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Impact of Soil Texture on Different Organic Carbon Pools in Sirsa District of Western Haryana, India

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Abstract

Soil organic carbon (SOC) pools are important in maintaining soil productivity and influencing the CO_2 loading into the atmosphere. Different soil textural classes of Sirsa district, Haryana were compared for SOC and its fractions *viz*; active (very labile, VLSOC; labile, LSOC) and passive (less labile, LLSOC; non-labile, NLSOC) pools. Maximum OC (0.66%) and TOC (0.78%) was observed in clay loam texture compared to loamy sand, sandy loam, loam and clay loam texture. Similarly, highest VLSOC (0.47%) and LSOC (0.11%) pools were recorded in sandy soils whereas highest LLSOC (0.12%) and NLSOC (0.18%) pools were recorded in clay loam soils compared to other textures. Highest RI_1 (0.50) and RI_2 (0.23) were found in clay loam soils whereas highest carbon lability index (CLI) was found in sandy (3.96) soils. The texture of soil significantly impacted SOC and its associated pools. VLSOC had significant positive correlation with LSOC ($p \leq 0.05$), while LSOC showed significant positive correlation with VLSOC ($p \leq 0.01$). Similarly, LLSOC had significant positive correlation with NLSOC reciprocated by NLSOC exhibiting a significant positive correlation with LLSOC ($p \leq 0.01$). Therefore, correlation amongst the pools of C showed that most of the pools were significantly correlated with each other.

Key words: Soil organic carbon pools, Soil texture, Recalcitrant index, Carbon lability index

Introduction

Soil organic carbon (SOC) plays a crucial role in sustaining soil resilience, which affects ecosystem services and climate change (Bhattacharyya *et al*., 2009; Wong *et al*., 2010). Since soil contains most of the terrestrial carbon, any effort to increase its concentration is likely to enhance the biological properties of soil. Due to its profound effects on climate change and potential benefits for crop productivity, understanding the dynamics of organic carbon accumulation in agricultural soils is becoming more and more important. By enhancing soil fertility and productivity, good agricultural practices can transform such soil into a net sink for carbon, reducing the amount of CO_2 in the atmosphere (Lal, 2004). The amount of soil organic carbon (SOC) at a given time represents the long-term equilibrium between the addition of organic carbon from various sources and its depletion via various pathways. Naturally, it (SOC) varies with land usage, soil type, soil texture and climate zone (Swarup *et al.,* 2000). Large-scale intensive cropping causes long-term balance disruption due to large-scale addition of carbon to the soil through crop residues. This carbon influx either results in a net build-up or depletion of SOC stock, or it exposes more and more of the C to oxidative losses due to continued cultivation (Kong *et al*., 2005). This stock of SOC is made up of stable, passive, recalcitrant pools with different residence times, as well as labile or actively cycling pools. Among these, the portion of SOC with the fastest turnover rates is known as the labile carbon pool (LCP). The movement of CO_2 from soils into the atmosphere is caused by oxidation of this particular carbon pool. LCP is crucial because it feeds the soil food web, which in turn affects nutrient cycling, critical for maintaining soil productivity and quality (Chan *et al*., 2001; Mandal, 2005; Mandal *et al*., 2007). The majority of current techniques for calculating SOC were created to optimize C oxidation and recovery (Walkley and Black, 1934; Nelson and Sommers, 1982). The characterization of SOC resulting from various soil management practices, such as cropping systems and the application of organic and inorganic sources of nutrients, may benefit from the use of techniques that can preferentially extract the more labile pools.

Carbon pool that is not readily available for microorganisms to access and require more time to decompose is the recalcitrant carbon pool (Lal, 2004). Recalcitrant carbon pools are highly variable in terms of their chemical composition and state of decomposition, and they are important for the health and function of soil (Stevenson, 1994). Humic compounds comprise 60%–80% of the total SOC and have the highest concentration of humin (de Almeida *et al*., 2014). Due to its higher fraction of aromatic functions and bonds to mineral components, humin has the strongest resilience against microbial degradation and is found in the highest concentration in soil (Lal, 2004). Thus, in tropical environments, both labile and recalcitrant carbon pools can provide information about the soil's past utilization and the best management practices for increasing carbon stocks (Basak *et al*., 2021)

The amount and distribution of different SOC pools depends on several factors like temperature, moisture, land use management, soil texture, agronomic practices etc. Among these factors, soil texture is a critical determinant of SOC pools within specific climatic conditions as protection of soil organic carbon from microbial breakdown strongly relies on soil texture. Hereunder, our objective was to determine how the quality and concentration of SOC pools varied among the various soil texture in Sirsa district of Haryana, India.

