Estimation of soil carbon stock in some wetlands of the northeastern region of Bangladesh

Md. Shiful Islam¹, Arafat Rahman², Humyra B. Murshed², A.S.M. Mohiuddin², Md. Jashim Uddin², Muhaiminur Rahman³ and Md. Khalilur Rahman²

¹Payra 1320 MW Thermal Power Plant, Bangladesh-China Power Company Limited, Dhaka - 1215, BANGLADESH
²Department of Soil, Water and Environment, University of Dhaka, Dhaka - 1000, BANGLADESH
³Department of Geography and Environment, University of Dhaka, Dhaka - 1000, BANGLADESH

Corresponding author’s E-mail: islamshiful998@gmail.com

INTRODUCTION

With climate change and environmental issues leading global concerns, carbon (C) stock in wetland soils has received increasing attention across the world because of its key role in the biogeochemical carbon cycle and its potential feedback on global warming. Taking carbon fluxes into account, soil can be a double-edged sword. Anthropogenic impacts on soil can turn it into either a net sink or source of atmospheric greenhouse gases (GHGs). The carbon-based GHGs emitted from soil are carbon dioxide (CO₂) and methane (CH₄). Information on global and regional soil organic carbon (SOC) pool in the topsoil is generally available for a variety of land use and climatic conditions (Batjes, 1996; Uddin et al., 2019). Apart from climatic factors, representative processes responsible for losses of soil carbon are soil degradation, mineralization of organic matter, leaching of dissolved organic and inorganic carbon, and soil erosion by water and wind. It is widely accepted that carbon cycling and carbon sequestration are most active in topsoil horizons, but growing evidence explains that deeper soil layers can sequester high amounts of stabilized SOC and this should be considered for SOC emission-storage analysis (Rumpel et al., 2012; Wang et al., 2004; Abrar et al., 2020). The importance of SOC sequestration in sub-soils regarding the mitigation of the greenhouse effect is related to the fact that subsoil SOC occurs in fairly stable and highly recalcitrant forms to biodegradation (Rumpel et al., 2012; Schmidt et al., 2011). The SOC surveys usually consider a fixed soil depth, typically 1 meter i.e. 100 cm (Uddin et al., 2019).
In recent decades, understanding of carbon dynamics in the different ecosystem may provide valuable information regarding their usage by estimating their carbon storage and sequestration. Flourishing carbon sink potential of the soil through proper proactive practices, carbonaceous gas emissions can be reduced to a great extent (Lal, 2004). Moreover, judicious soil management strategies must have been adopted to render soil as a sink rather than a source of atmospheric carbonaceous gases. To justify the potentiality of soils in climate change mitigation and adaptation and the drawback originated from organic carbon saturation in sequestering additional carbon, it is imperative to investigate the carbon storage in the basin areas of Bangladesh. Sylhet basin, a geographically distinct region of Bangladesh, occupies two-thirds of national carbon stock. Several wetlands of this region have been rendered extremely vulnerable to anthropogenic activities because of their economic significance, tourist values, intensive agricultural settings during dry season and so on. However, carbon stock estimation has not been comprehensively explored, especially in wetland soils. The relative importance of the edaphic factors as drivers or constraints of spatial heterogeneity of SOC content in these wetland soils is not well understood. Possibly due to the decrease of inundation level in the wetland sites of Bangladesh and consequent intensive agricultural and other anthropogenic activities, the basin soils are losing their carbon contents and thus wetland basin ecosystems are degrading. So, exploring soil organic carbon storage and its sustainable usage are very much important in recent days. Considering the above-stated facts, the present study aimed to estimate carbon stock throughout 1 m (100 cm) depth of both medium high and medium low lands in some wetlands soils underlying the stabilization of organic carbon, analyze the carbon and nitrogen contents of soil, compare different soil chemical properties in different vertical scale and evaluate some management strategies in these cropland soils.

**MATERIALS AND METHODS**

**Study area**
The Sylhet basin is located in the extreme northeastern part of the Bengal Delta Basin, surrounded by the Shilong plateau, Tripura hills, and the Madhupur terrace Pleistocene uplands. The south boundary is a major fault scarp. The basin area has an average altitude of about 4.5 m above mean sea level at its center. It was earlier considered as a part of the Ganges-Brahmaputra delta. The experimental sites are depicted in Figure 1.

