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Assessment of Soil Organic Carbon in particle-size aggregates under agricultural-land use types in subtropical India

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Abstract: *The aim of present study was to evaluate the levels and spatio-temopral variation of Soil Organic Carbon (SOC) in different particle-size aggregates (bulk, coarse sand, fine sand and silt+clay) in the agricultural field of National Capital Region (NCR) in subtropical India. Soil samples were collected from peri-urban vegetable cultivation areas during three seasons of 2011-12. The conventional analytical method (Walkley Black) was used to estimate the SOC levels for all the particle-size aggregates. The results showed that the mean SOC in bulk samples was 10.97 mg g^{-1} while values for Fraction-I (Coarse sand), Fraction-II (Fine sand) and Fraction-III (silt + clay) were estimated to be 9.17±1.87 mg g^{-1}, 12.61±3.08 mg g^{-1} and 18.04±3.81 mg g^{-1}, respectively during overall studied period. Distinct seasonal differences have been noticed in the levels of SOC in bulk and fractional samples as highest in winter followed by monsoon and summer. Different photochemical degradation rate due to temperature variation during different seasons could be attributed as reason for seasonal variability of SOC. The levels of SOC is increased with decreasing of the soil particle size aggregates which infers silt+clay having highest contribution followed by fine sand and coarse sand. Silt+clay are governing factor for SOC enrichment in soil because greater surface area to volume ratios of such finer particles provides more potential binding sites for organic carbon. Detailed investigation of SOC storage alongwith edaphic/vegetation factors and land use change is required to understand carbon sequestration, quality and sustainability of agricultural soil.*

Keywords: *Agriculture, NCR, Particle-size aggregates, Seasonal variability, Soil Organic Carbon*

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I. Introduction

Soil is a major reservoir for carbon (C) in terrestrial ecosystems stored about 1400–1600 Pg (1 Pg=10^{15} g) carbon in the form of organic material. It is approximately two and three times of the atmospheric C pool and aboveground biomass, respectively (Zhang et al. 2007). Approximately 10% (111-170 Pg) carbon of the earth's total soil carbon was estimated to be stored in the agricultural soil (Kong et al. 2005). Three basic forms of carbon namely; elemental, inorganic and organic are present in the soil. Elemental carbon is an incomplete combustion product of organic matter which includes charcoal, soot, graphite and coal or it is formed via geologic sources. Further, inorganic carbon present in the form of carbonates such as Calcite ($CaCO_3$), Dolomite [$CaMg(CO_3)_2$] and Siderite ($FeCO_3$) whereas organic carbon formed due to decomposition of plants and animals (Schumacher 2002).

Soil organic carbon (SOC) is considered as source and sink of atmospheric CO_2 which mainly depends on land-use practices, soil texture, climatic conditions, vegetation and topography (Choudhury et al. 2013; Dorji et al. 2014). SOC is sensitive to impact of human activities, viz. deforestation, biomass burning, land use changes and environmental pollution. Land use/cover change is one of the important features which influence storage and distribution of SOC in the terrestrial environment (Liu et al. 2013). Even a small change in SOC storage could greatly affect atmospheric CO_2 concentrations (Cheng et al. 2013). SOC acts as an important determinant factor of soil quality which affects the physico-chemical and biological functions (structure maintenance, nutrient cycling, retention of organic pollutants and water) of the soil (Choudhury et al. 2013; Jandl et al. 2014). The amount of SOC in different kinds of soil vary in the range from < 1% (sandy soils) to >20% (wetlands or bogs soil). In case of agricultural ecosystem, various reports stated that SOC pools increased due to more vegetable cultivation (Kong et al. 2006; Zhang et al. 2007). Soils which are managed with no-tillage and intensified cropping systems could increase SOC at the rate of 0.1% per year (McVay and Rice 2002).

SOC plays a crucial role in the adsorption, degradation, binding, mobility, bioavailability and bioaccumulation of organic pollutants such as Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs) and Organochlorine Pesticides (OCPs) with soil (Meijer et al. 2003; Sweetman et al. 2005; Syed et al. 2011). Sorption of organic chemicals with SOC is an important process because it controls the fate and eco-toxicological risks of soil-bound pollutants (Cornelissen et al. 2005). Different particle size of the soil (sand, silt and clay) is a significant factor which governs the distribution pattern of SOC in soil (Christensen 1992). As the physico-chemical properties (specific surface area, size, shape, buffering capacity and cation exchange capacity) of the different size fractions vary, the interaction of SOC with these size fractions also vary (Ray 2009). Therefore, an investigation of SOC levels in different size fractions of soil is significant as it provides information about the retention of SOC.