Material and Methods

Description of study area

Sirsa is a north-western district of Haryana state, located between latitudes 29°14' to 30°0' N and longitudes 74°29' to 75°18' E. Out of total geographical area of 4276 km^2, 4050 km^2 area is under cultivation.

The seven blocks of the district—Nathusari Choupta, Rania, Sirsa, Baragudha, Odhan, Ellenabad, and Dabwali—are included in the study area (Fig. 1). The Sirsa district has a hot, dry tropical climate. In May and June, the mean

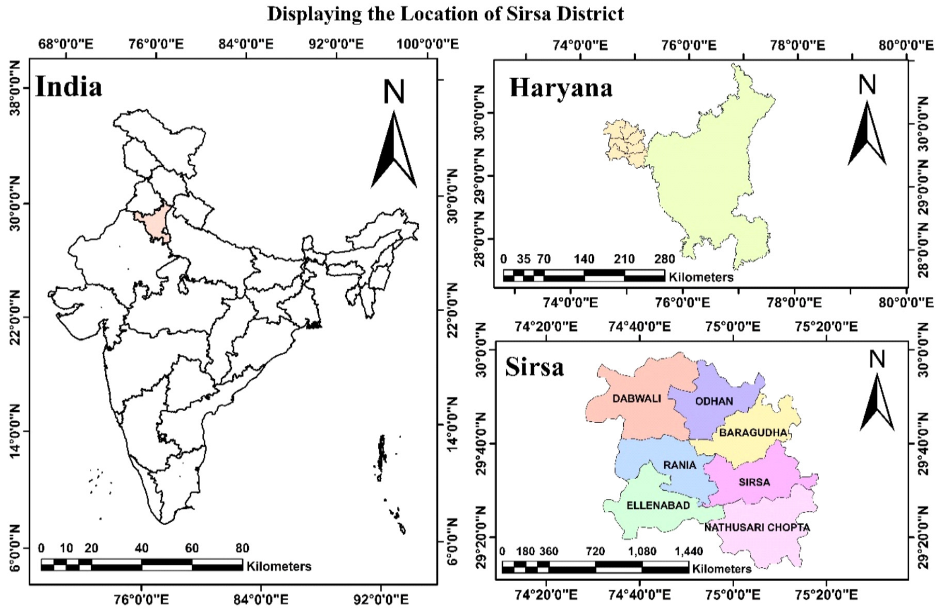

Fig. 1 Location map of study area

maximum temperature is 41.1°C, while in January, the mean lowest temperature is 5.1°C. The district receives an average rainfall of 318 mm, including 253 mm of monsoon rainfall. Major cropping systems in the area are cotton- wheat, rice – wheat, groundnut – mustard, pearl millet – wheat, cluster bean – mustard, green gram – wheat and guava.

Soil sampling and laboratory analysis

Total 350 soil samples (up to 0-15 cm soil depth) were collected randomly from seven blocks of Sirsa district. Out of these samples 15 samples from each texture (determined by feel method) except clay loam (7) sorted for further analysis. All the samples were brought to the lab, air-dried, manually crumbled to remove the root materials, and then passed through 0.5 mm sieve. The pH and electrical conductivity of soils were measured using 1:2 soil-water suspension with standard procedures as described by Jackson (1973). Organic carbon (OC) was determined using the rapid titration method (Walkley and Black, 1934). Total organic carbon(TOC) content of soil samples was evaluated by wet oxidation method using a 1N $K_2Cr_2O_7$ (potassium dichromate) solution followed by one hour of heating at 150°C (Snyder and Trofymow, 1984).

Oxidizable pools of SOC

The oxidisable organic C content of the soil was determined by modified Walkley and Black method as described by Chan *et al*. (2001) (Table 1). The total organic C (TOC) might be divided into the following four pools based on decreasing order of oxidizability.

