Soil Organic Fractions in Cultivated and Uncultivated Soils of Costal Area in Bangladesh

Ipsita Sarkar, Md. Zulfikar Khan*, Md. Hanif

Soil, Water and Environment Discipline, Khulna University, Khulna, Bangladesh
Email: *zulfikar.ku11@gmail.com

Abstract

Assessment of soil organic matter fractions can be instrumental in understanding the causes of limited nitrogen supply, and thus soil fertility restoration. A study was conducted in cultivated and uncultivated saline soil, in order to assay soil organic carbon (SOC), its particle-size fractions and their influence on cultivation and soil fertility at Sundarbans costal area in Bangladesh. Soil samples were taken from the 0 - 15 and 15 - 30 cm depths from four cultivated fields and from four nearby sites in a native mangrove forest as references. Soil samples were physically fractionated into sand (2000-50 μm), silt (50-2 μm) and clay (<2 μm). Total SOC and N were analyzed in bulk samples and each size fraction, and the Carbon Management Index (CMI), a widely used indicator of soil quality, was calculated for each field. The CMI in cultivated soils was far below the 100% in reference soils, reaching 38.16%, 25.70%, 32.21% and 34.43% in Field 1, Field 2, Field 3 and Field 4 respectively. SOC and N concentrations decreased in particle size separates in the order clay > silt > sand. The SOC pool and N in the clay-sized fraction were correlated to soil fertility indicators. More N was stored in the silt + clay size fractions, a generally more stable pool, than in the more labile sand-sized pool. The SOC pool in sand size fractions was far below in cultivated soils than in a reference uncultivated soil. Thus, the sand-sized pool emerged as the most likely cause of limited N supply in cultivated soils.

Keywords

Particle Size Fraction, Soil Organic Carbon, Nitrogen, Saline Soil

1. Introduction

Soil salinity is a hazard in coastal area just as in Sundarbans in Bangladesh. The Ganges Floodplain in the area includes char land and very young alluvial land

along the main Ganges channel. The cultivable lands in this region are affected with varying degrees of soil salinity and thus restrict plant growth. Sodium (Na^+) is the predominant soluble cation in most saline soils of the coastal area [1]. The plants which grow in the saline media exhibit an accumulation of Na^+ and Cl^- and the reduced uptake of mineral nutrients, especially Ca^{2+}, K^+, N and P [2]. Salt-affected soils exhibit poor soil structure resulting from soil physical processes such as slaking, swelling, and dispersion of clay [3]. Soils of this area are also poor in fertility with low (1.0% - 1.5%) organic matter content. The farmers use chemical fertilizers in an unbalanced proportion as a supplemental source of nutrients [4]. Low SOC concentrations and reduced nutrient retention capacity further increase leaching of applied nutrients and lead to land abandonment by farmers [5].

Particle size fraction of SOC is most related with N supply and Soil fertility in general. While several studies suggest that the labile SOC associated with sand-sized fractions is the most influential to C and N cycling [6]; others have implied a strong role of less labile organic fractions associated with silt and clay-sized particles [7] [8]. As a result, there is a continuous debate among researchers regarding linkages between soil texture, mineralogy, SOC fractions and N cycling [6]. Furthermore, there is limited knowledge on which particle size fraction of SOC is most related with N supply and soil fertility and how continuous cultivation affects the distribution of SOC and N in costal soils. Such research efforts would certainly improve the understanding of SOC and N cycling dynamics in costal soils and provide insights on the best approach to address major nutrient limitation. The main objectives of the research work were: 1) to assess which soil fraction contains the highest level of SOC, 2) to identify the SOC fractions most influential in N supply and soil fertility and 3) To understand how these fractions are affected by cultivation in saline soil.

2. Materials and Methods

2.1. Study Area

The study was undertaken at Joymany ghol and nearby Sundarbans area of Mongla Upozilla, Bagerhat district which is situated beside the Posur River and directly connected to Bay of Bangle. This study was carried out to investigate the present situation of organic content with salinity in the forest and nearby cultivated areas. This area is selected because about 53% of the coastal areas of Bangladesh are affected by salinity. Agricultural land use in these areas is very poor, which is much lower than country's average cropping intensity. Salinity causes unfavorable environment and hydrological situation that restrict the normal crop production throughout the year. The factors which contribute significantly to the development of saline soil are tidal flooding during the wet season (from June to October), direct inundation by saline water, and upward or lateral movement of saline ground water during the dry season (from November to May) [9]. According to the farmers most soils of this area had been under culti-

vation for more than 15 years. But most of the land is now fallow since Aila* (Severe Cyclonic Storm Aila was the worst natural disaster to affect Bangladesh since Cyclone Sidr in November 2007. The second tropical cyclone of the 2009 North Indian Ocean cyclone season, Aila formed over the Bay of Bengal on May 23. A relatively strong tropical cyclone, it caused extensive damage in Bangladesh).