A number of studies have been performed among the scientific community in terms of SOC to understand the soil properties, carbon sequestration, land categorisation and sustainability of agricultural ecosystem (Ray et al. 2012; Choudhury et al. 2013; Jandl et al. 2014; Udom et al. 2015; Li et al. 2016). However, there is dearth of literatures regarding SOC in agricultural soil of National Capital Region (NCR) in India. In addition to this, no detailed study regarding an estimation of SOC in different size fractions of the agricultural soil has been carried out. Thus, the current work presents as first effort to measure SOC in soil with the following objectives: (a) To estimate the levels of SOC in bulk and different size fractions of agricultural soil in NCR, India; (b) Seasonal and spatial variability of SOC in bulk and different size fractions; (c) Percentage contribution and correlation of different fraction in the bulk soil and (d) Comparison of observed SOC in the present work with the previous studies.

II. Materials And Methods

2.1 Study area

The present study was conducted in National Capital Region (NCR) of India which mainly comprises of Delhi and adjoining towns. It lies between 27° 03′ to 29° 29′ N latitude and 76° 07′ to 78° 29′ E longitude. The region has humid to semi-arid climatic conditions with extremely hot summers and moderately cold winters. The average annual temperature is about 22 °C while annual average precipitation is 500–700 mm. The NCR climate is majorly influenced by the Himalayas in the north and the Thar Desert in the west. The approximate area of NCR in India is 46208 km^2, of which the major agricultural part is stretched over floodplain of river Yamuna. The floodplain of Yamuna is very fertile as it is enriched with silt and alluvium deposits.

In the last 25 years, land use pattern of Delhi (covered major portion of NCR) has been changed drastically due to rapid population growth, intensive urbanization and industrialization. It is reported that the agricultural practices are performed on approximately 42 % of the total area in Delhi, of which 35 % accounts for vegetable cultivation (Babu et al. 2000; Chourasiya et al. 2014). Peri-urban area of NCR is also thoroughly cultivated with vegetable crops because of greater market demand and higher returns to the farmers (NAAS 2004).

2.2 Description of the sampling sites

Fourteen different sites from seven blocks (2 sites from each block) having intensive vegetable cultivation in the NCR of India, were chosen as sampling sites for the present study (Fig. 1). The abbreviations of the selected seven blocks are as follows: Kanjhawala (KJ), Najafgarh (NG), Mehrauli (MR), Shahadra (SD), Alipur (AP), Ghaziabad (GB) and Faridabad (FB). As shown in Fig. 1, five major agricultural blocks (KJ, NG, MR, SD and AP) comes under the peri-urban area and mainly situated in different directions of Delhi in NCR. The studied blocks KJ, NG and AP are situated in the northwest, south west and north direction of the NCR, respectively. MR is located in the south where soil is mainly characterized as sandy loam to loam texture while SD covers the area of Yamuna flood plain positioned in east of Delhi. Further, other two blocks GB and FB are well known for intensive agricultural practices.

