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Soil Organic Carbon Pool and its Storage in Arial Beel Wetland Soils of Bangladesh

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Abstract: The actual quantity of Soil Organic Carbon (SOC) stored in wetlands can only be estimated within a broad range of uncertainty. An accurate assessment of the size and distribution of the SOC storages in wetland resources is very difficult to obtain, therefore, the proposed research objective is to measure SOC storage and its pool on wetland soils of Arial beel in Bangladesh. Initial results of Arial beel soil profiles indicates SOC concentrations are high in surface soils ranges from 1.67 to 1.95% but its concentrations are decreasing with depth whereas SOC stock in kg C m^{-2} is increased with depth due to increse soil bulk density with depth. However, carbon in deeper layers may be more stable than that in surface soils due to difference in source, composition and environmental conditions. Soil organic C stored in the three different locations of wetlands soils to 1 m depth such as 16.47, 18.27 and 17.22 kg C m^{-2}, respectively with an average of 17.32 kg C m^{-2}. On the other hand, SOC stored in upland soils to 1m depth such as 11.24 kg C m^{-2}, significantly less than the wetland soils, which indicates that wetland soils serve as a major source of SOC. However, this SOC act as a conditioner to enhance fertility status while combating with climatic extremes, not only that it is a vital component of soil with important effects on the functioning of terrestial ecosystems. For SOC pool, different extraction methods are used such as, highly labile fraction of SOC extracted with hot water (about 3-8% of toal SOC), water soluble fraction of SOC extracted with water (about 1% of total SOC), labile fraction is extracted using $CaCl_2$ (about 1% of total SOC), moderately labile fraction extracted by pyrophosphate (about 4-10% of total SOC), polyaromatic SOC is extracted using toluene + methanol (trace amount of total SOC), microbial biomass C extracted by K_2SO_4 (about 2-5%) and the resistant fraction remaining after extraction. However, the SOC concentration is high in surface layer but with depth concentration decreases. In addition, soil bulk density and thickness values increase with depth, as a result deeper layers stored more carbon than surface layer in Arial beel soils. There is increasing evidence from the results that wetlands have an important and under-estimated role in carbon storage and its pool the regualation of greenhouse gas emission. Some types of wetlands play a particularly key role as C stores, these include forested wetlands and vegetated inter-tidal wetlands and hence, Sundarban mangrove forest and Tengarchar SOC stocks and pools measurement are an urgent issue for the Climate Change researchers and policy makers.

Keyword: Wetland, Arial Beel, Soil Organic Carbon Stocks, Climate Change Policy, Greenhouse Gas Emission, Bangladesh

Introduction

The world's soils hold about 1500 GT (1Gt = 109 t) of organic carbon, which is about twice the atmospheric carbon pool 720 Gt (Hossain *et al.*, 2007). Thus, a relativey small change in the SOC pool could have significant impacts in atmospheric CO_2 concentration and other Green House Gases (GHGs) and hence, on climate. Therefore, an in-depth understanding of the content and distribution of the Soil Organic Carbon (SOC) in a given area would contribute to enhance the capacity to predict and subsequently to ameliorate, the consequence of climate change. Efforts to study the potential of soils to regulate global warming and green house gas effects as a function of the ability of soils to storage large quantities of carbon are increasing worldwide (Hossain *et al.*, 2007; Tang *et al.*, 2012; Marín-Spiotta and Sharma, 2013; Stockmann *et al.*, 2013; Hossain *et al.*, 2014; Jandl *et al.*, 2014; Hossain *et al.*, 2015a; 2015b).

Soils represent the largest carbon reservoirs in the terrestrial ecosystems with approximately 6% of the Earth's land surface, which equals approximately 800 million hectares (approxi. 2 billion acres) is covered by wetland soils worldwide (Tarnocai and Smith, 1992; Eswaran *et al.*, 1999; Dey, 2005; Hossain *et al.*, 2007; Wiesmeier *et al.*, 2012; Negi *et al.*, 2013; Yuan *et al.*, 2013; Aticho, 2013; Cambule *et al.*, 2014; Hossain *et al.*, 2015a).

Due to climate change, SOC is variable across landscape, soil types and climatic zones. It is generally characterized by high levels of C in recalcitrant or humified forms in wetland soils as they store a substantial amount of carbn in their topsoil horizons. There is concern that climate warming could release this SOC to the atmosphere as green house gases but situations may vary from place to place, time to time and between wetland types as they are capable of sequestering and storing carbon through photosynthesis and accumulation of organic matter in soils, sediments and plant biomass. Small changes in SOC resulting from changes in soil management are often to measure, but can have pronounced effects on soil behaviour and microbial processess. However, in any given landscape, wetlands are located in areas with low elevation and high water table. Therefore, wetland soils are on the major carbon sinks on earth, because of the higher amounts of organic matter stored in wetland soils. The soils of the Arial Beel wetland soil ecosystems are also a major carbon sink because of their capacity to sequester large amounts of atmospheric carbon dioxide and thus, can mitigate climate change and its effects (Grand and Lavkulich, 2011; Karchegani *et al.*, 2012; Ryan *et al.*, 2011; Xiaojun *et al.*, 2013; Hoffmann *et al.*, 2014; Eva *et al.*, 2018). The Arial Beel wetland soil ecosystems are found, among other places, in the Bangladesh wetland soil ecosystems. However, studies on the content and distribution of carbon in the soil component in the Arial Beel wetland ecosystems have not been undertaken yet. The quantity of C contained in a pool, meaning a reservoir or system which has the capacity to accumulate or release carbon known as carbon storage. The generous size of the SOC pool especially in wetland soils makes it a potentially important carbon sink that requires accounting. Wetlands are the major C sink while vegetation traps atmospheric CO_2 in wetlands other ecosystems alike, the net sink of wetland is attributed to low decomposition rates in anaerobic soils. Numerous factors like groundwater level, temperature, substrate availability and microbial population affect the decomposition rates and hence carbon sequestration. The SOC pool is very active in the surface layer to a depth of 1 m and it is estimated about 60% SOC occurs in this surfacce layer (Hossain *et al.*, 2015a; 2015b). Climate change may affect the role of wetlands as a source and sink of C. Because of increased temperature, sea level rise, change in precipitation, the storage of carbon in wetlands may be changed. However, the quantities of SOC storage in Arial Beel wetland soils would represent the potential of carbon. The carbon stored in the upper horizons of soils is more susceptibe to loss through soil erosion, when vegetation cover is disturbed.

