (WSA) and mean weight diameter(MWD) of soil than other cropping systems. Sugarcane fodder cropping system has significantly higher soil pH than other cropping systems while basmati rice - wheat cropping system has significantly lower electrical conductivity (EC) and higher soil bulk density (BD) compared to other cropping systems. In the top soil (0-7.5 and 7.5-15 cm depths) SOC, SOCS, AAS, EC, WSA and MWD were significantly higher than subsurface layers (15-22.5 cm and 22.5-30 cm depth) whereas soil pH and BD were significantly lower in surface soil than subsurface soil.

Keywords: *Soil organic carbon, soil carbon stock, aggregate associated carbon, soil pH, soil electrical conductivity, water stable 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 multi-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 25 fold in last one decade (Gopinath *et al.,* 2016). 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 (Mukherjee and Lal, 2014), 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 quantitative 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 (Notaris *et al.,* 2021). Quantification of soil carbon cycling through 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 importance than its total nutrient content because of their beneficial effects 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, long term effect of different organic cropping systems on changes in soil physic-chemical properties was studied.

2. MATERIAL AND METHODS

The research work was conducted at *Bhagat* Puran Singh Natural Agriculture Farm and Research Centre, Dherekot, Jandiala Guru, Amritsar (31.573^0 N, 75.066^0 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. In the poplar + turmeric cropping system (CS$_1$) the poplar plants are harvested after every 4 years age and new one are transplanted in the third year (one year before harvesting) for next four years with row to row and plant to plant spacing of 28' (East-West) and 20'(North-South) respectively resulting in 200 plants/ha. In the third year (2018), 200 plants were transplanted in between the rows and now in start of 2020 eighty plants of 4th year age were harvested. This cycle of growing and harvesting of the poplar is in operation for the last fifteen years. Every year turmeric is sown as inter crop within the poplar trees 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 with 30 furrow in between two beds.

Paddy straw mulch was applied @ 9 t ha^{-1} after the first irrigation after 15-20 days of sowing. No chemical fertilizer was added to this cropping system. About 5 to 6 cm Irrigation was applied as flooding in the rows when volumetric soil moisture content was about 15 per cent. In sugarcane + (bottle gourd – broccoli) cropping system (CS$_2$), sugarcane (Co J 85 var.) was sown in two rows within 4' and vegetables in 12' inter row spacing in the North-South direction. The inter row spacing of sugarcane (12') was used for sowing of vegetables (bottle gourd and broccoli) continuously from last 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 The harvest of bottle gourd in the months of December-February. Only organic manures (added through compost @ 5 t ha^{-1} + *Jeeva Amrita* (10% foliar spary of fermented microbial culture of cow dung) 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 variety Sona Moti was sown as 8 rows on 120 cm beds and furrows of 30 cm width. 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 (bred through common hexaploid wheat (*Triticum aesticum*) + *Agropyron glaucum)* 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 by using *jiva amrita, bijamrita* (microbial seed treatment) *and acchadana (mulching)* to supply nutrients. Other important principles of organic farming for crop growth were intercropping of legumes and use of local species of earthworms (*Eisenia fetida)*. 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 (Wang *et al*., 2022). Sprinkler system was used for irrigation at weekly intervals.

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 Singh *et al.,* 2009) under each cropping system following the grid sampling (0.5-1 acre) 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 (SOCS)(Mg ha^{-1}) as

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

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 per cent soil water stable aggregates (WSA) 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:

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

Where, di, is mean diameter of ith 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 by 20.5, 39.7, 79.5 and 29.4 per cent respectively. However no significant differences in soil organic carbon were recorded between CS_2 and CS_5 but these have significantly higher SOC than CS_4 by 48.9 and 38.7 per cent respectively . 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 Lorenz and Lal (2014) and Benbi *et al.* (2012) where soil organic carbon (SOC) 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 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 by 47.3 and 32.7 per cent respectively. Significant difference in SOC was also observed in 0-7.5 cm and 15-22.5 cm layers. 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 (Mamta *et al.,* 2020).

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 (SOCS)

Irrespective of depths, CS_1 has significantly higher SOCS than CS_2, CS_3, CS_4 and CS_5 (Table 2) by 17.7, 29.8, 71.3 and 26.2 per cent respectively. No any significant difference in SOCS was observed among CS_2, CS_3 and CS_5 but these have significantly higher SOCS than CS_4 by 45.4, 31.9 and 35.7 per cent respectively. Irrespective of cropping systems, SCS of 0-7.5, 7.5-15 and 15-22.5 cm depths were significantly higher by 29.6, 24.4 and 19.6 per cent than 22.5-30 cm layer respectively. However, no significant difference in SOCS was observed in 0-7.5, 7.5-15 and 15-22.5 cm depths. Higher SOCS in agro forestry systems has also been reported by Mayer *et al.* (2022).