The surface soil is inundated every year during monsoon season and becomes dry during the winter season. Geomorphologically, the basin area possesses natural and continuously meandering levees with dendritic drainage. Predominant soils are acidic and the sediment composition of the basin grades from sandy or silty near the surface to fine sand at a depth of about 12 m.

**Soil sampling and processing**
Forty soil and core samples were collected depth wise from eight profiles of Balai, Hakaluki, Hail and Nikli wetland (haor) areas during dry season in the year of 2019 at the different soil depth including 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm. The sampling at different soil depths was used to assess soil carbon storage and distribution as affected by soil depths and inundation land types (Uddin et al., 2019; Wang et al., 2004). The inundation land is a unique feature in Bangladesh and has taken into account for the land management. Among the five categories of inundation land types as identified by FAO-UNDP (FAO-UNDP, 1988). Medium high land (MHL) and medium low land (MLL) sites of the selected four wetland ecosystems were taken into consideration regarding the estimation of carbon stock since these land types contain a significant proportion of basin properties and possess a large area (almost 50% area out of five land types) of the basin ((FAO-UNDP, 1988; SRDI, 2010).
The soil series and sampling location area of the land type including MHLs and MLLs are represented in Table 1. By using fixed depth (1 meter) of the soil profile (surface, sub-surface, and sub-stratum), the sampling was performed in a topo sequence arrangement e.g. two profile samples were from the Balai wetland at the Zakiganj border near Barak river where Surma and Kushiyara coincide, four profile samples were from the Hail and Hakaluki wetland sites which cover the largest influential wetland area of Moulvibazar district of Sylhet basin and the other two profile samples were from the wetland sites of Kishorganj district named Nikli wetland. Soil samples from each wetland site were collected in thick polythene bags. The samples were air-dried, ground and sieved through 2 mm sieve and mixed thoroughly. The samples were then preserved in plastic containers for subsequent analysis.

**Analysis of carbon stock and other soil properties**

Soil organic carbon (SOC) analysis is based on 2 mm soil fraction and was determined using the Walkley and Black wet oxidation method (Nelson and Sommers, 1982). The soil pH was measured in a 1:2.5 soil-water ratio with a glass electrode calibrated Hanna-212 pH meter maintaining 25°C temperature. Total soil Nitrogen was determined by using Micro-Kjeldahl distillation method (Bremner and Mulvaney, 1982). Carbon-nitrogen ratio was calculated by dividing the SOC percent by total nitrogen in percent. Bulk density was measured by the core method (Blake and Hartge, 1986). It may be noted that the bulk density and SOC concentration (%) are the two prerequisites for estimating SOC stock or storage. Thus, the SOC storage and total soil nitrogen (TSN) storage were calculated using the following equations (Batjes, 1996; Guo et al., 2020).

\[ \text{Total soil organic carbon (TSOC)} = \text{SOCi} \times BDi \times Di \quad \text{Eq. (1)} \]
\[ \text{Total soil nitrogen (TSN)} = \text{TNi} \times BDi \times Di \quad \text{Eq. (2)} \]

Where SOCi is the SOC content in the ith layer (g/kg soil), TNi is the total Nitrogen content on the ith layer (g/kg), BDi is the bulk density of the ith layer (g/cc) and Di represents the thickness of the ith layer (cm).