The Arial Beel wetland soils show alarming deterioration rates following disturbances and land degradation (Woolen *et al.*, 2012; Eva *et al.*, 2018) and it would be important to formulate plans and actions for minimizing such disturbances to prevent SOC losses. Therefore, the study here to determine quantities of SOC storages in the dominant soil types of the Arial Beel wetland soils and to establish the distribution patterns of SOC storages in the study area.

Materials and Methods

Description of the Study Area

Arial Beel is a large depression between the Ganges and Dhaleswari rivers south of Dhaka, which is chosen as the site for the study as one of the major wetland soils of Bangladesh. As an Agro-Ecological Zone (AEZ-15) and part of bio-ecological zone 4b (IUCN, 1993), the beel has a great ecological, commercial and socio-economic importance. The upper part of Arial Beel is Sara soil series and the lower part has Arial soil series. The total area of the Arial Beel is about 14436 h. It lies approximately between 23°32′N to 23°71′N latitudes and 90°10′E to 90°37′E longitudes. The Arial Beel belongs to Dhaka and Munshigonj Districts and located at Dohar, Nawabgonj and Sreenagor Upazillas (Fig. 1). The Wetland soils differ from terrestial soils in that they are anaerobic. The absence of oxygen produces characteristics, especially differences in soil color and

texture that are uniquely different from aerobic, terristial soils. In anaerobic soils, a shift in microbial metabolism occurs, from one of aerobic, oxygen-driven metabolosim to one drivrn by other energy-producing compounds. Unlike plants and animals that require oxygen (i.e., they are obligate aerobes) to support metabolism, many microorganisms are facultative aerobes.

Sample Collection

Soil samples were collected from 1 m depth because, SOC in the top 1 meter of soil comprises about ¾ of the earth's terriestial carbon (Hossain *et al*., 2007; Lal, 2012; Hossain *et al*., 2014; 2015a). Within each soil type a 20 m by 20 m square plot was set out and partitioned into four 10 m by 10 m quadrants. With each quadrant, five points were randomly selected for collection composite soil samples. Finally soils samples were collected from natural horizons in profiles pits up to the 100 cm depth,

in five replicates, from each dominant soil type at three different depth viz. 0 to 15 cm, 15 to 40 cm and 40 to 100 cm from each soil profiles. The first three soil samples were from Sara series and another three were from Arial soil series. Sara soil was collected in field moisture condition whereas Arial soils were in wet condition and inundation depth increased with Arial 1 to Arial 3 (3 replications from each soil), respectively. Sara soil usually remains under water for about four to six months and Robi (winter) crops are mainly cultivated, whereas Arial 3 remains under water for about 9 to 10 months and only Boro rice is cultivated. After collection, soil samples were placed in a seperate polythene bag, labeled and brought to the laboratory for analyzing different soil parameters. At each sampling point, undisturbed core samples with three replications were collected from each depth for the determination of soil bulk density.
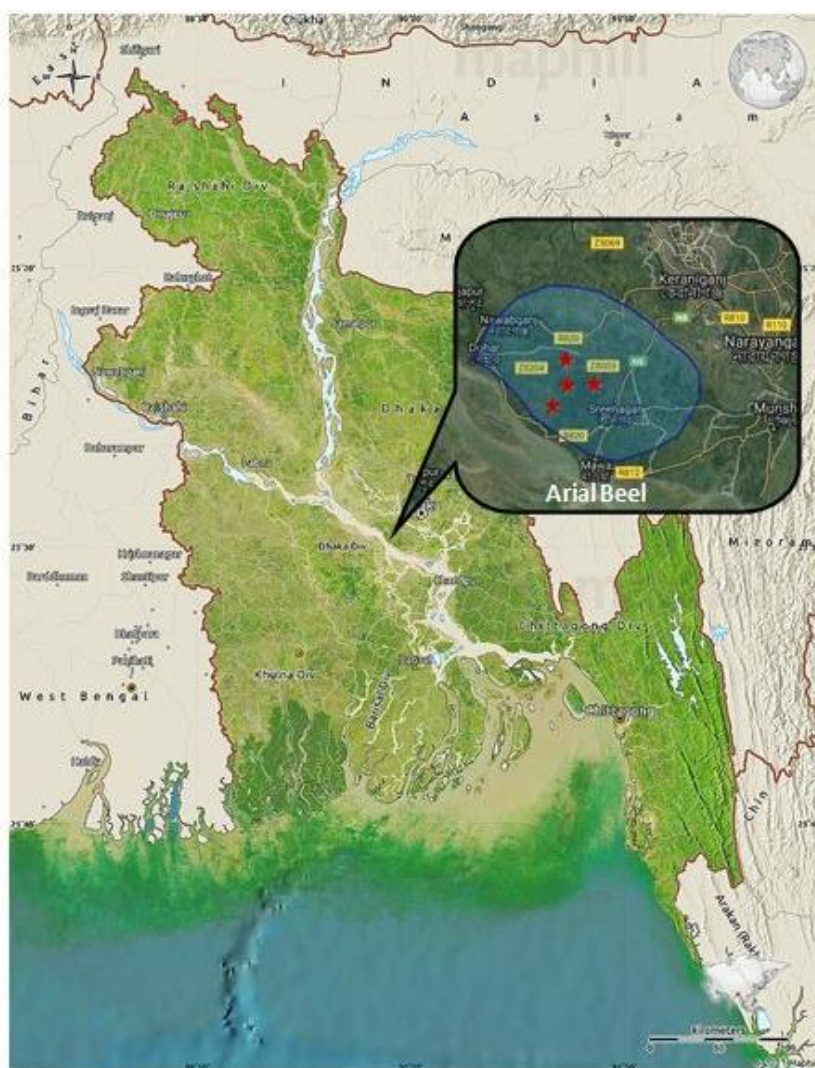