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

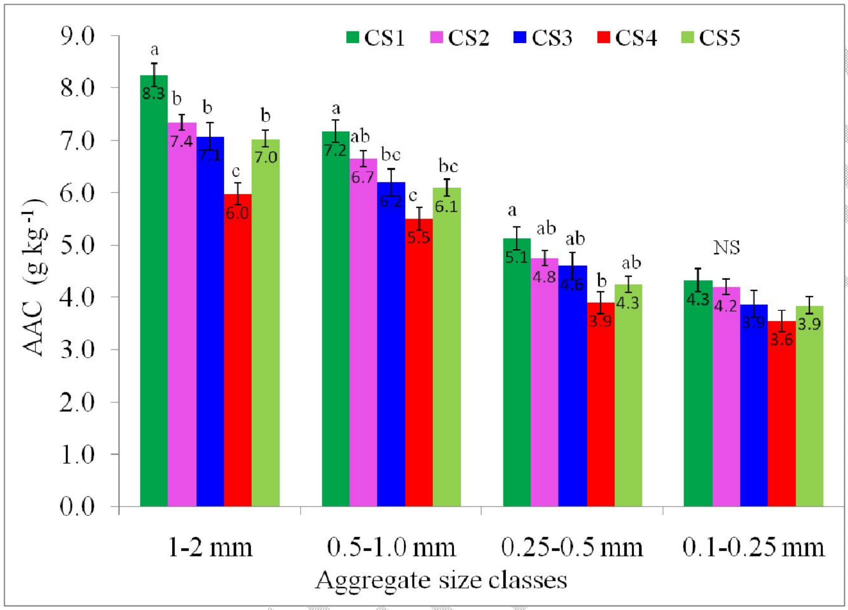
3.3 Aggregate associated carbon

Carbon fraction associated with different size aggregates (1.0-2.0, 0.5-1.0, 0.25-0.5 and 0.1-0.25 mm) under different cropping systems and depths is presented in Fig. 1 in which it can be easily observed that macro-aggregates (1.0-2.0 mm) act as main carrier of organic carbon (7.2 g kg^{-1}). Irrespective of cropping systems, highest aggregate associated carbon (AAC) of 0.716 per cent was observed in 1.0-2.0 mm size aggregates. Highest C content was recorded in 1.0-2.0 mm size aggregates followed by 0.5-1.0 mm (6.34 g kg^{-1}), 0.25-0.5 mm (4.54 g kg^{-1}) and 0.10-0.25 mm (3.98 g kg^{-1}). Macro-aggregates were found to be main carrier of organic carbon (Kumar et al., 2019 and Sheng et al., 2020). The higher aggregate associated carbon in macro aggregates of 1.0-2.0 mm size may be due to more density and humic fractions (Sheng *et al.,* 2020). The carbon content decreased as aggregates become smaller than 1-2 mm size because of decrease in humic fractions in small aggregates. Irrespective of soil depths, poplar + turmeric cropping system (CS_1) has significantly higher AAC (8.3 g kg^{-1} soil) in size fraction of 1.0-2.0 mm compared to CS_2, CS_3, CS_4 and CS_5 by 12.2, 16.9, 38.3 and 18.5 per cent respectively. 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 by 23.7, 18.3 and 16.7 per cent respectively. In size fraction of 0.5-1.0 mm, CS_1 has significantly higher AAC than CS_3, CS_4 and CS_5 by 16.1, 30.9 and 18.0 per cent respectively. However 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 by 30.8 per cent. The AAC in 0.25-0.5 mm size aggregates in CS_1, CS_2, CS_3 and CS_5 was at par. In micro aggregates (0.1-0.25 mm size) AAC was at par in all cropping systems.

Irrespective of cropping systems, depth wise AAC decreased in all size aggregates. In aggregates of 1.0-2.0, 0.5-1.0 and 0.25-0.5 mm size the AAC was significantly higher in 0-7.5 cm depth compared to 7.5-15, 15-22.5 and 22.5-30 cm depths because of more root biomass carbon. In all size fractions, no significant difference in AAC was observed in 7.5-15, 15-22.5 and 22.5-30 cm soil depths because of less difference in SOC (Table 1). 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 as related to SOC pattern(Table 1).