**RESULTS AND DISCUSSION**

**Distribution of soil physicochemical characteristics**

**Soil reaction:** The soil reaction (pH) in the studied sites of medium high land (MHL) in the Balai, Hakaluki, Hail and Nikli wetlands under Sylhet basin was varied from 5.88 to 6.81, 5.45 to 6.44, 6.65 to 7.72, and 5.98 to 6.38, respectively and the average pH values were 6.47 ± 0.37, 6.01 ± 0.38, 7.42 ± 0.44 and 6.25 ± 0.16, respectively (CV% = 5.72, 6.33, 5.94 and 2.56) which are demonstrated in Table 2 and Figure 2. In MHL sites, the pH levels tended to increase in the upper soil layers whereas it remained steady with the increase in depth in Balai wetland (Figure 3). In Hakaluki wetland, the pH status was markedly increased with depth while the fluctuation in pH levels was most prominent in the depth of 0-40 cm in contrast to deeper soil layers (40-100 cm) in Hail wetland. In Nikli wetland, the variation of soil reaction was found in the lower layers. In medium low land (MLL) sites, pH distribution in the Balai, Hakaluki, Hail and Nikli wetlands was ranged from 5.57 to 5.94, 7.02 to 7.28, 7.50 to 7.92 and 6.69 to 7.50, respectively. The mean pH values were 5.84 ± 0.15, 7.19 ± 0.11, 7.80 ± 0.17 and 7.06 ± 0.34, respectively (CV% = 2.57, 1.53, 2.17 and 4.82) (Table 2 and Figure 2). The pH levels were found to be highest in the deeper soil layers in Balai wetland. In Hakaluki wetland, the pH status fluctuated with the increase in depth whereas it was unchanged in the deeper soil layers. Quite similar observation was reported by Guo et al. (2020) in the cropland soils. The soil reaction status was gradually higher with depth which is presented in Figure 3.

**Bulk density of soil:** The distribution of bulk density in the MHL sites was ranged from 1.12 to 1.43 g/cc for Balai wetland soils, 1.29 to 1.56 g/cc for Hakaluki wetland soils, 0.91 to 1.19 g/cc for Hail wetland soils and 1.10 to 1.32 g/cc for Nikli wetland soils. The bulk density has been observed as the highest in Hakaluki wetland soils in contrast to other sites (Figure 2). In the MHL sites, the peak value of bulk density was found in the upper layer of soil (0-20 cm) and then gradually decreased with the increase in depth in both Balai and Hakaluki wetland soils (Figure 3). The distribution of bulk density for Hail wetland also followed the decreasing pattern with an exception in 40-60 cm depth where bulk density increased slightly in comparison to its immediate upper layer in MHL sites. The fluctuation in bulk density was most prominent in Nikli wetland soils (Figure 3). In case of MLL sites, the values of bulk density were ranged from 1.09 to 1.31 g/cc for Balai, 1.29 to 1.48 g/cc for Hakaluki, 1.15 to 1.32 g/cc for Hail and 1.13 to 1.37 g/cc for Nikli wetland soils (Figure 2). The higher bulk density has been observed in the deeper layer of Hakaluki wetland soils. Figure 4 (a, b, c and d) exhibits that 48.4, 75.4, 61.7, and 11.1% of the variation in total SOC storage could be explained by the bulk density in Balai, Hakaluki, Hail and Nikli wetland sites, respectively. Bulk density was highest in the layer 20-40 cm for Balai wetland, then with the increase in depth, the bulk density was decreased gradually. In Hakaluki wetland, the bulk density was highest in the deeper soil layers (80-100 cm) in MLL whereas the fluctuation was most remarkable in Nikli wetland soils (Figure 3).

**Table 1.** Soil series and land type with area of the studied wetland sites.

| Wetland sites | Sampling location of the studied wetlands | Soil series | Land type with area MHL (hectare) | MLL (hectare) |
|---------------|------------------------------------------|-------------|----------------------------------|---------------|
| Balai wetland | 24°54'N to 92°21'E                       | Goyainghat, Kanaigrhat, Phagu | 9,515              | 7,875          |
| Hakaluki wetland | 24°41'N to 92°08'E                   | Phagu, Balaganj, Kanaigrhat | 10,319             | 13,182         |
| Hail wetland  | 24°23'N to 91°42'E                      | Kanaigrhat, Goyainghat, Balaganj | 8,920               | 12,938         |
| Nikli wetland | 24°18'N to 91°01'E                      | Ghatail, Silmandi, Phagu       | 8,757               | 13,805         |

(Source: Land area was adapted from FAO-UNDP 1988 technical report)
Figure 2. Distribution of soil pH, bulk density, SOC storage and Nitrogen contents in both medium high (MHL) and medium low land (MLL) sites of Balai, Hakaluki, Hail and Nikli wetlands.