Fig. 1: Sampling location (Arial Beel, Munshigonj, Bangladesh)

Soil Sample Preparation and Analysis

In the laboratory, soil samples were air dried to constant weight after which they were ground and sieved through a 2 mm sieve to get the fine earth fraction ready for laboratory analysis. The collected composite soil samples were prepared as required following the standard procedure. Moisture content of the air dry soil, bulk density, Cation Exchange Capacity (CEC) and particle size were analyzed following the standard procedures (Black, 1965; Blake and Hartge, 1986). The textural classes were determined by Mrshall's triangular coordinates (USDA, 2017). Soil pH was measured electrochemically and the total organic carbon content was determined by Walkely and Black wet oxidation method (Jackson, 1973; Nelson and Sommer, 1983). Soil organic carbon concentration was also determined by dry combustion method using LECO carbon analyzer. The results obtained from the dry combustion method were used for the description of the analysis. Organic matter content of the soil was determined by multiplying the percent value of organic carbon by conventional Van Bemmeten's factor of 1.724 (Piper, 1950).

Determination of Soil Organic Carbon Storage

Storages of organic C in soils are determined from three variables, namely SOC concentrations, bulk density and horizon thickness. Organic carbon (kg C m^{-2}) content for the horizon is expressed on an oven dry weight basis, using the percent organic carbon, bulk desity ad horizon thickness. The following formula is used for organic C storages (Hossain *et al.*, 2007).

Soil organic C storage in each depth (kg C m^{-2}) = % organic C/100 × bulk density (g cm^{-3}) × depth thickness (cm) ×10 (conversion factor units from g cm^{-2} to kg m^{-2}).

The bulk density (g cm^{-3}) measurement is necessary to determine on the volume of soil C in soil profile.

Procedure for Fractionation of SOC

Hot-Water Extractable C

The Hot-Water extractable C (HWC) was determined on fresh field samples by a modified method (Ghani *et al.*, 2003). The extraction of HWC was conducted in two simples steps (Fig. 2). The first step involved removal of readilty soluble C from the soils that may have come from recent liming of the soil or from animal excreta and soluble plant residues. The second steps involved extraction of lable components of soil carbon at 80°C for 16 h. This was subsequently refereed to as hot-water extractable C (Fig. 2). Soil samples (equivalent 3 g oven dry weight) were weighed into 50 mL polypropylene centrifuge tubes. These were extracted with 30 mL of distilled water for 30 min on an end-over-end shaker at 30 rpm and at 20°C, centifuged for 20 min at 3500 rpm and all the supernatant from is filtered thorugh 0.45 mm

cellulose nitrate membrane filter into separate vials for C analysis. This fraction of the SOC was classifed as Water Soluble C (WSC). A further 30 mL of distilled water was added to the sediments in the same tubes and were shaken on a vorted shaker for 10 s to suspend the soil in the water. The tubes were capped and left fo 16 h in a hot-water bath at 80°C. At the end of the extraction period, each tube was shaken for 10 s on avorted shaker to ensure that HWC released from the SOM is fully suspended in the extraction medium. These tubes were then cetrifuged for 20 min at 3500 rpm. The supernatants were filtered thorugh 0.45 mm cellulose nitrate membrane filters. The total C (organic and inorganic C) in both the first and second extracts were determined on Shimadzu Total Organic Carbon (TOC) analyzer. Volumes of 40 mL of the extracts were injected in the detection chamber for the analysis of total C. Three injections of the same volume were analyzed for each sample. This method gave 98% reproducibility of results from the same extracts (unpublished data). The HWC was the organic fraction of the total extractable C that was determined by subtracting the inorganic C values from the total hot-water extractable C. The inorganic C content in the extracts were generally less than 4% of the total hot-water extractable C.

Labile C Fraction

Soil samples were extracted using 10 mM CaCl$_2$. Extraction step employed bte soil to extraction fluid ration of 2 g to 30 mL and 24 h end-over-end rotation (40 rpm) at 25°C. Suspension was allowed to settle overnight and then the supernatant was carfully decanted and filtered. Filtered extracts were analyzed for total oragnic carbon using TOC analyzer.

Moderately Labile C Fraction

Soil samples were extracted using 125 mM Na$_4$P$_2$O$_7$ (p^H 5). Pyrophosphate is traditionally utilized to release Fe and Al bound DOC in soil samples (Erich *et al.*, 2012). Extraction step employed the soil to extract fluid ratio of 2 g to 30 mL and 24 h end-ver-end rotation (40 rpm) at 25°C. Then suspension could settle overnight and then the supernatnat is carefully decanted and filtered. Filtered extracts were analyzed for total organic C using TOC analyzer (Table 1).