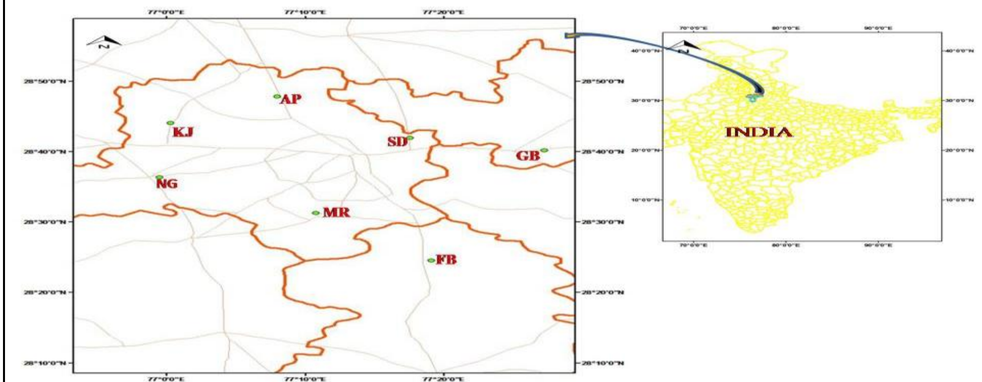

Fig. 1 Geographical locations of sampling sites in NCR, India

2.3 Sample collection and processing

To examine the levels of SOC, soil samples were collected from the studied sites during three season namely, monsoon, winter and summer (2011-12). Soil samples were taken at the depth of 0-10 cm using a stainless steel soil auger. All the necessary precautions were taken before the soil sampling which includes the removal of grass, twigs and other plant debris from the surface of each sampling location. Afterwards, soil samples were put in sterile polyethylene bags transported to the laboratory and was kept in refrigerator at 4 $^{\circ}C$ until analysis.

Firstly, soil samples were dried in dark room at the room temperature. Before making composite sample, these samples were pooled and homogenised. Removal of pebbles, plant debris and leaves were done by hand picking and coarse sieving. To break the large size soil aggregates, soil samples were crushed gently. Afterwards, soil samples were sieved through 2 mm sieve and representative samples were obtained after quartering and coning. Quartering and coning is a method in which soil sample is mixed and shaped into a circular heap cone. The heap was then divided diametrically into four equal quarters. Two opposite quarters were discarded and the remaining two opposite quarters were retained and formed into a second heap cone. The process was repeated until the four equal quarters contain the desired amount (100 g) of sub-samples.

2.4 Fractionation of soil samples

Soil samples were fractionated by sieving using sequential sieve sizes from 2000 µm down to 53 µm mounted on a sieve shaker, Fritsh Analysette (Germany), Type-03.502, No. 6635. Four fractions in the present study are as follows: 0 - 2000 µm (Bulk sample) – Bulk, 500 - 2000 µm (Coarse sand) – Fraction I, 53 - 250 µm (Fine sand) – Fraction II and <53 µm (Clay + silt) – Fraction III.

2.5 Analytical procedure for SOC estimation

Literature suggested various non-destructive and destructive methods can be applied for the estimation of SOC. The most common technique is destructive techniques which involves sample preparation or pre-treatment followed by sample extraction and quantification. The three different principles of the destructive methods are as: (a) Wet oxidation followed by titration with ferrous ammonium sulphate (Walkey and Black 1947) or photometric determination of Cr^{3+}. (b) Wet oxidation followed by collection and measurement of evolved CO_2 and (c) Dry combustion at high temperatures in a furnace with the collection and detection of evolved CO_2 using carbon analyzer (Carter and Greorich 2006). On the other hand, non-destructive technique is based on the principal of non-elastic neutron scattering process (Schumacher 2002).

The wet oxidation method followed by titration with ferrous ammonium sulphate is a conventional and most frequently used method. Therefore, SOC was analysed using this conventional method (Walkely and Black 1947) and the results were verified on CHNSO analyzer (Euro Elemental Analyzer, Euro Vector EA3000).

2.6 Statistical analysis

Statistical analyses were carried out by SPSS (version 16.0.; SPSS Inc., Chicago, IL, USA). Paired sample t-test was used to compare the difference in the levels of SOC in various fractions. In addition to this, the seasonal difference was checked using ANOVA test. Regression analysis was performed to evaluate the association of different fractions with bulk samples. A significance value of 0.05 was used in all statistical testing.

III. Results And Discussion

3.1 Soil Organic Carbon (SOC) in NCR agricultural soil

A total number of 168 soil samples including one bulk and three fractions have been taken into consideration for SOC analysis. Fig. 2 illustrates the variability of Soil Organic Carbon (SOC) in bulk and three fractions of soil samples at the studied locations during the whole observation period. It shows the box whisker plots indicating the 25th, 50th (median) and 75th percentile of the SOC. In addition, whiskers above and below the box indicate maximum and minimum values, respectively. It is noted that the mean concentration of SOC in bulk samples was found to be 10.97 mg g^{-1} (ranged from 4.87 to 19.6 mg g^{-1}) in the present study. Similar results of SOC have been observed in agricultural soil (ranged from 3 to 25 mg g^{-1}) and rural soil (11.6±3.71 mg g^{-1}) of Delhi region (Agarwal et al. 2011; Ray et al. 2012). The studies carried out in horticulture and farmland soil from Hohhot, North-West China and Hong-Kong showed similar mean levels of SOC as 13.3 mg g^{-1} and 12.3 mg g^{-1} , respectively (Zhang et al. 2006; Zhang et al. 2013). However, much higher concentrations of SOC (ranged from 2.2 to 36.6 mg g^{-1}) were observed in the bulk samples of agricultural surface soil in Jiulong River, China (Zhang et al. 2012).