2.2. Collection of Soil Samples

The soil samples were collected from four different agricultural field and natural sites. The natural forest sites were bench-marked as reference sites. From each selected site, soil samples were taken from 0 - 15 cm (topsoil) and 15 - 30 cm (sub soil) depths, using an auger. The sampling sites along with the cropping pattern were shown in Table 1.

2.3. Preparation of Soil for Chemical Analysis

The collected soil samples were air dried by spreading on separate sheet of papers after it was transported to the laboratory. After drying in air, the larger aggregates were broken gently by crushing it by a wooden hammer. A portion of the crushed soils was passed through a 2.0 mm sieve. The sieved soils were then preserved in plastic bags and labeled properly. These were later used for various chemical analyses. The chemical analyses of these collected soil samples were carried out in the laboratory of the Soil Science Discipline, Khulna University.

Table 1. General information about sampling sites.

Sample no.	GPS	Physiography	Land type	Fertilizer used	Cropping pattern	Cultivation duration
			Cultivated soils			
Field 1	22˚21.530'N 89˚38.068'E			Urea, TSP, Cow dung	Fallow-Rice-Rice + Shrimp	About 10 years, halt after Aila* (since 2009), started again 2014
Field 2	22˚21.541'N 89˚38.070'E	Gangstidal floodplain	Low land	Urea, TSP, Cow dung, Poultry manure, Compost	Vegetables-Rice-Fallow	About 20 years
Field 3	22˚21.530'N 89˚38.069'E			Urea, TSP, Cow dung, Poultry manure, Compost	Fallow-Rice-Rice + Shrimp	About 18 years
Field 4	22˚21.520'N 89˚38.060'E			Urea, TSP, Cow dung	Fallow-Rice-Rice + Shrimp	About 18 years
			Reference forest soil (mangrove vegetation)			
Location 1	22˚21.54'N 89˚38.370'E					
Location 2	22˚21.55'N 89˚38.374'E	Gangs tidal floodplain	Low land			
Location 3	22˚21.60'N 89˚38.76'E					
Location 4	22˚21.60'N 89˚38.76'E					

2.4. Analytical Procedure for Soil Analysis

Measurements of selected physical and chemical properties of the soils were carried out in triplicate according to conventional methods. Electrical conductivity (EC) of soil was estimated by EC meter (Jackson EC meter). The ratio with of soil and water was 1:5 and the result was converted to the ratio of 1:1 (soil: water) as suggested by USDA [10]. pH value of the soil samples was measured by Jackson pH meter maintaining the ratio of soil to water was 1:2.5 as suggested by Jackson [11]. The CEC of the soils were determined by extracting the soil with ammonium acetate solution (NH_4OAc at pH 7) along with replacing the ammonium in the exchange complex by 2 M KCL solution. The displaced ammonium was distilled in for CEC determination in a way similar to the detection of available ammonium nitrogen [12]. Available K of soil was determined after extraction with from NH_4OAc (pH 7.0) as described by Jackson [11]. The extract was then analyzed for available K by a flame emission spectrometer method at 589 nm by Jackson [11]. Available Phosphorus was extracted from the soil with 0.5 M $NaHCO_3$ (Olsen's Method) at pH 8.5 after extraction Molybdophosphoric blue colour method was employed for determination of phosphorus [11]. After extraction with NH_4OAc (pH 7.0), available Ca and Mg were determined by titrimetric method as described by Jackson [11]. Organic carbon of the soil sample was estimated by the wet oxidation method of Black [12]. The underlying principle of this method is to oxidize the organic matter with an excess of $K_2Cr_2O_7$ in presence of concentrated H_2SO_4 and to titrate the residual $K_2Cr_2O_7$ solution with 0.5 M $FeSO_4$ by Jackson [13]. Total nitrogen content of soil samples was determined by micro-Kjeldahl method as described by Jackson [11] through the digestion of organic matter with concentrated H_2SO_4 acid, H_2O_2 and catalyst mixture of potassium sulphate (K_2SO_4), copper sulphate ($CuSO_4$) and selenium powder in the ratio of 10:1:1. After completion of digestion, 40% NaOH was added with digestion mixture for distillation. The distillate was received in 2% boric acid (H_3BO_3) solution with 4 drops of mixed indicator of bromocresol green ($C_{21}H_{14}O_5Br_4S$) and methyl red ($C_{10}H_{10}N_3O_3$) solution. Finally, the distillate was titrated with standard H_2SO_4 (0.01 N) until the color changed from green to pink.