Polyaromatic DOC

Soil samples were extracted using toluence + methanol (1:6 v/v). The toluene + methanol (1:6 v/v) was used to recover polyaromatic SOC structures (Jonker and Kaelmans, 2002). The extraction step employed the soil extraction fluid ratio of 2 g to 30 mL and 24 hour's end-over-end rotation (40 rpm) at 25°C. Suspension was allowed to settle overnight and then the supernatant is carfully decanted and filtered. Filtered extracts were analyzed for total organic carbon using TOC analyzer.
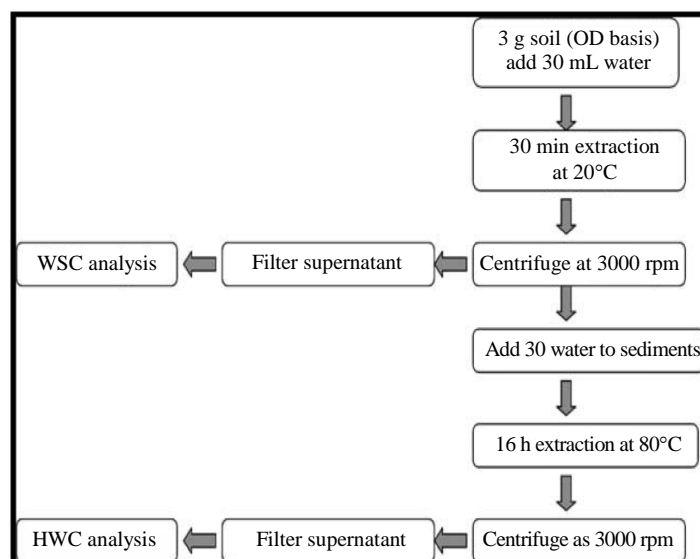
Fig. 2: Schematice description of procedure for extracting Warer-Soluble (WSC) and Hot-Water extractable C (HWC)

Table 1: Extraction methods for fractionation of SOC

Fractions	Extract solution	Soil (g)	Solution (ml)	Conditions	References
Hot water extractable C	Distilled water	3	30	30 min extraction at 20ºC and 20 min rotation at 3500 rpm	Ghani *et al*. (2003)
Water soluble C	Distilled water	3	30	16 h extraction at 80°C and 20 min rotationat 3500 rpm	Ghani *et al*. (2003)
Labile C fraction	10 mM $CaCl_2$	2	30	24 h end-over-end rotation (40 rpm) at 25°C	Erich *et al*. (2012)
Moderately labile C fraction	125 mM $Na_4P_2O_7$ (pH 5)	2	30	24 h' end-over-end rotation (40 rpm) at 25°C	Erich *et al*. (2012)
Polyaromatic DOC	Toluene +methanol (1:6 v/v)	2	30	24 h' end over end rotation (40 rpm) at 25°C	Jonker and Kaelmans (2002)
Microbial biomass C	0.5M K_2SO_4	20	100	1 h shake, sterilization and extraction	Ghani *et al*. (2003)

Microbial Biomass C

Field moist soil samples were analyzed for microbial biomass C (Ghani *et al*., 2003). Duplicate soil samples (5 g dry weight) are fumigated with chloroform for 24 h then extracted with 0.5 M K_2SO_4 for 2 h on end-ever-end shaker. The suspended samples were cenrifuged and filtered through Whatman 42 filter paper. Similar sets of non-fumigated samples were extracted the same way. The amounts of total C in the extracts of the fumigated and non-fumigated soils were determined on Shimadzu TOC analyzer. The extracts (40 mL) were injected into the detection chamber for the analysis of total C. Three injections of the same volume were analyzed from each sample. Given that soils from different ecosystems one K_c factor may not be suited to estimate microbial biomass C, hence, C flush values were used as the indicator of microbial biomass C. Therefore, microbial biomass C was calculated as the difference between the values for fumigated and non-fumigated soils (Ghani *et al*., 2003).

Statistical Analyses

Data analysis was carried out using Statistical Analysis System (SPSS version 19) following the Completely Randomized Design (CRD). Descriptive statistical analysis was used to establish trends and differences of date between variables like mean, median, standard deviation, minimum and maximum and also to produce tables, bars while inferential statistical analysis were used to test the relationships between different variables under the study.

Results and Discussion

Fractionation Soil Organic Carbon in Studied Soil Samples

The values of SOC fractions in soil samples and the percentage of each fraction of the total SOC in the soils are presented in Table 2 and Fig. 3, respectively.