After examining the SOC concentrations in fractional samples, it is noted that mean values of SOC in Fraction-I (coarse sand) were found to be lower (9.17±1.87 mg g^{-1}) as compared to bulk samples. On the other hand, Fraction-II (fine sand) and Fraction-III (silt+clay) showed greater accumulation of SOC with average level of 12.61±3.08 mg g^{-1} and 18.04±3.81 mg g^{-1}, respectively. The concentration ranges of SOC are observed as 4.18 to 14.75 mg g^{-1}, 6.43 to 21.53 mg g^{-1} and 9.70 to 27.93 mg g^{-1} for coarse sand, fine sand and silt+clay, respectively during the whole studied period.

Frequency distribution of SOC for all the fractions of the soil have been evaluated and depicted in Fig. 3. It is the graphical representation of SOC levels in each category range on the scale of measurement. It provides the information regarding which category range has higher and lower frequency of SOC. Results explained that the frequency of SOC is higher in the range of 5-10 mg g^{-1} for bulk and coarse sand, both. However, find sand and silt+clay showed higher SOC in the range of 10-15 and 15-20 mg g^{-1}, respectively.

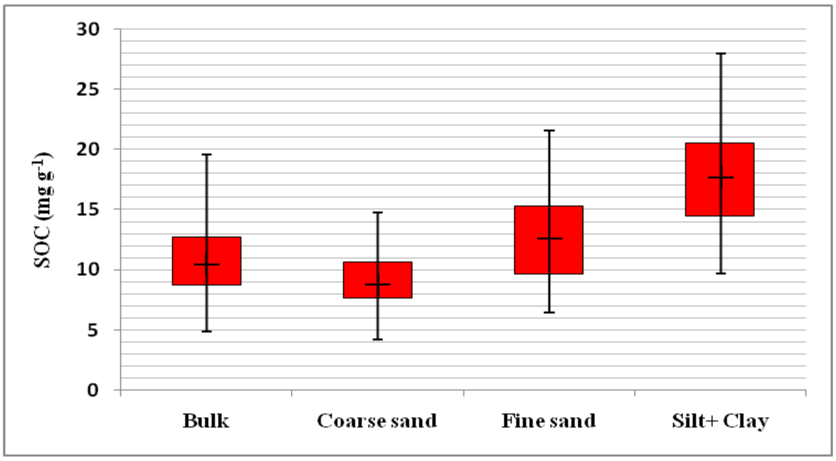

Fig. 2 Box plot showing SOC concentrations in bulk and different fractions of soil