The VLSOC and LSOC together constitute the active pool [Active pool = Σ(VLSOC + LSOC)]; while LLSOC and NLSOC collectively represents the passive pool [Passive pool = Σ(LLSOC + NLSOC)] of organic C in soils (Chan *et al*., 2001).

Carbon Lability Index (CLI)

Equation (1) provided by Majumder et al. (2007) was used to calculate the carbon lability index (CLI) of SOC based on the relative oxidizability of the CVL, CL, and CLL pools of SOC.

$$\text{Carbon Lability Index (CLI)} = \frac{VLSOC}{TOC} \times 3 + \frac{LSOC}{TOC} \times 2 + \frac{LLSOC}{TOC} \times 1 \quad (1)$$

Recalcitrant Index (RI)

The recalcitrant index (RI) of SOC was computed to assess effect of soil texture on the stability of organic C in the soil by using Equations (2) and (3) given by Datta *et al*. (2018) as:

$$RI_1 = \frac{CLL+CNL}{CVL+CL} \quad (2)$$

$$RI_2 = \frac{CNL}{TOC} \quad (3)$$

Between the two indices, RI_1 indicates the relative amount of labile and non-labile SOC pools; on the other hand, RI_2 represents the percentage of non-labile. To evaluate the soil organic C stability, place the SOC pool over the TOC. RI mean was determined by averaging RI_1 and RI_2 for the corresponding soil texture (Basak *et al*., 2021).

Descriptive statistics of the analysed soil data viz., minimum, maximum , mean value and standard deviation were determined using SPSS software (29.0.1.0). Correlation matrix among different parameters was prepared using OPSTAT software of Haryana Agricultural University (Sheoran *et al*., 1998).

Table 1. Description of soil organic carbon pools

S.No.	Carbon Pools	Description
1.	VLSOC, Very Labile Soil Organic Carbon	Organic C oxidizable under 12.0 N H_2SO_4
2.	LSOC, Labile Soil Organic Carbon	Difference in SOC extracted between 18.0 N and 12.0 N H_2SO_4
3.	LLSOC, Less Labile Soil Organic Carbon	Difference in SOC extracted between 24.0 N and 18.0 N H_2SO_4 (the 24.0 N H_2SO_4 is equivalent to the standard Walkley and Black method)
4.	NLSOC, Non-Labile Soil Organic Carbon	Residual organic C after reaction with 24.0 N H_2SO_4 when compared with TOC

Table 2. Descriptive statistics of physico-chemical properties of soil under different texture in Sirsa district

Soil Texture	pH				EC (dS m^{-1})				OC (WBC) (%)				TOC (%)			
	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
Sandy	8.70	7.40	8.27	0.22	0.75	0.16	0.32	0.18	0.51	0.30	0.38	0.06	0.53	0.35	0.43	0.05
Loamy Sand	8.74	7.50	8.35	0.17	0.82	0.12	0.37	0.22	0.55	0.32	0.45	0.06	0.66	0.41	0.55	0.08
Sandy Loam	8.71	7.50	8.38	0.18	0.69	0.15	0.35	0.23	0.61	0.40	0.52	0.06	0.72	0.49	0.63	0.07
Loamy	8.75	7.55	8.47	0.18	0.71	0.20	0.38	0.16	0.77	0.50	0.62	0.08	0.88	0.62	0.76	0.08
Clay Loam	8.80	7.62	8.48	0.15	0.80	0.34	0.41	0.19	0.75	0.55	0.66	0.07	0.90	0.72	0.78	0.05

EC: Electrical Conductivity; OC: Organic Carbon (Walkley and Black Carbon); TOC: Total Organic Carbon; SD: Standard Deviation

Results and Discussion

Soil pH and electrical conductivity

It was observed that soil pH varied significantly under different soil texture. Average soil pH of sandy, loamy sand, loam, sandy loam, clay loam texture was 8.27, 8.35, 8.38, 8.47 and 8.48, respectively (Table 2). Among different soil texture, the lowest soil pH was observed in sandy (8.27) soils whereas the highest soil pH was observed in clay loam (8.80) soils. This might be due to more leaching of basic ions in sandy soils compared to clay loam soils (Ulrich and Sumner, 2012).