2.4.1. Particle Size Analysis (PSA)

After removing of binding agents ($CaCO_3$ and OM) Particle size analysis of the soil samples were done by hydrometer method as described by Gee and Bauder [14]. Textural class was determined by Marshall's Triangular co-ordinate system.

2.4.2. Particle-Size Fractionation

Particle-size fractionation of samples (0 - 15 and 15 - 30 cm depths) from cultivated lands and the four sites of forest land was carried out by submerging a 50 g air-dried sample in deionized water for 30 min in plastic bottles, and then adding samples of 100 ml of 5% sodium hexametaphosphate. The bottles were tightly capped and shaken for 16 h using an end-over-end shaker, and the resulting suspensions were passed through a set of sieves of 2000, 250 and 63 μm,

with the help of spraying distilled water and a rubber spatula. The fractions retained on the 250 and 63 μm sieves consisted of coarse sand and fine sand, respectively, whereas the material passing the 63 μm sieve was the clay + silt suspension. The clay fraction was separated by sonification-sedimentation-siphoning method. The sonification-sedimentation-siphoning process was repeated until the clay was separated completely. After separating clay, the rest of the samples were silt fraction. Total SOC and N concentrations of each size fraction were determined by oxidation method [12] and micro-Kjeldahl method [11] as described before.

The sand-sized organic fraction was considered as labile or particulate component of soil organic matter, while silt- and clay-sized fractions as less-labile fractions [6] [7] [8]. The C/N ratio was also computed for bulk soil and particle-size fractions.

2.5. Computation of Carbon Management Index (CMI)

The CMI was calculated using the physically fractionated carbon as in Equations (1)-(3) [15]; on the basis of the Carbon Pool Index (CPI) and the Lability Index (LI) [Equation (1)]. Lability Index was computed from the Lability (L) associated with each soil, which in this case is the fraction of the labile C to non-labile C. The LI is a relative index that gives the fraction (FL) of labile carbon (LC) and non-labile carbon (NLC) from a cultivated field, as compared to a similar fraction (FR) at reference land use [Equation (2)]. This has been applied as a tool for assessing soil quality in terms of increments of total SOC, considering a shift of C to the labile pool as a result of agricultural practices. High CMI suggests high amounts of carbon associated to sand-sized fraction (labile component), thus high soil quality [15] [16]. The CPI compares total SOC $(mg \cdot g^{-1})$ from a cultivated soil (C_S) with total SOC $[C_R (mg \cdot g^{-1})]$ in a reference soil [CR, Equation (3)].

$$CMI = CPI \times LI \times 100 \tag{1}$$

$$LI = FL/FR \tag{2}$$

$$CPI = C_S \left(\text{cultivated soil} \right) / C_R \left(\text{reference soil} \right) \tag{3}$$

2.6. Statistical Analysis

With SPSS software version 23 for windows, soil properties of different sites of cultivated soil were analyzed using Analysis of Variance (ANOVA). The ANOVA test also used for significant differences of C and N associated with each of the particle-size fractions. Mean values of soil properties and C and N concentrations in the particle size fraction were compared using the Fisher's Protected Least Significant of Difference (LSD) at 5% level of significance.

3. Results and Discussion

3.1. Results

Soil fertility heterogeneity was evident in all fields after stratification by SOC concentration limits, although soil property EC was not significantly different.

All other properties such as pH, total SOC, total N, available P, available K^+ available Na^+, Ca^{2+} and Mg^{2+}, CEC were significantly different across the fields (Table 2). Irrespective of soil fertility status, extractable P was far below the critical concentration of 15 $\mu g \cdot g^{-1}$ [17].

3.1.1. pH and EC

pH was significantly different among cultivated fields. The range in cultivated surface soil was 7.67 to 8.10 (Table 2) which is higher than reference soil (8.0). The same results are found for cultivated sub-surface soil.