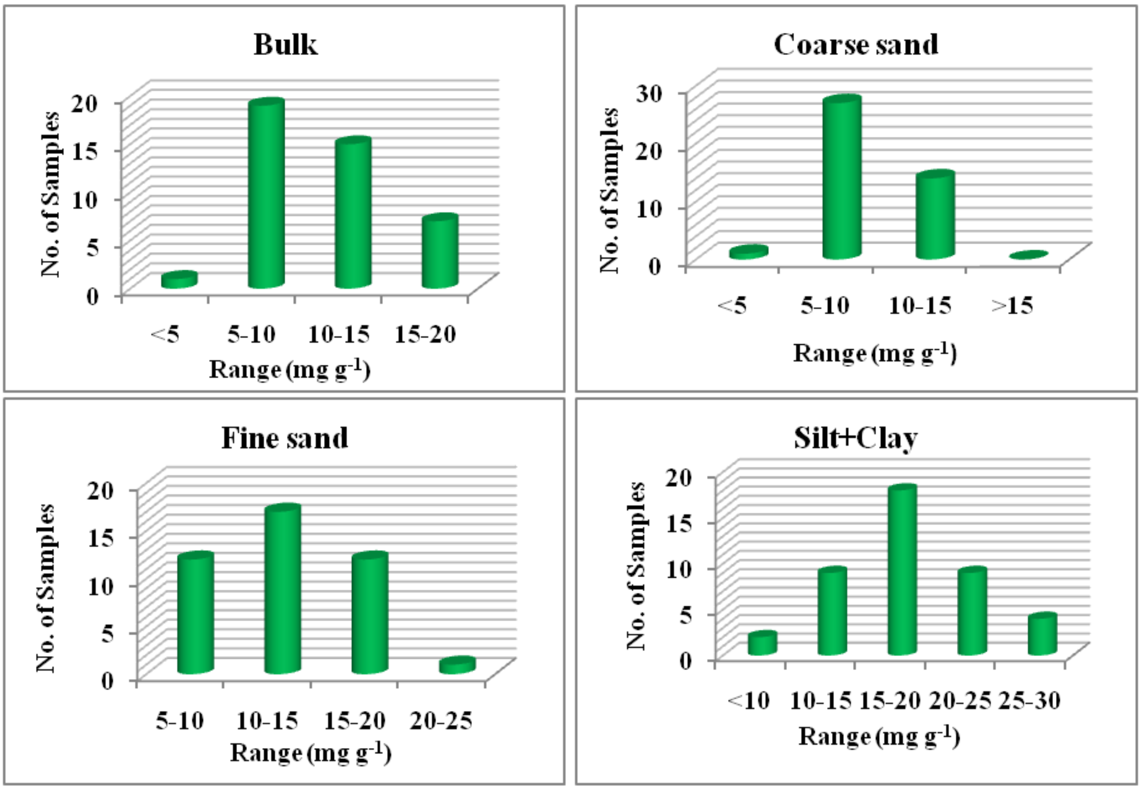

Fig. 3 Frequency distribution of SOC in various ranges for bulk and fractional samples

3.2 Seasonal and spatial variation of SOC

Table 1 documents the statistical summary of seasonal variation for observed SOC levels in bulk and fractional soil samples. The highest and lowest mean values of SOC in bulk samples are found to be as 12.49 (ranged from 8.18 to 19.55) mg g^{-1} and 10.18 (ranged from 7.03 to 15.13) mg g^{-1} during winter and summer, respectively. ANOVA test (*p<0.05*) was performed to see the seasonal difference for SOC which infers that significant difference occurred between winter and summer. Photochemical degradation of SOC in summer season due to elevated temperature might be the reason for lesser concentration in agricultural soil (Ray 2009). Apart from seasonal influence, the organic carbon dynamics of soil in terms of its quantity and quality has also affected by complex interaction of combined management practices (e.g. tillage, fertilization, change in plant species composition and inputs of organic residues) (Yan et al. 2012).

Table 1: Statistical summary of SOC (mg g^{-1}) in agricultural soil in different seasons of NCR India

		Bulk	Fraction-I (Coarse sand)	Fraction-II (Fine sand)	Fraction-III (Silt+Clay)
Winter	Average	12.49	10.76	14.19	20.56
	SD	3.05	2.25	3.60	4.07
	Min	8.18	6.23	8.57	14.13
	Max	19.55	14.75	21.53	27.93
	Median	11.88	10.79	13.34	20.62
Summer	Average	10.18	8.33	11.21	16.28
	SD	2.28	1.27	2.89	2.60
	Min	7.03	5.47	7.03	11.10
	Max	15.13	10.58	15.97	20.60
	Median	9.30	8.52	10.81	16.75
Monsoon	Average	10.25	8.41	12.43	17.27
	SD	3.80	2.62	3.93	5.31
	Min	4.87	4.18	6.43	9.70
	Max	17.35	12.66	18.75	26.60
	Median	8.86	8.10	11.98	17.45

Similar to the bulk samples, the mean values of SOC in the three fractional samples followed the order as winter > monsoon > summer. Further, three fractions (Fraction-I, Fraction-II and Fraction-III) showed the mean values of highest (10.76, 14.19 and 20.56 mg g^{-1}) and lowest (8.33, 11.21 and 16.28 mg g^{-1}) SOC levels during winter and summer, respectively. It is inferred from the Table 1 that Fraction-III (silt+clay) has the highest mean SOC concentrations followed by Fraction-II (fine sand) and Fraction-I (coarse sand) during all the three seasons. The abundance of SOC in the Fraction-III suggested that silt+clay are governing factor for its enrichment in soil, as expected. Similar results regarding SOC concentration in silt+clay fractions have been observed by number of previous studies (McGrath and Zhang 2003, Zhao et al. 2006; Ray et al. 2012). These results are crucial from a geochemical perspective which suggested that greater surface area to volume ratios of the finer particles provide more potential binding sites for organic carbon (Ray 2009; Dahl et al. 2016). Distribution of SOC in different size fractions of soils from Chinese loess plateau showed that highest accumulation has monitored in clayey loess (1.85 – 51.81 mg g^{-1}) followed by loess (1.16 – 22.7 mg g^{-1}) and sandy loess (0.31 – 3.56 mg g^{-1}) (Zhan et al. 2013). Similarly, Yan et al. (2012) also reported highest SOC content in the silt + clay grain size among various studied fractions.