Electrical conductivity exhibited variability under different soil texture. Average EC of sandy, loamy sand, loam, sandy loam, clay loam texture was 0.32, 0.37, 0.35, 0.38, and 0.41 dS m^{-1}, respectively (Table 2). The highest EC was recorded in clay loam (0.80 dS m^{-1}) texture while lowest EC was recorded in sandy (0.32 dS m^{-1}) soils. This was probably due to higher surface area in clay loam soils than sandy soils, that facilates more particle-to-particle contact, coupled with higher moisture retention capacity, making them more conductive (Rhoades and Corwin, 1990).

Soil organic carbon (Walkley and Black carbon) and total organic carbon

Maximum SOC (0.66%) and TOC (0.78%) content was recorded in clay loam soils while minimum value of SOC (0.38%) and TOC (0.43%) were recorded in sandy soils (Table 2). This might be due to less aeration in clay loam soil texture, which results in lower rate of oxidation of organic matter and consequently increase the carbon storage (SOC and TOC) (Antil *et al.*, 2016; Gora, 2013).

Soil organic carbon fractions

Oxidizable fractions of organic carbon significantly varied under different soil texture. Maximum VLSOC (0.47%) and LSOC (0.11%) fractions were observed in sandy texture while minimum VLSOC (0.18) and LSOC (0.05%) fractions was observed in clay loam soils (Table 3). It might be attributed to more aeration in sandy soils which promotes the conversion of non-labile or recalcitrant pool in very labile and labile pools by decomposition process (Gillis and Price, 2011; Marschner *et al.*, 2008). Similarly, maximum LLSOC (0.12%) and NLSOC (0.18%) pools were recorded in clay loam soils whereas minimum

Table 3. Descriptive statistics of oxidizable organic carbon pools under different soil texture in Sirsa district

Soil Texture	VLSOC (%)				LSOC (%)				LLSOC (%)				NLSOC (%)			
	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
Sand	0.56	0.35	0.47	0.06	0.09	0.01	0.11	0.03	0.13	0.02	0.06	0.03	0.11	0.01	0.05	0.03
Loamy Sand	0.55	0.37	0.44	0.05	0.11	0.01	0.10	0.03	0.27	0.02	0.08	0.07	0.15	0.03	0.09	0.03
Sandy Loam	0.53	0.31	0.38	0.06	0.24	0.01	0.08	0.05	0.13	0.02	0.09	0.03	0.19	0.01	0.11	0.05
Loamy	0.33	0.23	0.28	0.03	0.24	0.03	0.05	0.05	0.25	0.02	0.10	0.06	0.19	0.11	0.15	0.03
Clay Loam	0.23	0.14	0.18	0.03	0.28	0.05	0.05	0.06	0.21	0.02	0.12	0.06	0.25	0.09	0.18	0.04

VLSOC: Very Labile Soil Organic Carbon; LSOC: Labile Soil Organic Carbon; LLSOC: Less Labile Soil Organic Carbon; NLSOC: Non-Labile Soil Organic Carbon

LLSOC (0.06%) and NLSOC (0.05%) pools were recorded in sandy soils (Table 3). This might be due to less aeration in clay loam soils and consequently lower rate of decomposition of less labile and non-labile or recalcitrant carbon pools (Marschner *et al.*, 2008).

Recalcitrant index (RI) and carbon lability index (CLI)

Maximum RI$_1$ (0.50) and RI$_2$ (0.23) were observed in clay loam soils whereas minimum RI$_1$ (0.38) and RI$_2$ (0.11) were observed in sandy soils (Table 4). This might be due to higher amount of recalcitrant carbon and less labile carbon in clay loam soil (Basak *et al.*, 2021). Highest CLI (3.96) was recorded in sandy soils while minimum (0.91) was recorded in clay loam soils (Table 4). This might be attributed to higher amount of very labile, labile and less labile pools in sandy soils (Basak *et al.*, 2021).

Relationship among different organic carbon pools and soil properties

Correlation analyses revealed a significant correlation among majority of carbon pools (Table 5). Soil pH showed significant positive correlation with OC, TOC, LLSOC and NLSOC ($p \leq 0.01$). EC also displayed significant positive correlation with OC, TOC, LLSOC, NLSOC ($p \leq 0.05$). Similarly, TOC showed significant positive correlation with LLSOC and NLSOC ($p \leq 0.01$). VLSOC had significant positive correlation with LSOC ($p \leq 0.05$) and strong negatively correlation with LLSOC and NLSOC ($p \leq 0.01$). LSOC showed significant positive correlation with VLSOC ($p \leq 0.01$) whereas strong negative correlation with LLSOC and NLSOC ($p \leq 0.01$) was recorded. Similarly, LLSOC had significant positive correlation with NLSOC and NLSOC had significant positive correlation with LLSOC ($p \leq 0.01$).