Electrical conductivity (EC) was the same for all the surface and sub-surface cultivated soils (10.0 $dS \cdot m^{-1}$). But much higher than uncultivated forest soil. The EC of uncultivated forest surface soil was 7.850 $dS \cdot m^{-1}$ and sub-surface soil was 7.820 $dS \cdot m^{-1}$ (Table 2).

3.1.2. Total Soil Organic Carbon and Total Nitrogen

Uncultivated soils registered the highest mean SOC, total N. Both SOC and total N were significantly different among the cultivated fields. The highest SOC for surface cultivated soils was found for Field 1 (1.424%) and the lowest was for Field 2 (1.307%) (Table 2) as well as the highest SOC for subsurface cultivated soils was found for Field 1 (1.034%) and the lowest was for Field 3 (0.950%). SOC for uncultivated forest surface soil was 1.691% and for subsurface 1.344% (Table 2).

The highest total N for surface cultivated soils was found for Field 3 (0.159%) and the lowest was for Field 2 (0.149%) (Table 2) along with the highest total N for subsurface cultivated soils was found for Field 1 (0.133%) and the lowest was for Field 3 (0.114%). Total N for uncultivated forest surface soil was 0.175% and for subsurface 0.153% (Table 2).

3.1.3. CEC and Soil Nutrients (P, K, Na, Ca and Mg)

The CEC of uncultivated Forest soil is higher than cultivated Field soil. It was 33.25 for surface and 22.75 for subsurface (Table 2). Highest CEC (30 meq/100g soil) was found in Field 4 for cultivated surface soil and 23 meq/100g soil was for Field 3. For cultivated subsurface soils, highest CEC was found at Field 4 (25 meq/100g soil) and the lowest was at Field 1 (20 meq/100g soil).

The available P of uncultivated Forest soil is higher than cultivated Field soil. It was 15 ppm for surface and 12 ppm for subsurface. Highest available P (10 ppm) was found in Field 1 for cultivated surface soil whereas the highest available P (30 ppm) in subsurface cultivated soils was found in Field 1. Consequently, the lowest available P (5.7 ppm) was found in Forest 3 for surface soil and 5.1 ppm in Forest 4 for subsurface soil (Table 2).

Uncultivated soils registered the highest mean of available K and available Na. Both available K and Na were significantly different among the cultivated fields. The highest available K for surface cultivated soils was found for Field 1 and Field 2 (5848 ppm) and the lowest was for Field 4 (4386 ppm) (Table 2). Meanwhile, the highest available K for subsurface cultivated soils was found for Field 2 (5555.6 ppm) and the lowest was for Field 4 (4110 ppm). Available K for uncultivated for-

est surface soil was 6724.90 ppm and for subsurface 5958.33 ppm (Table 2).

The highest available Na for surface cultivated soils was found for Field 3 (2954.38 ppm) and the lowest was for Field 1 (1342.90 ppm) (Table 2). And the highest available Na for subsurface cultivated soils was found for Field 2 (2148.65 ppm) and the lowest was for Field 1 and Field 4 (905.74 ppm). Available Na for uncultivated forest surface soil was 4161.13 ppm and for subsurface 3558.51 ppm (Table 2).

Cultivated soils registered the highest mean of available Ca and Mg. Both available Ca and available Mg were significantly different among the cultivated fields. The highest available Ca for surface cultivated soils was found for Field 2 (0.50%) and the lowest was for Field1 (0.32%) (Table 2). Available Ca for subsurface field soils was not significantly varied among themselves. Available Ca for uncultivated forest surface soil was 0.25% and for subsurface 0.20% (Table 2).

Highest available Mg for surface cultivated soils was found for Field 1 (0.19%) and lowest was for Field 2 (0.11%). Highest Mg for subsurface cultivated soil found in Field 1 (0.13%). Available Mg for uncultivated forest surface soil was 0.08% and for subsurface 0.030% (Table 2).