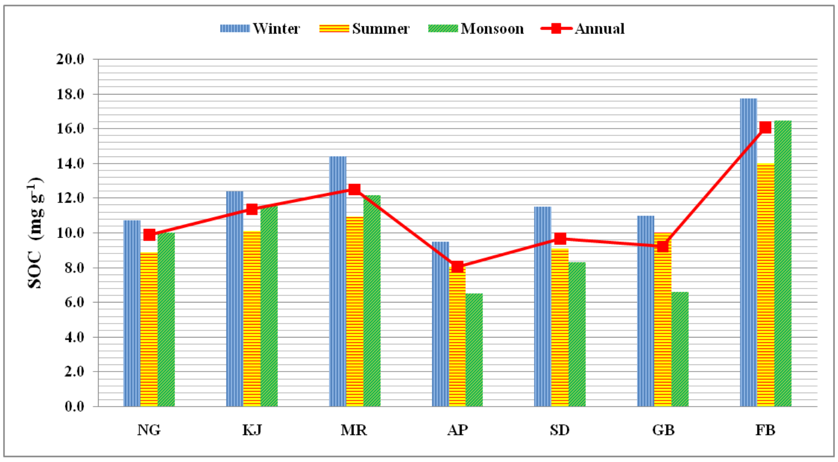

Fig. 4 Spatial variability of SOC levels in bulk soil samples during three seasons

The spatial distribution of SOC in bulk soil samples during the three seasons is depicted in Fig. 4. Among the studied locations, FB and AP exhibited the highest (16.1 mg g^{-1}) and lowest (8.0 mg g^{-1}) mean levels of SOC. The observed SOC levels at FB are approximately two times higher of AP. The other five locations also experienced significant SOC concentration as GB (9.2 mg g^{-1}), SD (9.7 mg g^{-1}), NG (9.9 mg g^{-1}), KJ (11.4 mg g^{-1}) and MR (12.5 mg g^{-1}). The variability of SOC in the studied locations could be attributed to different soil type, texture, agricultural practices and microbial degradation rate (Yan et al. 2012; Li et al. 2016).

In addition to this, site wise variation of SOC levels for fractional soil samples during the three seasons are illustrated in Fig. 5. It is clearly noticed that the concentration of SOC at most of the sites was increasing with decreasing of the particles size (coarse sand > fine sand > silt+clay) of soil. Pattern of SOC association with different size of soil particles suggested that the SOC levels in silt+clay fraction is 1.2 to 1.7 and 1.7 to 2.4 times higher of fine sand and coarse sand, respectively.

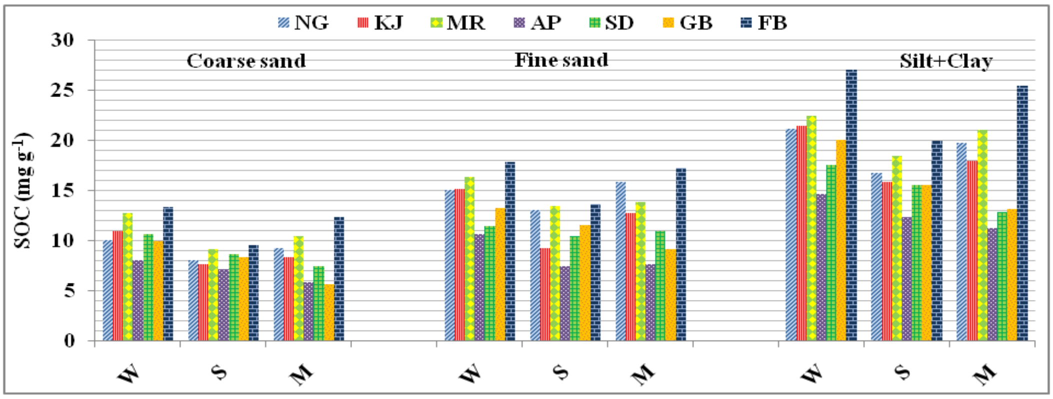

Fig. 5 Spatial variability of SOC levels in fractional samples during three seasons