Figure 3. Changes of soil pH, bulk density, SOC storage, and soil N contents with the depths of MHL and MLL sites of A) Balai, B) Hakaluki, C) Hail and D) Nikli wetlands.
Soil carbon and nitrogen dynamics: Nitrogen contents of the studied wetland soils are presented in Figure 2. It indicates that N was higher in MLL sites compared to MHL sites except for Hail wetland soils which means low land sites contain higher soil N. The C/N ratios of MHL sites in the Balai, Hakaluki, Hail and Nikli wetland soils were varied from 9.80 to 12.00, 8.75 to 13.44, 8.07 to 10.90, and 8.80 to 11.36, respectively where the mean C/N ratios were 10.60 ± 0.85, 11.02 ± 1.68, 9.09 ± 1.18 and 10.04 ± 1.10, respectively (CV%= 8.02, 15.25, 12.98 and 10.95) demonstrated in Table 2.

The C/N ratios of MLL sites were ranged from 6.63 to 13.55 for Balai, 7.60 to 12.6 for Hakaluki, 8.40 to 12.25 for Hail and 9.05 to 16.10 for Nikli haor soils and the mean C/N ratios were 8.97 ± 2.75, 10.00 ± 1.93, 9.61 ± 1.60 and 12.23 ± 3.24, respectively (CV%= 26.72, 19.30, 16.64 nd 26.50) illustrated in Table 2. From the study, it was observed that C/N ratios were higher in deeper soil layers (60–80 and 80–100). The increased mineralization of N in topsoil because of high SOC and microbial activity might be one of the possible reasons for lower C/N ratios (Table 2). Almost collateral findings were reported by Abrar et al. (2020). Application of crop residues (especially the ones with wider C/N ratio) to soil instead of using it as an energy source has a positive effect on the improvement of soil fertility and OC stabilization and its turnover, carbon restoration and mitigation of climate change (Grace et al., 2012).

The primary sources of organic matter input into the subsoil are roots and root exudates, dissolved organic matter, and topsoil SOC translocated by bioturbation (Rumpel and Kögel-Knabner, 2011). SOC distribution in the soils of MHL sites was recorded as 0.94 to 1.11% for Balai, 1.05 to 1.49% for Hakaluki, 0.81 to 1.21% for Hail and 0.82 to 1.25% for Nikli wetland soils under Sylhet basin from surface to 100 cm depth and the average organic carbon values were 0.99 ± 0.07, 1.26 ± 0.16, 1.02 ± 0.18 and 1.00 ± 0.17%, respectively (CV%= 7.07, 12.69, 17.65 and 17.00) showed in Table 2.

---

**Table 2.** Descriptive statistics of the selected soil physicochemical properties in the medium high land (MHL) and medium low land (MLL) of the studied wetlands.