Table 2. Mean values of soil properties in 0 - 15 cm surface and 15 - 30 cm subsurface soil from 4 cultivated and 4 uncultivated sites.

	pH	EC (dS·m⁻¹)	Total‖ SOC%	Total N%	Available P (ppm)	Available K (ppm)	Available Na (ppm)	Available Ca%	Available Mg%	CEC (meq/100g soil)	Texture
					Cultivated Soil						
					Surface (0 - 15 cm)						
Field 1	8.10a	10	1.424a	0.157ab	10a	5848.0a	1342.9c	0.32d	0.19a	25b	Clay
Field 2	7.67d	10	1.307d	0.149c	8b	5848.0a	2148.64b	0.5a	0.11c	29a	Clay
Field 3	8.00c	10	1.317c	0.159a	5.7c	5637.2b	2954.38a	0.37c	0.13b	23b	Clay loam
Field 4	8.05b	10	1.34b	0.152bc	8b	4386c	2148.64b	0.42b	0.15b	30a	Clay loam
					Sub-surface (15 - 30 cm)						
Field 1	8.34a	10	1.034a	0.133ab	6a	4386c	905.74c	0.3a	0.13a	20b	Clay
Field 2	8.00b	10	0.956b	0.121bc	5.5b	5555.6a	2148.65a	0.28a	0.07b	23a	Clay
Field 3	8.05b	10	0.95b	0.114c	5.3b	5120.1b	2148.61b	0.32a	0.05b	21b	Clay loam
Field 4	8.34a	10	0.961b	0.14a	5.1b	4110d	905.74c	0.28a	0.08b	25a	Clay loam
					Uncultivated Soil (n = 4)						
Forest surface soil (0 - 15 cm)	8.00	7.85	1.691	0.175	15	6742.9	4161.13	0.25	0.08	33.25	Clay
Forest sub-surface (15 - 30 cm)	8.00	7.82	1.344	0.153	12	5958.33	3558.51	0.20	0.03	22.75	Clay

Here, a, b, c letters represent soil properties that are significantly different among the sites ($p < 0.05$). Same letters among a column represent no significant differences observed on comparing means using LSD (Least Significant Differences).

3.1.4. Carbon and Nitrogen in Particle-Sized Fractions

In cultivated fields, there was a positive pattern of significant increase in C and N concentrations in all particle sizes (Table 3). This was evident in both the topsoil (0 - 15 cm) and the lower soil depth (15 - 30 cm). And this also related well to the differences in bulk soil C and N (Table 3). In both cultivated and uncultivated soils, SOC concentrations in the clay-sized fractions were at least fourth times as high as that of sand-sized fractions. This is in accordance with the SOC dilution effect and the high SOC sorption on clays as observed by Zinn *et al.* [18].

The same occurred for soil N, although with much more intensity, and the clay fraction of cultivated soils showed N concentrations that were at least three times higher than those in the sand fraction.

The C/N ratio in clay-sized fraction of cultivated soils was on average 9 to 6, lower than what was registered in sand-sized fraction (10 to 14) (Table 4). The C/N ratio was 7 - 10 in the silt-sized fraction. In top bulk soil C/N ratio was 9.07 in Field 1 (contains highest SOC) and 8.77 (contains lowest SOC) in Field 2, but high 9.7 in the uncultivated reference soil.

The clay-sized fraction was the largest SOC pool in cultivated soils, ranging between 46.27% - 56.63% in both depths (Figure 1), and Field 3 soil registered the lowest percent share of C in the sand-sized fraction. However, in the uncultivated soils, the clay-sized SOC pool was generally smaller with slightly more

Table 3. Carbon and nitrogen concentration in sand-sized (63 - 2000 μm), silt-sized (2 - 63 μm) and clay-sized (<2 μm) fractions in cultivated and uncultivated soils.

	C-Sand	C-Silt	C-Clay	N-Sand	N-Silt	N-Clay
C and N in particle size fractions%						
Cultivated soils						
0 - 15 cm (Surface)						
Field1	0.1755a	0.521a	0.7295a	0.0162b	0.0492b	0.0842d
Field2	0.1560b	0.452ab	0.6990ab	0.0122c	0.0480c	0.0920b
Field3	0.1463b	0.450b	0.6710b	0.0101d	0.0497a	0.0986a
Field4	0.1320c	0.369c	0.6120c	0.0210a	0.0492b	0.0910c
15 - 30 cm (Sub-surface)						
Field1	0.1365a	0.312c	0.5841a	0.0121b	0.0369b	0.0742b
Field2	0.1270b	0.322b	0.5170c	0.0180a	0.0306a	0.0772a
Field3	0.1191c	0.312c	0.5270b	0.0118b	0.0369b	0.0665c
Field4	0.1107d	0.331a	0.5310b	0.0201a	0.0350a	0.0741b
Uncultivated soils (n = 4)						
Forest soil (0 - 15 cm)	0.4005	0.5107	0.7825	0.0312	0.0543	0.0910
Forest soil (15 - 30 cm)	0.2694	0.3939	0.6677	0.0254	0.0417	0.0830