3.3 Percentage contribution and correlation of SOC in soil fractions with bulk samples

The relative SOC contents of the coarse sand, fine sand and silt+clay sized fractions of soil are shown in Fig. 6. The relative contributions of SOC are in the range of 21.1 to 25.3 %, 30.3 to 34.1 % and 43.6 to 46.3 % for coarse sand, fine sand and silt+clay, respectively. It clearly infers that silt+clay had largest contribution in terms of SOC as compared to other two fractions in the bulk samples. A study carried out by Li and Pang (2014) in southern loess plateau, China also reported much higher SOC contribution in silt and clay as 96 and 98%, respectively. On the other hand, Zhao et al. (2006) estimated SOC levels in the clay, silt and silt+clay and found that the silt+clay exhibited the lesser contribution.

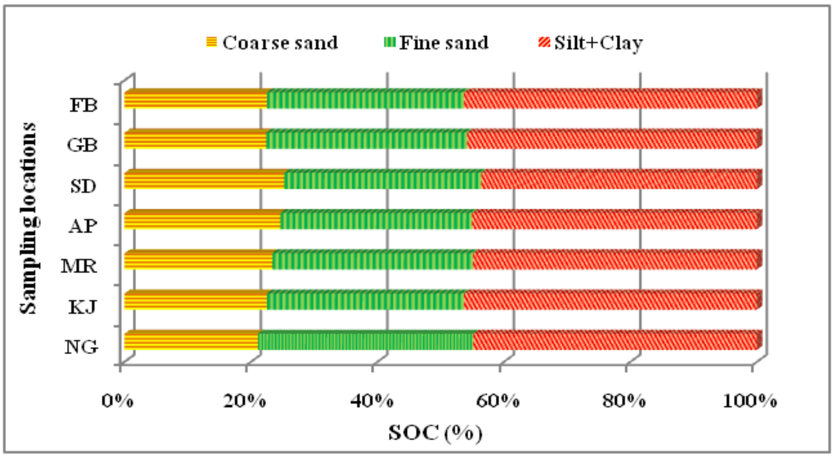

Fig 6 Relative SOC contribution (percentage) in the coarse sand, fine sand and silt+clay sized fractions of soil

To evaluate the correlation between the SOC levels in different particle size fraction with bulk soil, the regression analysis has been carried out. The association of different particle size fraction with bulk soil is depicted in Fig. 7. It infers that the all size fractions showed significant positive moderate to strong correlation with the bulk soil. It is noted that silt+clay experienced highest coefficient of determination (r^2=0.77) as compared to coarse sand (r^2=0.74) and fine sand (r^2=0.60) at 95 percent of confidence interval with bulk soil. The significant positive correlation for sandy fractions (coarse and fine sand) with bulk soil indicated that these fractions also have good carbon association capacity. Yang et al. (2016) reported that SOC storage occurs on sand-sized soil particles after the organic carbon storage capacity on silt- and clay-sized particles is saturated.

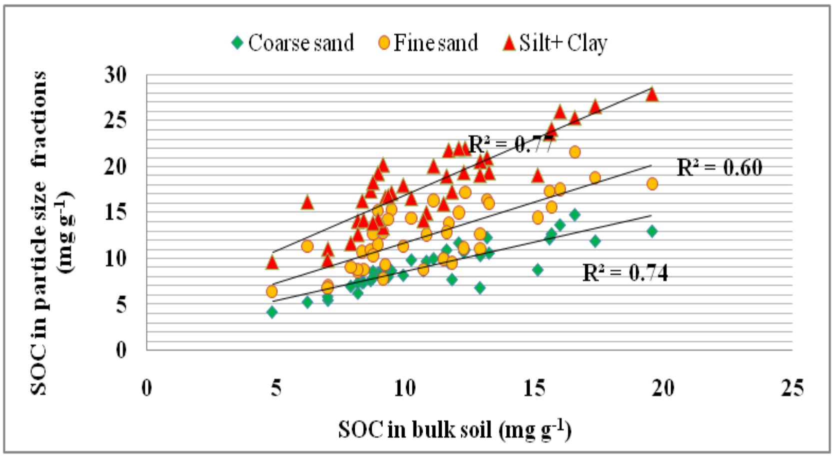

Fig. 7 Relationships between the SOC levels in particle size fractions with bulk soil