Hot-water Extractable C

The HWC values ranges from 361 to 865 $\mu g\ C\ g^{-1}$ soil or 3-8% of total SOC (Fig. 3). Considerably higher amounts of C in the HWC are since it would be extracted not only the microbial biomas C but also root exudates, soluble carbohydrates and amino acids. The C bound to soil enzymes would also be extracted because most of the soil enzumes in these soils would be denatured at 80°C. Most of these components of SOM are regarded as labile in nature (Ghani *et al.*, 2003; Muñoz Rojas *et al.*, 2012; Kukal and Bawa, 2014). The relationships between HWC and SOC and CEC are positively significant (Table 3). The availability of HWC increases with increase in SOC and CEC, whereas no relationship is observed between HWC and pH, clay and BD indicates HWC are not dependent on any significant extent on any of these properties.
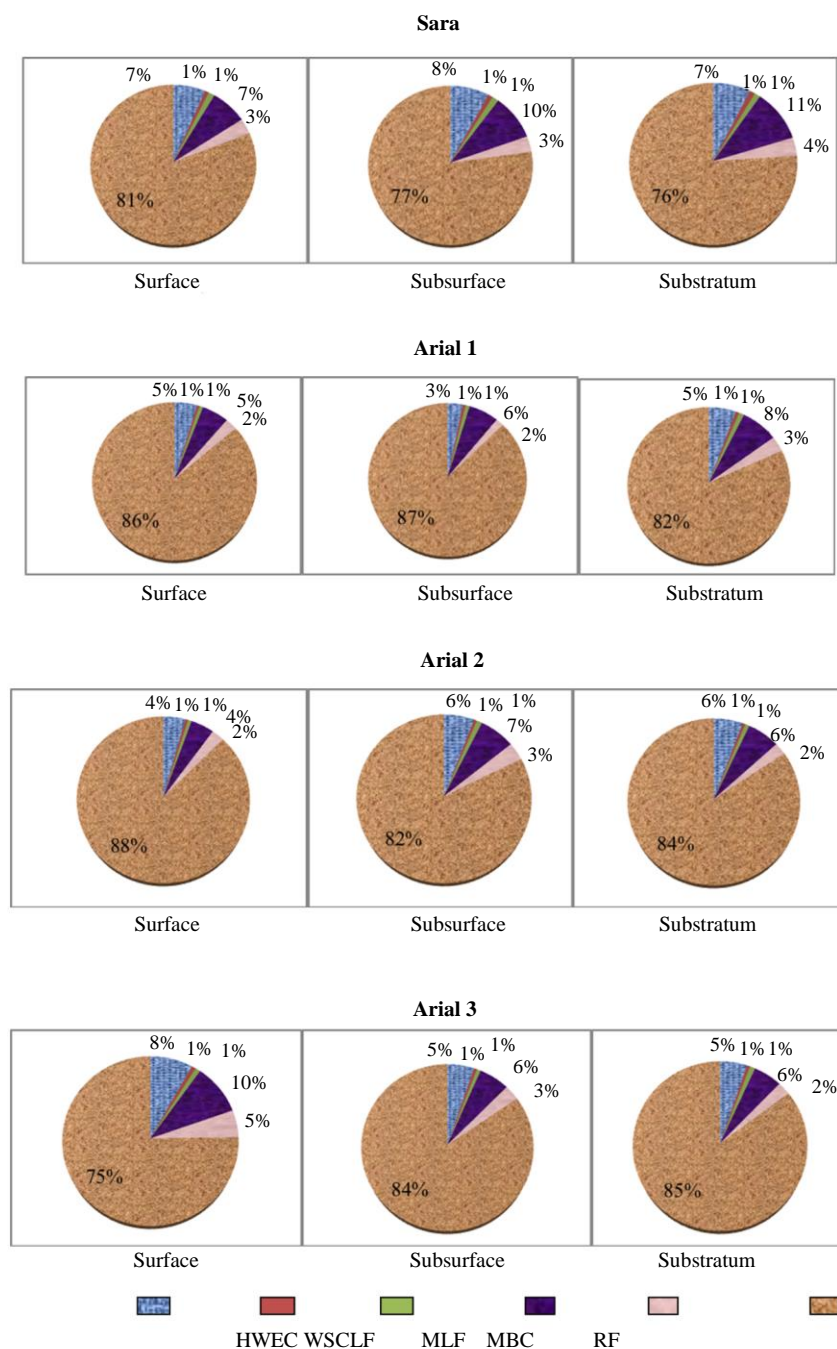

Fig. 3: Percent contribution of each fraction to the total SOC of soil samples

Table 2: Fractionation of soil organic C ($\mu g\ g^{-1}$) in studied samples

Soils	Layers	HWC	WSC	LF	MLF	MBC	PDOC	RF
	Surface	713	89	137	807	346	Trace	8905
Sara	Subsurface	600	73	102	712	245	Trace	5863
	Substratum	534	78	95	760	264	Trace	5468
	Surface	765	82	128	907	405	Trace	14400
Arial 1	Subsurface	361	67	97	707	186	Trace	9780
	Substratum	643	78	125	876	369	Trace	9409
	Surface	825	106	159	876	476	Trace	17055
Arial 2	Subsurface	646	63	117	765	385	Trace	9225
	Substratum	757	73	112	845	312	Trace	11400
	Surface	812	82	98	987	524	Trace	7597
Arial 3	Subsurface	865	98	126	991	498	Trace	14120
	Substratum	578	68	114	613	275	Trace	9550

Note: HWC = Hot Water-Extractable C, WSC = Water Soluble C, LF = Labile Fraction, MLF = Moderately Labile Fraction, PDOC = Polyaromatic Dissolved Organic C and RF = Resistant Fraction

Table 3: Correlation coefficient of individual SOC fractions and some soil properties

SOC fractions ($\mu g\ g^{-1}$)	Soil properties				
	pH	Clay %	CEC me/100g	BD g cm^{-3}	SOC ($\mu g\ g^{-1}$)
HWC	-0.1586	0.2225	0.7742**	-0.1357	0.6193*
WSC	-0.2546	0.095	0.04764	0.0421	0.6560*
LF	0.1147	-0.1986	0.4851	0.5425	0.7277**
MLF	-0.1088	-0.0921	0.5166	-0.3804	0.5118
MBC	-0.0603	0.1386	0.6841*	-0.2191	0.5815*
RF	-0.1451	-0.1389	0.7434**	0.4277	0.9967**

Note: * indicates 0.05 level of significant and ** indicates 0.01 level of significant

Water Soluble C

There have been suggestions that the WSC being part of the highly labile pool of C, may also be sensitive to perturbation and stress in the soil-plant ecosystems and therefore, could be used as a sensitive indicatior of soil quality. However, WSC is usually considerably smaller than other labile pools. It is about 1% and values ranges from 63 to 106 $\mu g\ C\ g^{-1}$ in soil (Fig. 3). Percent value of WSC is quite like the founding value of 1 to 1.25% WSC in the plots of the Maine Potato Ecosystems (Erich *et al.*, 2012). Fierer and Schimal (2003) found 0.2 to 0.5% WSC in air-dry surface soils and 0.1 to 0.4% WSC in oven dry A, B and C horizons. Using field moist soils generally yields somewhat less WSC e.g., 0.01 to 0.3% (Gregorich *et al.*, 1994; Saiz *et al.*, 2012). The amount of WSC varies from soil to soil primarily depending on soil C content. Also, WSC being a highly labile pool of C, had a greater variablity than the HWC (Ghani *et al.*, 2003). Water soluble carbon shows only positive and meaningful relationship with SOC.