Here, a, b, c letters represent soil properties that are significantly different among the sites ($p < 0.05$). Same letters among a column represent no significant differences observed on comparing means using LSD (Least Significant Differences).
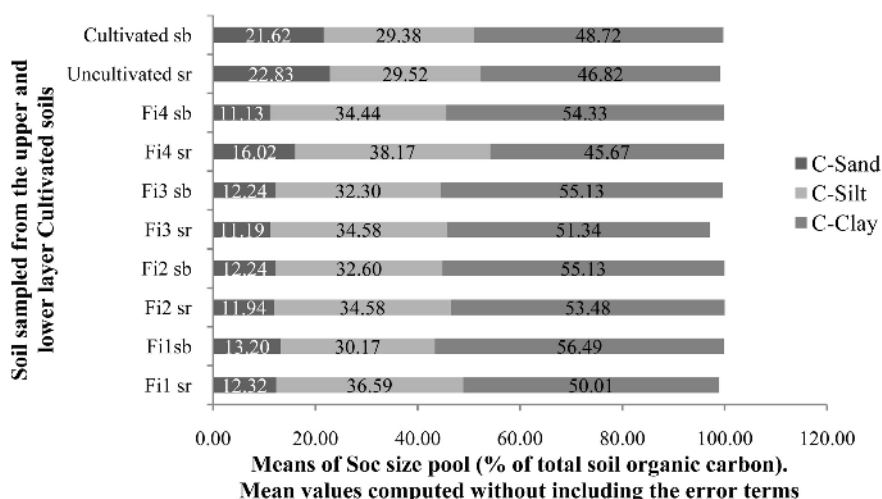
Figure 1. Percent share of carbon in particle-sized fractions as related to total SOC in the bulk soils of different sites sampled at 0 - 15 and 15 - 30 cm in a cultivated (n = 4) and uncultivated (n = 4) soil.

Table 4. Computed C/N ratio derived from C and N concentrations of particle size fractions in cultivated and uncultivated soils.

	Sand sized (63 - 2000 μm)	Silt sized (2 - 63 μm)	Clay sized (<2 μm)
Cultivated soils			
0 - 15 cm (Surface)			
Field 1	10	10	9
Field 2	12	9	7
Field 3	14	9	6
Field 4	12	7	6
15 - 30 cm (Sub-surface)			
Field 1	11	8	7
Field 2	9	10	6
Field 3	10	8	7
Field 4	9	9	7
Uncultivated soil (n = 4*)			
0 - 15	12	9	8
15 - 30	10	9	8

*4 uncultivated soils from the Sundarbans had taken as references.

total SOC stored in the sand fraction. In the lower depth, there was a general increase in the importance of the silt-sized SOC pool.

A comparison of the different organic carbon indicates cultivated soil 1registered significantly higher CPI, labile C, non-labile C, computed Lability, LI and CMI than other fields, demonstrating variations in SOC quality (Table 5). Only cultivated soil 2 and cultivated soil 3 registered as low lability and lability

Table 5. Carbon Pool Index (CPI), Carbon Lability (L), Lability Index (LI), and Carbon Management Index (CMI) in 0 - 15 cm of cultivated and uncultivated soils.

	Total SOC	CPI	Labile C	Non-labile C	Lability	Lability Index	Carbon Management Index
Cultivated Soil 1	1.424	0.84	0.1755	1.2505	0.1403	0.45	38.16
Cultivated Soil 2	1.307	0.77	0.1560	1.5150	0.1030	0.33	25.70
Cultivated Soil 3	1.317	0.78	0..1436	1.1210	0.1281	0.41	32.21
Cultivated Soil 4	1.340	0.79	0.1320	0.9810	0.1346	0.43	34.43
Uncultivated Soil	1.691		0.4006	1.2932	0.3097		

Where CPI (Carbon Pool Index) = (SOC in cultivated soil/total SOC in uncultivated); L (Lability) = labile C/non-labile C; where the non-labile is referred as silt + clay C, and labile C is referred as sand C. Lability Index (LI) = lability in cultivated soil/lability in uncultivated soil; the CMI (Carbon Management Index) = CPI × LI × 100. Each fertility category consisted of 4 cultivated sites. Four uncultivated soils from the Sundarbans were taken as references.

index. The Carbon Management Index (CMI) was far below 100% in all the four cultivated fields. The CMI registered was 38.16%, 25.70%, 32.21% and 34.43% for cultivated soil 1, cultivated soil 2, cultivated soil 3 and cultivated soil 4 (**Table 5**).