3.4 Comparison of observed SOC levels with national and international studies

In the current section, the estimated levels of SOC in the agricultural soil have been compared with the previous studies performed across the world. Table 2 documents the relative comparison of observed SOC levels for agriculture soil in the present study with horticulture, vegetable soil, farmland soil, rural soil, wetland and forest soil etc.

Table 2: Comparison of SOC levels (mg g^{-1}) with other national and international studies across the world

Type Of Soil	Country	Mean (mg g^{-1})	Range (mg g^{-1})	References
Agricultural soil	NCR, India	10.9	4.9 - 19.6	Present Study
Agricultural soil	Jiulong River, China	14.0	2.2 - 36.6	Zhang et al. (2012)
Agricultural soil	Guanting Reservoir, China	15.0	3.1 - 32.0	Wang et al. (2007)
Agricultural soil	Alabama, USA	9.3	5.0 - 35.0	Harner et al. (1999)
Vegetable soil	Pearl River Delta, China	12.0	2.1 - 40.0	Yu et al. (2013)
Agricultural Soil	Vietnam	31.8	23.1 - 42.1	Toan (2015)
Horticulture soil	Northwest China	13.3	-	Zhang et al. (2013)
Farm land soil	Hong-Kong	12.3	-	Zhang et al. (2006)
Forest, Grassland, Tea Estate, Wildlife Sanctuary, Wetland and Roadside	North-Eastern States, India	-	7.0 - 32.0	Devi et al. (2013)
Soil	Watersheds of Beijing Reservoirs, China	-	3.5 - 37.4	Hu et al. (2009)
Soil	China		5.5 - 23.2	Liu et al. (2008)
Forest And Grassland Soils	Switzerland	-	10.4 - 129.6	Bucheli et al. 2004
Rural, Urban, Farm, Residential And Park Soil	Southern Mexico	-	8.0 - 64.0	Wong et al. (2008)
Rural Suburban Urban	Northeastern China	- - -	20.8 - 31.9 10.5 - 33.1 11.1 - 76.1	Wang et al. (2009)

In general, the mean levels of SOC were found to be comparable to those found elsewhere (Harner et al. 1999; Zhang et al. 2006; Yu et al. 2013). However, the studies carried out in agricultural soil of Vietnam and Guanting Reservoir, China exhibited much higher SOC levels as 31.8 and 15.0 mg g^{-1}, respectively. Bucheli et al. (2004) reported the significant range of SOC in grassland and forest soil of Switzerland. Various studies performed on urban, sub-urban and rural soil also explained wide range of SOC to those found elsewhere (Wong et al. 2008; Wang et al. 2009).

IV. Conclusions

In the present study, the levels of SOC were evaluated in the different soil fractions of agricultural field at peri-urban sites of NCR, India. The mean concentrations of SOC exhibited as 10.9, 9.2, 12.6 and 18.1 mg g^{-1} for bulk, coarse sand, fine sand and silt+clay fractions, respectively. Significant seasonal difference for all fractions as in the order of winter > monsoon > summer occurred due to varying photochemical degradation rate of SOC in soil. The relative contributions of coarse sand, fine sand and silt+clay fractions to bulk soil samples were found to be in the range of 21.1 to 25.3 %, 30.3 to 34.1 % and 43.6 to 46.3 %, respectively. It indicated that the maximum loading of SOC consistently occurs in the smallest particle size fraction (silt+clay) irrespective of site and season. After regression analysis, it is noted that silt+clay is highly correlated (r^2=0.77) with bulk soil samples as compared to coarse sand (r^2=0.74) and find sand (r^2=0.61).

The present work is useful in understanding the contribution, association and seasonal variability of SOC in different size fractions of agricultural soil. It also provides the knowledge regarding the soil structure, soil quality and sustainability in agricultural land. Further, more comprehensive study of SOC is needed along with bioavailability of pollutants, edaphic or vegetation factors and land use changes using various statistical and modelling tools to better delineate about carbon storage capacity of the agricultural soil.

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