Labile C Fraction

Labile C fraction of SOC extracted by $CaCl_2$ ranges from 93 to 159 $\mu g\ C\ g^{-1}$ in soil, which is about 1% of total SOC. The range of labile fraction is quite similar in all soils but slightly lower than literature value of 1 to 1.50% LF of total SOC (Jonker and Koelmans, 2002;

Erich *et al.*, 2012). The relationship between LF and SOC significantly positive (Table 3). Labile C fraction is decomposing plant and animal residues. This fraction breaks down relatively quickly and is an active source of nutrient. Labile carbon is the major food source of soil microbes.

Moderately Labile C Fraction

Dissolved organic carbon content pf pyrophosphate extracts ranges from 613 to 991 $\mu g\ C\ g^{-1}$ soil or 4 to 10% of total SOC (Fig. 3). Pyrophosphate extracted much greater amount of C than water and $CaCl_2$. There is no significant effect on the amount of C extracted by pyrophosphate, suggesting that mineral surface area or surface functional groups determine the amount if pyrophospahte-extractable C (Erich *et al.*, 2012). This fraction consists of molecules soluble through a ligant exchange reaction which removes Fe and Al cations. This fraction likely represents material that can chemically sorbed to soil surface and protected from decomposition.

Microbial Biomass C

Microbial biomass C values ranges from 186 to 524 $\mu g\ C\ g^{-1}$ in soil samples and 2 to 5% of total soil organic carbon. Generally microbial biomass C ranges from 1 to 5% of total SOC but not exceed 8% (Erich *et al.*, 2012). This fraction is a measure of the carbon contained within the living component of soil organic matter. Table 3

demonstrates that the relationships of MBC with SOC and CEC are positively significant.

Resistant Fraction

A substantial quantity of carbon is associated with the resistant fraction, the value ranges from 5468 to 17055 μg C g^{-1} which is about 75 to 88% of total SOC. RF shows meaningful relationship with CEC (r = 0.7434) and SOC (r = 0.9967) but no significant relationships with pH, clay and BD (Table 3).

All the data collected from the various fractions are pooled together to examine the correlations among these fractions. Correlation between HWC and WSC, LF, MLF and MBC are positive and significant (Table 3 and Fig. 3). Various scientist also reported a strong positive correlation HWC and microbial biomass C (Ghani *et al.*, 2012). The amounts of HWC extracted from soils are much higher than extracted as microbial biomass C. The amounts of HWC extracted from soils are much higher than extracted as microbial biomass C. The relationships of WEC with MLF, MBC and RF are positively significant at 0.05 level and LF with RF and MLF with MBC are positively significant at 0.01 level (Table 3).

Measurement of SOC Storage in Arial Beel Wetland Soils

The total SOC storages in Sara and both Arial Beel soil series, which are dominant soil types of the study areas, are represented in Table 4. In mineral soils (Sara series) SOC concentration in surface soil (1.10%) is higher than subsurface (0.76%) and substratum (0.72%; Table 4) but SOC strogae in kg C m^{-2} is not as different as that of the SOC concentration among the horizn due to the increase in soil bulk density with depth (Fig. 4). Because substratum is thicker than surface and subsurface, the total SOC content in substratum (6.05 kg C m^{-2}) is much higher than surface (2.51 kg C m^{-2}) and subsurface (2.68 kg C m^{-2}) but the SOC concentration of mineral soils horizons is measured in northern Canada is much higher in A horizon then B and C, while the concentration in C horizon is almost the same as in B horizon (Hossain *et al.*, 2007; 2015a; 2015b). On the other hand, SOC density, in kg C m^{-3} is not as different as that of the SOC concentration among the layers due to the increase in bulk density with depth.

Bulk density and organic carbon are significantly co-related to each other. Higher bulk density indicates lower organic carbon content. So, soil C stocks are not only depended on soil C concentration but also soil bulk density, which also indicates a strong relationship between soil carbon stock and bulk density (Hossain *et al.*, 2015a). The SOC stock measurement in wetlands is very sensitive because of the development of anaerobic conditions in wetland profile, which attributes the production methane (CH_4) and the decay plant material in wetlands results in the production of dissilved organic carbon, a mixture of comlex organic molecules (Hossain *et al.*, 2015b).

Table 3: Relationship among different fractions of SOC in wetland soils

Fractions of SOC (μg g^{-1})	HWC	WSC	LF	MLF	MBC	RF
HWC						
WSC	0.6977*					
LF	0.5822*	0.5651				
MLF	0.7943**	0.6432*	0.3291			
MBC	0.8867**	0.6658*	0.4837	0.8538**		
RF	0.5584	0.6199*	0.7171**	0.4483	0.5180	