3.2. Discussion

Carbon and Nitrogen in Particle-Sized Fractions

Routine soil tests in bulk samples indicate that pH, EC, available P, available K^+ varied little among fields. This is a consequence of inheritance properties of saline soil. In costal soil, soil salinity is usually combined with high pH conditions, due to the presence and enrichment of calcium carbonate in the uppermost soil layers (alkaline saline soils) or to hydrolysis of sodium carbonate (sodic soils). In these regions, shallow water tables and improper irrigation practices often accelerate salinization [19].

Monovalent cations such as Na^+ play a very important role in deflocculating clay particles and consequently increasing the tendency to slake, disperse and swell under specific conditions, so that soils become impermeable and ultimately infiltration and percolation of water cease from the upper surface and within the soils [20] [21]. High salt levels often cause poor physical and chemical soil characteristics including low aggregate stability, impervious subsoil layers, low infiltration rates, low hydraulic conductivities, and soil surface crusting [22] [23].

The data presented in this study express important insights on SOC and N dynamics in saline soil. However, the significant difference of SOC among fields was used to identify most influential SOC fractions in N supply and soil fertility. SOC is widely known for its positive influence on aggregate stability, cation ex-

change and water holding capacity, infiltration, percolation and consequently on soil productivity [8].

Clay-sized fractions have shown high SOC and N concentrations, when compared with the sand-sized-fraction in both cultivated and uncultivated soils. The observed trends of SOC in particle-size fractions agree with Lehmann *et al.* [24], who found high SOC concentrations in both clay- and silt-sized fractions. The clay fraction is often able to absorb plant-derived aromatics or microbial products [18] across a disparate range of chemical functions and electrical charges. In consequence, the clay is often the richer fraction in SOC, especially in soils with moderate clay contents such as those observed in this study. In addition, some studies in sub-tropical soils assert a direct relationship between SOC and clay contents [8]. However, in the present work, soils have almost the same textural class, which suggests that SOC variability was driven by human-induced practices such as cultivation and use of organic amendments. In fact, base cations such as Na^+, Ca^{2+}, Mg^{2+} cultivated than in uncultivated soils, which can be ascribed to some organic fertilizer applications, although this can hardly occur with enhanced SOC depletion due to aggregate disruption by tillage [25].

The SOC concentrations in particle-size fractions are, however, less indicative of SOC retention than the relative pools. The dominant role of the clay-sized fraction in total SOC retention in cultivated soils is shown in **Figure 1** and it is clear that SOC bound to silt and especially clay was lost. Similar trends were noted in the 15 - 30 cm depth, although the silt-sized fraction was more important than in the topsoil. Feller *et al.* [26], who noted that most SOC lost with cultivation of clayey soils the losses occurred in the <2 μm size class, with no effect of soil mineralogy. Feller *et al.* [26] also reported that after adoption of fallow, SOC gains occur in the sand- and clay-size pools in clayey soils. The fact that considerable amounts of SOC are stored in the clay sized fraction explains why bulk SOC and clay contents are related [18]. It is noteworthy that most bars in **Figure 1** do not reach 100% due to the variable recovery of the total SOC after the particle-sized fractionation, and the non-recovered SOC can be safely ascribed to the clay fraction as proposed by Zinn *et al.* [18]. The data in the present study supports the stated that SOC and N in silt- and clay-sized fractions are more important to overall soil fertility than the sand-sized fraction. In addition, there is support which stated that the distribution of SOC across particle-size fractions is influenced by cultivation, since the clay-size SOC pool is relatively lower in uncultivated soils.