Macro-aggregates provide physical protection to organic carbon from decomposition (Benbi and Senapati, 2010). Improved AAC 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 (Anshuman *et al.,* 2021). The lowest AAC in CS_4 (ratoon sugarcane fodder) may be due to less soil organic carbon (Table 1).

a)



b)

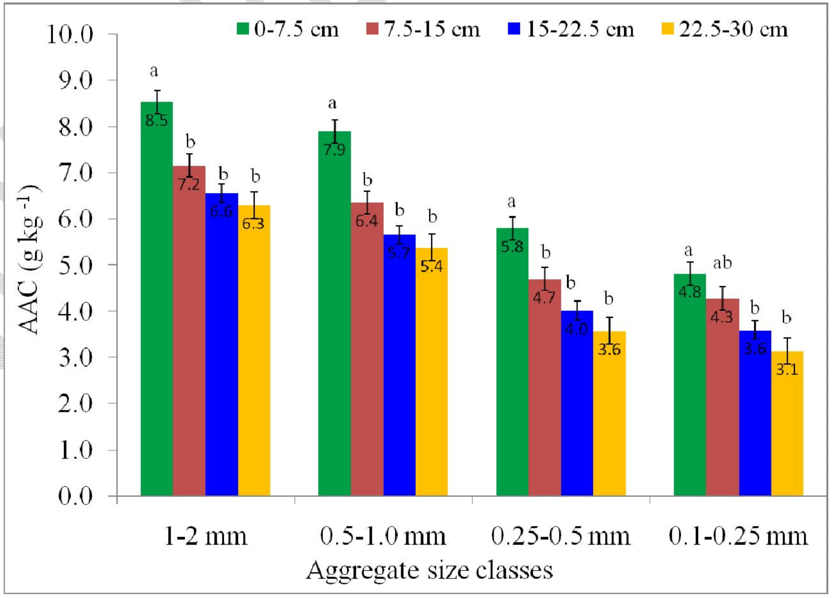


Fig. 1 Aggregate associated carbon (g kg^{-1}) in relation to different cropping systems (a) and soil depths (b). Vertical bars and dissimilar letters indicate standard errors of means and significant differences at 5% level of significance respectively

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 (8.13) value than CS_1, CS_2, CS_3 and CS_5 by 4.6, 2.7, 8.3 and 4.9 per cent respectively. No significant difference in pH was observed between CS_1 and CS_5. Soil pH of CS_3 (7.51) was significantly lower than all other cropping systems. Lowering of soil pH of alkaline soil in Basmati rice-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 was lower in top soil and it increased with soil depth. These lower pH values may be because of higher organic matter In the topsoil and the decomposition of organic matter will lead to the production of more organic acids, thus lowering pH of topsoil (Hong *et al.,* 2019). In 15-22.5 cm and 22.5-30 cm depths pH was significantly higher by 2.7 and 4.0 per cent than 0-7.5 cm depth. 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) by 27.5, 28.7, 22.3 and 21.9 percent respectively. 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. Soil EC in 7.5-15, 15-22.5 and 22.5-30 cm depths was significantly decreased by 9.6, 19.9 and 30.2 per cent respectively. 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 water stable soil aggregates (WSA) in different cropping systems at different depths and seasons is presented in Table 5. Irrespective of depths, CS_1 has significantly higher WSA than CS_2, CS_3, CS_4 and CS_5 by 6.2, 9.5, 19.1 and 12.8 per cent respectively. However, no significant difference in WSA was observed among CS_2, CS_3 and CS_5 but these have significantly higher WSA than CS_4 by 12.9, 9.6 and 6.3 per cent respectively. The order of decrease in WSA with different cropping systems is $CS_1>CS_2>CS_3>CS_5>CS_4$. Irrespective of cropping systems, the WSA 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. In 0-7.5 cm depth WSA were significantly higher than 7.5-15.0, 15.0-22.5 and 22.5-30.0 cm depth 6.9, 16.1 and 23.9 per cent respectively.

Table 5 Effect of different cropping systems on water stable soil aggregates (per cent) at varying soil depths

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 of 0.1-0.25 mm size among all sized aggregates and 1-2 mm sized aggregates 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 0.1-0.25 mm size, CS_3 has significantly higher per cent aggregates than all other cropping systems. Overall the higher proportion of macro-aggregates was observed for 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 $CS_3 > CS_4 > CS_5 \geq CS_2 = CS_1$. 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 al.,* 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 al.,* 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). Water stable 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 (MWD) of soil aggregates

Irrespective of depths, CS_1 has significantly higher MWD than CS_2, CS_3, CS_4 and CS_5 by 1.22, 1.67, 2.04 and 1.52 times respectively (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 by 1.22 and 1.33 times respectively. 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 because of higher soil organic carbon in the surface layers (Table 1) as Chellappa *et al., (*2021) also observed positive relation between soil organic carbon and MWD.