| Wetland sites | Soil properties | Mean ±SD (MHL) | Range (MHL) | CV(%) (MHL) | Mean ±SD (MLL) | Range (MLL) | CV(%) (MLL) |
|---------------|-----------------|----------------|-------------|-------------|----------------|-------------|-------------|
| Balai wetland | pH              | 6.47±0.37      | 5.88-6.81   | 5.72        | 5.84±0.15      | 5.57-5.94   | 2.57        |
|               | Bulk density (g/cc) | 1.29±0.12    | 1.12-1.43   | 9.30        | 1.19±0.09      | 1.09-1.31   | 7.56        |
|               | SOC content (%)  | 0.99±0.07     | 0.94-1.11   | 7.07        | 1.3±0.08       | 1.22-1.45   | 6.11        |
|               | C/N ratios      | 10.60±0.85    | 9.80-12.00  | 8.02        | 8.95±2.75      | 6.69-13.56  | 26.72       |
|               | SOC storage (kg m⁻²) | 2.56±0.37    | 2.15-3.17   | 14.45       | 3.12±0.29      | 2.81-3.43   | 9.29        |
| Hakaluki wetland | pH              | 6.01±0.38      | 5.45-6.64   | 6.33        | 7.19±0.11      | 7.02-7.28   | 1.53        |
|               | Bulk density (g/cc) | 1.41±0.10    | 1.29-1.56   | 7.09        | 1.35±0.08      | 1.29-1.48   | 5.93        |
|               | SOC content (%)  | 1.26±0.16     | 1.05-1.49   | 12.69       | 1.25±0.07      | 1.14-1.32   | 5.60        |
|               | C/N ratios      | 11.02±1.68    | 8.75-13.44  | 15.25       | 10±1.93       | 7.60-12.60  | 19.3        |
|               | SOC storage (kg m⁻²) | 3.58±0.69  | 2.88-4.64   | 19.27       | 3.37±0.32      | 2.95-3.73   | 9.49        |
| Hail wetland  | pH              | 7.42±0.44      | 6.65-7.72   | 5.94        | 7.80±0.17      | 7.50-7.92   | 2.17        |
|               | Bulk density (g/cc) | 1.05±0.11    | 0.91-1.19   | 10.48       | 1.24±0.06      | 1.15-1.32   | 4.84        |
|               | SOC content (%)  | 1.02±0.18     | 0.81-1.21   | 17.65       | 1.13±0.23      | 0.84-1.42   | 20.35       |
|               | C/N ratios      | 9.09±1.18     | 8.07-10.90  | 12.98       | 9.61±1.60      | 8.40-12.15  | 16.64       |
|               | SOC storage (kg m⁻²) | 2.18±0.58  | 1.48-2.88   | 26.80       | 2.81±0.64      | 2.03-3.75   | 22.77       |
| Nikli wetland | pH              | 6.25±0.16      | 5.98-6.39   | 2.56        | 7.06±0.34      | 6.69-7.50   | 4.82        |
|               | Bulk density (g/cc) | 1.22±0.09    | 1.10-1.32   | 7.38        | 1.25±0.09      | 1.13-1.37   | 7.2         |
|               | SOC content (%)  | 1.00±0.17     | 0.82-1.25   | 17.00       | 1.74±0.11      | 1.61-1.90   | 6.32        |
|               | C/N ratios      | 10.04±1.10    | 8.80-11.36  | 10.95       | 12.23±3.24     | 9.05-16.10  | 26.50       |
|               | SOC storage (kg m⁻²) | 2.45±0.30  | 2.16-2.80   | 12.24       | 4.37±0.54      | 3.93-5.20   | 12.35       |
The SOC content was found to be the highest (1.26%) in MHL of Hakaluki haor soils and the sequence is: Hakaluki wetland (1.26%) > Hail wetland (1.02%) > Nikli wetland (1.01%) > Balai wetland (0.99%).

On the other hand, SOC distribution in the soils of MLL sites in the Balai, Hakaluki, Hail and Nikli wetlands was measured as 1.22 to 1.45%, 1.14 to 1.32%, 0.84 to 1.42%, and 1.61 to 1.90%, respectively from the surface to 100 cm depth whereas the mean organic carbon was 1.31 ± 0.08, 1.25 ± 0.07, 1.13 ± 0.23 and 1.74 ± 0.11%, respectively (CV% = 6.11, 5.60, 20.35 and 6.32) (Table 2). The SOC content was found to be maximum (1.74%) in the MLL of Nikli haor site and the order is: Nikli wetland (1.74%) > Balai wetland (1.31%) > Hakaluki wetland (1.24%) > Hail wetland (1.13%).

The highest SOC concentration was found in the topsoil (0-20 cm) samples with respect to land types and sites. The topsoil layer is tilled and receives greater residue inputs which are subsequently mineralized. Thus, this layer possesses higher SOC than the other soil layers. Hence, the topsoil layer may be able to sequester atmospheric CO$_2$. Also, nitrogen fertilization to topsoil of agricultural systems typically increases SOC concentrations due to increased biomass of residues returned to agricultural soils (Abrar et al., 2020). The SOC concentration showed a decreasing trend from the topsoil to the bottom layer for all land types of the study area. It is important to note that medium low land (MLL) sites contained higher SOC than the medium high land (MHL). As found in the present work, topographically higher land i.e. MHL due to less of inundation had higher cropping intensities and lower SOC’s than lower land (MLL), which had lower cropping intensity with greater extent and duration of inundation. Uddin et al. (2019) also reported that upland sites have significantly lower SOC than soils in depositional areas.

However, recent work suggests that erosion can increase both the loss and sequestration of SOC (Uddin et al., 2019). The SOC threshold for sustaining soil quality is widely suggested to be about 2% (20 g/kg) below which deterioration in soil quality occurs (Patrick et al., 2013). Krull et al. (2004) discussed some of the minimum and maximum thresholds of SOC, above or below which the effects of SOC on soil functions are noticeable. However, Sparling and Schipper (2002) argued that other than defining such maximum values, it is reasonable if minimum SOC levels (e.g., 2% or 20 g/kg) were established to inform the farming community on levels below which there would be a loss of important soil characteristics. Thus, it is found that the study sites belong to the minimum threshold of SOC level.