Note: *indicates 0.05 level of significant and **0.01 level of significant

Table 4: Soil organic carbon storage by layers in studied areas

| Soils	Layers	Thickness (cm)	BD (g cm^{-3})	SOC (%)	SOC storage (kg C m^{-2})	SOC storage to 1 m depth (kg C m^{-2})
Sara	Surface	0-15	1.38	1.10	2.510	
	Subsurface	15-40	1.41	0.76	2.680	11.24
	Substratum	40-100	1.40	0.72	6.050	
Arial 1	Surface	0-15	1.32	1.67	3.310	
	Subsurface	15-40	1.35	1.12	3.780	16.47
	Substratum	40-100	1.36	1.15	9.380	
Arial 2	Surface	0-15	1.30	1.95	3.800	
	Subsurface	15-40	1.35	1.12	3.780	18.27
	Substratum	40-100	1.32	1.35	10.69	
Arial 3	Surface	0-15	1.35	1.01	2.050	
	Subsurface	15-40	1.38	1.67	5.760	17.22
	Substratum	40-100	1.40	1.12	9.410	
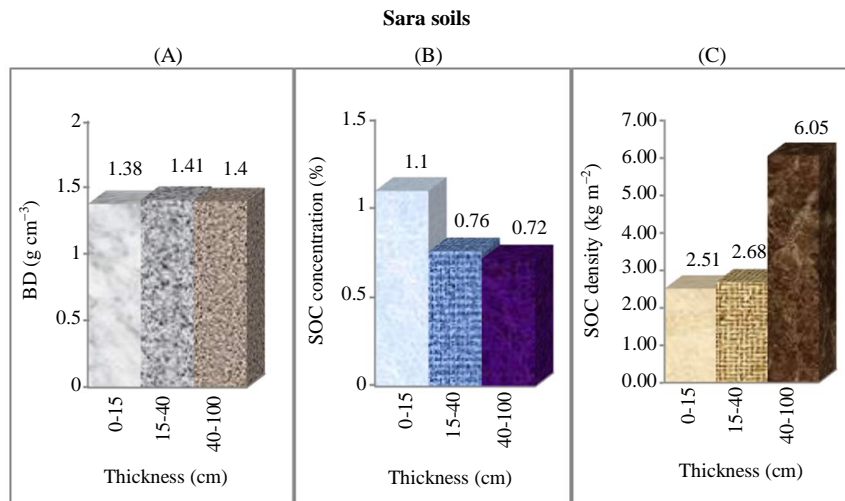
Sara soils

Fig. 4: Mean distribution of (A) bulk density (B) SOC concentration and (C) SOC density with depth in Sara soils
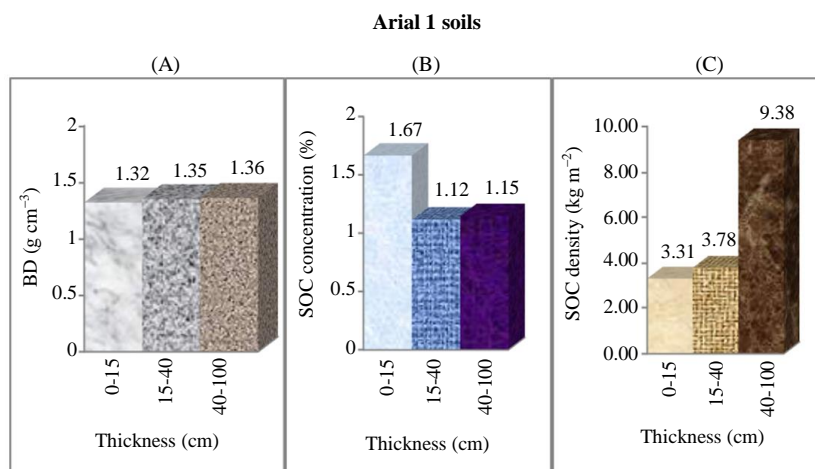
Arial 1 soils

Fig. 5: Mean distribution of (A) bulk density (B) SOC concentration and (C) SOC density with depth in Arial 1 soils

Arial 2 soils
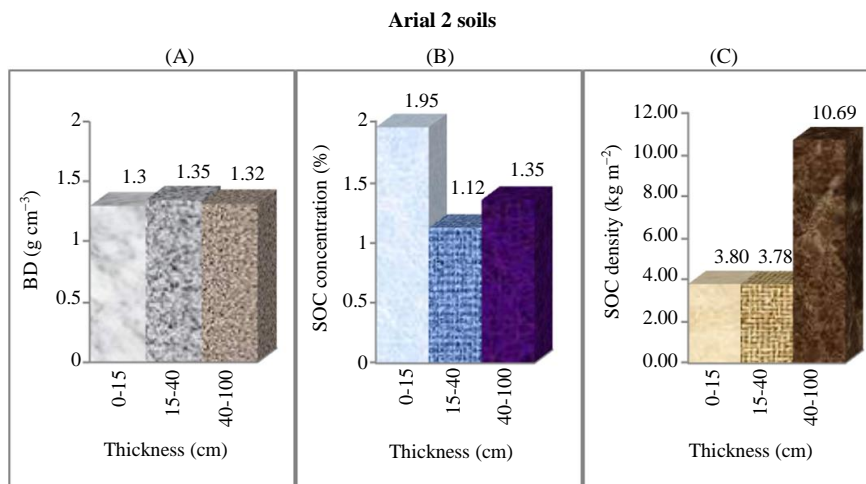

Fig. 6: Mean distribution of (A bulk density (B) SOC concentration and (C) SOC density with depth in Arial 2 soils
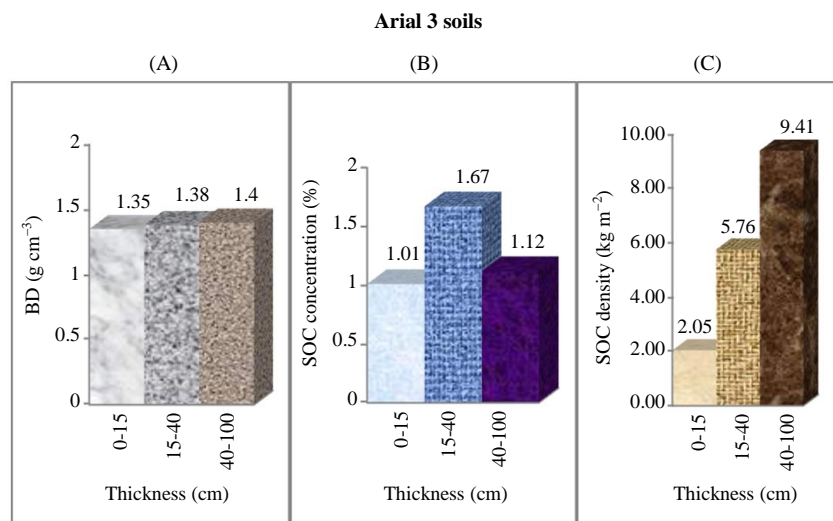
Arial 3 soils