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

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

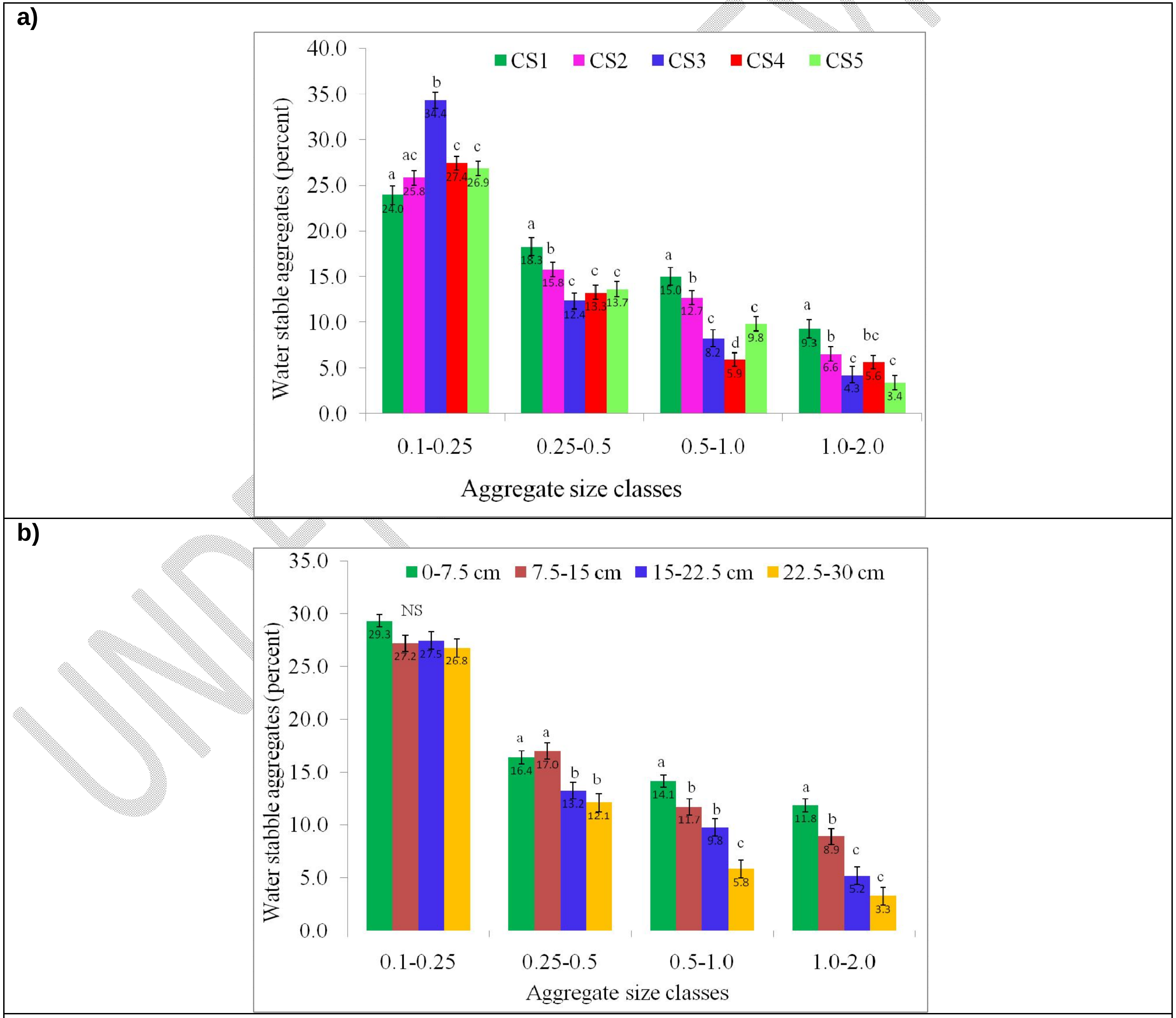


Fig. 2 Water stable aggregates (percent) in different size fractions in relation to cropping systems

(a) and soil depths (b). *Vertical bars and dissimilar letters indicate standard errors of means and significant differences at 5% level of significance respectively

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 Mamta *et al.,* (2020) observed lower bulk density in maize-chick pea rotation compared to maize-maize cropping system. 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 soil organic carbon was observed in poplar + turmeric cropping system which further resulted improvement in aggregate associated carbon, water stable aggregates, 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 physico-chemical properties were more in surface soil layers compared to sub surface soil layers. Thus, poplar + turmeric cropping system is promising for build-up of soil 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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