All cultivated soils had a CMI (Carbon Management Index) < 100%, implying lower amounts of labile C (sand-sized C) and thus a likely poor SOC quality. Organic material applications by farmers in high fertility cultivated soils could not boost the sand-sized C (labile C) to be higher than what was registered in uncultivated soil. This showed that cultivation is a key factor resulting in carbon breakdown and loss; thus, changing to minimal tillage approaches may be attractive for C sequestration [16]. However, the lability indices provide a good basis to detect the changes in active pools of cultivated soils, and this emerged

crucial for monitoring short-to medium-term N supply, that would otherwise be difficult using total SOC concentrations and the CPI (Carbon Pool Index). In the present study, potential N limitations can be associated with low N supply from low carbon concentrations associated with sand-sized/labile pool, with or without cultivation. In addition, the cultivated soils in low input systems often lack sufficient residue incorporation, which is critical since this is a key entrance pool for building sand-sized SOC pools. The ratio of labile C to non-labile C (lability) further reflected the aforementioned challenge, and this ratio was far less than 50%, clearly demonstrating the dominance of the non-labile C, and the likely less effectiveness of the active pool in N cycling. In order to improve this labile N pool, judicious use of organic amendments such as cattle manure and adoption of soil conservation practices such as minimal cultivation must be adopted, in accord with the Integrated Soil Fertility Management approach [27].

The low SOC and N concentrations in the sand-sized fractions, as well as the small relative pools in this size somehow contrast with the often-assumed important role this fraction exerts on N-cycling in the tropics [28]. The computed C/N ratio of the sand fraction in top soil was higher (10 to 14) than in the clay-sized fraction (Table 4), which is coherent with the fact that this fraction is composed of free particulate organic matter. The increase in C/N ratio in silt-sized fraction in the lower soil layer (15 - 30 cm) suggests impacts of cultivation, increasing the distribution of C that does not easily mineralize [29]. In the top soil layer, the high C/N occurs because, in contrast with the clay-sized organic fraction, there is no possibility of forming mineral organic complex in the sand size that could stabilize organic matter [7]. Besides, the low C/N ratio in the clay fraction indicates the high humification degree of constituent organic carbon [7]. Diekow *et al.* [16] described the sand fraction as the most sensitive pool to soil management, and indeed our data clearly show that this pool was preferentially depleted in cultivated soils, a tendency that has been observed in tropical climate [16]. In consequence, continuous cultivation in the smallholder farming systems can easily disrupt this labile C component, resulting in overall decline in soil quality.

It was also evident that the clay-sized fraction is even more important for the retention of N than for SOC. This can perhaps be related to the mechanisms through which SOC is absorbed by clay minerals, chiefly kaolinite and oxides. Similar results were found in different soils in different parts of the world [30] [31]. The low N concentrations in the silt and especially the sand fractions could be attributed to its mineralization; and the little N released can be easily lost due to the high precipitation patterns in the region, even in the uncultivated soils [32]. This trend suggests that the clay-sized fraction is the main N pool in soils and perhaps the main source of N to plants in low-input, cultivated soils. Consequently, clay-sized SOC can be the fraction most related with chemical fertility, notwithstanding some assertions that this would be a rather recalcitrant or passive pool, unlikely to affect soil productivity within certain agro-ecological zones [33]. Further studies are needed to explore N release mechanisms from the

silt and clay fractions to further improve the understanding of N retention and dynamics in the costal saline soils.

4. Conclusion

This study has been conducted to identify the soil fraction containing highest level of soil organic carbon along with influential effect in Nitrogen supply and soil fertility as well as to understand how these fractions are affected by cultivation in saline soil. In this study indicate that the soil organic carbon and nitrogen were significantly decreased after cultivation within the cultivated fields and cultivation decreases the organic matter in soils. It was also observed that silt-sized and clay-sized fraction contained more OC that sand fractions and these two fractions were significantly different within the cultivable fields. In both cultivated and uncultivated soils, SOC concentrations in the clay-sized fractions were at least fourth times as high as that of sand-sized fractions and at least three times for N. The C/N ratio in clay-sized fraction of cultivated soils was on average 9 to 6, lower than what was registered in sand-sized fraction (10 to 14). The C/N ratio was 7 - 10 in the silt-sized fraction. The clay-sized fraction was the largest SOC pool in cultivated soils, ranging between 46.27% - 56.63% in both depths. However, in the uncultivated soils, the clay-sized SOC pool was generally smaller with slightly more total SOC stored in the sand fraction. In the lower depth, there was a general increase in the importance of the silt-sized SOC pool. In addition, the clay-sized fraction holds most of the total SOC and N in cultivated soils, and is probably the most important size fraction affecting soil fertility in general. On the contrary, low SOC and N concentrations in the sand-sized fraction can be a common cause of N limitations in cultivated and even uncultivated saline soils. Practices that preserve the clay- and silt-sized C organic fraction while increasing SOC pools in the sand size, are the best options to enhance N supply and crop productivity in the studied soils.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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