Fig. 7: Mean distribution of (A) buld density (B) SOC concentration and (C) SOC density with depth in Arial 3 soils

In Arial 1 and 2 profiles SOC concentrations are high in surface soils but with depth SOC concentrations decrease in subsurface soils and bulk density increase (Fig. 5 and 6). In substratum soils, there are a slight increase in SOC concentrations with the highest SOC storage 9.38 and 10.69 kg C m^{-2}, respectively. Otherwise in Arial 3 profile SOC concentration is high in subsurface but SOC density is high in substratum soil (9.41 kg C m^{-2}; Fig. 7).

However, soil organic C stored in the three different profiles of Arial beel wetlands to 1 m depth such as 16.47, 18.27 and 17.22 kg C m^{-2}, respectively with an average of 17.32 kg C m^{-2}. Hossain *et al.* (2015b) reported that SOC stroed in the 41 profile to 1m depth ranges from 1 to 74 kg C m^{-2} with an average of 35 kg C m^{-2} in the Yellowknife and 19 profiles to 1 m depth ranges from 4 to 70 kg C m^{-2} with an average of 37 kg C m^{-2} in the Lupin gold mining areas is more than double, even triple than Arial Beel wetland soils of Bangladesh, where most potential SOC storage reported (Personal communication with SRDI). Similiarly, a wide range of soil profile study in SOC storage are noted for the northern Canada (Guo *et al.*, 2011; Don *et al.*, 2011; Wang *et al.*, 2012), they reported 3 to 101 kg C m^{-2} for a transect of 47 Canadian Cryosols from the High Arctic to Boreal zone. On the other hand, 4 to 63 kg C m^{-2} reported for a group of 14 Canadain Arctic Cryosols (Tarnocai and Smith, 1992), which is more than four to six times than Arial Beel wetland soils of Bangladesh. Thus, the variation in SOC stocks worlwide could be contributed by different soil types, climate and different management strategy undertaken. These findings call for sustainable conservation and management strategies of the Arial Beel wetland soils and to avoid those activities that decrease SOC storages. Thus, sustainable management of Arial Beel wetland soils reserve would increase the SOC storage and contribute to climate change regulation and adaptation when CO$_2$ emission are kept low. Literature has acknowledged the importance of wetland soil types in providing livelihoods worldwide, especially to people living in Arial Beel areas. Thus, sustainable management of these soils would guarantee their capacity to store carbon and thereby contribute to climate change mitigation.

Conclusion and Recommendations

Conclusion

The total SOC storage in the dominant soil types i.e., Sara and Arial Beel wetland soils of Munshigonj varies from 2.51 to 6.05 kg C m^{-2} with total storage to 1 m depth is 11.24 kg C m^{-2} (Sara Soils). On the other hand, the bottom soil of Arial Soils SOC ranges from 3.31 to 9.38 kg C m^{-2} with total storage to 1 m depth is 16.47 kg C m^{-2} (Arial 1), 3.78 to 10.69 kg C m^{-2} with total storage to 1 m depth is 18.27 kg C m^{-2} (Arial 2) and 2.06 to 9.91 kg C m^{-2} with total storage to 1 m depth is 17.22 kg C m^{-2}. On an average, the Arial Beel wetland soils SOC storage ranges from 11.24 to 18.27 kg C m^{-2} with total storage to 1 m depth is 15.80 kg C m^{-2}. The soil organic carbon increased with increasing in elevation, horizon thickness and density of soil clay but it decreased with increasing in slope gradient and with increasing in percentage of sand. However, it has clear ideas that Arial Beel wetland soils has a huge potential in SOC storage which could contribute to climate change mitigation.

Recommendations

Sustainable conservation and management strategies of the Arial Beel wetland soils Munshigonj should be devised to insure sustainable provision of livelihoods and ecosystem services. Thus, avoidance of manure and

water hyacinth burning, deforestation and soil erosion will enhance the building up of organic matter and accumulation of greater SOC storages. More detailed information or data in the contents and distribution of SOC for those soil types should be gathered, taking into consideration specific profile, topographical features, soil physic-chemical properties, soil environment and vegetation types, taking into consideration specific profile, topographical features, soil physico-chemical properties, soil environment and vegetation types.

Furthermore, in large scale quantification of SOC storages would provide vital information to stakeholders in designing interventions in response to changes in global climate. Such interventions would assist in mitigation and adaptation to climate change in this Arial Beel wetland soils as well as to provide information that may be of use to stakeholders like Ministry of Agriculture and Ministry of Environment and Climate Change for purpose of analysis and coordination of national efforts to mitigate the effect of climate change.

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Author's Contributions

Md. Faruque Hossain: Literature review, Research plan, design, supervision and manuscript writings.

ASM Maksud Kamal: Grant support, Research Supervision and Critical review.

Monera Akter Eva: Sampling, laboratory analysis, statistical analysis and draft manuscript preparation.

S Mosaddeq Ahmed: Assist laboratory analysis and statistical analysis.

Zakia Parveen: Research plan, Close Supervision and Manuscript critical review.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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