Table 4. Descriptive statistics of recalcitrant index-1 (RI$_1$), recalcitrant index-2 (RI$_2$) and carbon lability index (CLI)

Soil Texture	RI$_1$				RI$_2$				CLI			
	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
Sand	0.91	0.10	0.38	0.25	0.25	0.02	0.11	0.07	4.84	2.99	3.96	0.51
Loamy Sand	0.87	0.22	0.50	0.19	0.26	0.07	0.17	0.06	3.77	2.37	3.05	0.53
Sandy Loam	0.64	0.16	0.39	0.14	0.27	0.02	0.18	0.07	2.56	1.91	2.15	0.20
Loamy	0.70	0.25	0.47	0.13	0.23	0.11	0.18	0.04	1.72	1.11	1.40	0.18
Clay Loam	0.63	0.35	0.50	0.10	0.28	0.12	0.23	0.05	0.98	0.76	0.91	0.08

RI: Recalcitrant Index; CLI: Carbon Lability Index; SD: Standard Deviation

Table 5. Correlation among different soil properties and carbon fractions

Variable	pH	EC	OC (WBC)	TOC	VLSOC	LSOC	LLSOC	NLSOC	RI$_1$	RI$_2$	CLI
pH	1										
EC	0.901^{*}	1									
OC (WBC)	0.990^{**}	0.879^{*}	1								
TOC	0.997^{**}	0.878^{*}	0.994^{**}	1							
VLSOC	-0.937^{*}	-0.877^{NS}	-0.971^{**}	-0.939^{*}	1						
LSOC	-0.979^{**}	-0.815^{NS}	-0.989^{**}	-0.984^{**}	0.949^{*}	1					
LLSOC	0.959^{**}	0.931^{*}	0.973^{**}	0.962^{**}	-0.963^{**}	-0.927^{*}	1				
NLSOC	0.985^{**}	0.925^{*}	0.993^{**}	0.985^{**}	-0.975^{**}	-0.965^{**}	0.991^{**}	1			
RI$_1$	0.636^{NS}	0.866^{NS}	0.561^{NS}	0.582^{NS}	-0.554^{NS}	-0.492^{NS}	0.626^{NS}	0.632^{NS}	1		
RI$_2$	0.889^{*}	0.935^{*}	0.890^{*}	0.890^{*}	-0.870^{NS}	-0.813^{NS}	0.967^{**}	0.930^{*}	0.679^{NS}	1	
CLI	-0.929^{*}	-0.922^{*}	-0.883^{*}	-0.919^{*}	0.791^{NS}	0.837^{NS}	-0.905^{*}	-0.904^{*}	-0.759^{NS}	-0.821^{*}	1

*Significant at the 0.05 level (2-tailed) and **Significant at the 0.01 level (2-tailed)

EC: Electrical Conductivity; OC (WBC): Organic Carbon (Walkley and Black Carbon); TOC: Total Organic Carbon; VLSOC: Very Labile Soil Organic Carbon; LSOC: Labile Soil Organic Carbon; LLSOC: Less Labile Soil Organic Carbon; NLSOC: Non-Labile Soil Organic Carbon; RI: Recalcitrant Index; CLI: Carbon Lability Index

Conclusions

This study underscores the role of soil texture in shaping SOC dynamics. A consistent trend was recorded where higher clay and silt content increased SOC levels under similar climatic conditions. Highest SOC and TOC was recorded in clay loam soils. Similarly, highest very labile and labile fraction were recorded in sandy soils whereas less labile and non-labile or recalcitrant carbon were recorded in clay loam soils. Furthermore, indices like RI1, RI2, and CLI exhibit texture-specific patterns, affirming the profound effect of soil texture on organic carbon variations. The interrelationships observed among different carbon pools through correlation analyses further emphasize the interconnected nature of these fractions within soil systems, highlighting the complex dynamics governed by soil texture.

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