**Figure 5.** Soil C stock in medium high and medium low land sites of four investigated wetlands.

**Figure 6.** Spatial distribution map of soil C stock in Balai, Hakaluki, Hail and Nikli wetland sites irrespective of land type.
Soil organic carbon (SOC) storage: SOC storage in MHL sites was noted as 2.15 to 3.17 kg/m² for Balai wetland, 2.88 to 4.64 kg/m² for Hakaluki wetland, 1.48 to 2.88 kg/m² for Hail wetland and 2.16 to 2.75 kg/m² for Nikli wetland soils under Sylhet basin region from the surface to 100 cm depth and the total organic carbon storage was 12.82, 17.90, 10.89 and 12.23 kg/m², respectively (Table 2 and Figure 2). In MHL sites, the SOC storage was found to be decreased with the increase in depth in Balai wetland soils. It was highest in the topsoil layer, gradually decreased to 2.88 kg/m² and finally slightly increased in the deepest layer which was observed in Hakaluki wetland. The SOC storage was sharply decreased with the increment in depth for Hail wetland with an exception for layer 40-60 cm (Figure 3). Nikli wetland followed a decreasing pattern with increasing depth. Figure 4 (e) shows that 84.1% of the variation in total SOC storage could be explained by soil depth in MHL sites. The dominant land use types in Balai and Hail wetlands were transplanted by Aman and Boro rice. Hakaluki soils are used for the cultivation of Boro rice during the dry season. These grasslands are used for grazing cattle. The dominant land use of this study site is deep transplanted Aman rice and it becomes waterlogged for most of the year. Wetland rice cultivation represents the most complex system in relation to carbon sequestration (De Stefano and Jacobson, 2018), where residue management is an important method of sequestering C in soil and increasing the soil organic matter content (Abrar et al., 2020). Crop residues vary in their inherent decomposability due to differences in their physicochemical characteristics. Thus, growing different crop types represents the variability of carbon storage in different locations of wetland soils. Increasing food demand due to growing population is the main driver for the widely seen expansion and intensification of agriculture, which in turn causes SOC storage depletion in the wetland soils. Regarding MLL sites, SOC storage in the Balai, Hakaluki, Hail and Nikli wetland soils was ranged from 2.81 to 3.39, 2.95 to 3.60, 2.03 to 3.75, and 3.93 to 5.20 kg/m², respectively from surface to 100 cm depth and the total organic carbon storage was 15.58, 16.83, 14.05 and 21.84 kg/m², respectively (Figure 2). The SOC storage tended to decrease in the deeper soil layers (Figure 3). An inverse relationship between the soil depth and SOC storage was also noted for rest of the wetlands excluding Hakaluki wetland where soil has an increasing carbon load in the deeper layer (80-100 cm) demonstrated in Figure 3. Figure 4 (f) shows that 96.4% of the variation in total SOC storage could be explained by soil depth in MLL sites. Variation in SOC storage possibly due to their land use, inundation level and land cover variations. A decrease in soil degradation through soil conservation and management practices can help soil organic C sequestration in the investigated area. The variability of soil properties within the investigated sites was classified as low (<15%) to medium (15-75%) based on the coefficient of variation (CV) values according to the groupings described by Dahiya et al. (1984). This indicates that the variability of the studied soil properties was most pronounced in the medium high land for Balai and Hakaluki wetlands (Table 2). For medium low land, the variability was most remarkable in Hail and Nikli wetlands. Among the analyzed chemical soil attributes, SOC storage and C/N ratios exhibit medium variability whereas pH and bulk density show low variability.

Soil carbon stock: Carbon (C) stock across the study sites at 100 cm depths was estimated for both MHL and MLL sites which were about 5.7 and 8.4 Tg, respectively. The total C stock in the study area was nearly 14 Tg. In MHL sites, C stock was calculated as 1.2 Tg for Balai wetland, 1.8 Tg for Hakaluki wetland, 1.0 Tg for Hail wetland and 1.1 Tg for Nikli wetland soils (Figures 5 and 6). In case of MLL sites, soil carbon stock was estimated as 1.3 Tg for Balai, 2.2 Tg for Hakaluki, 1.8 Tg for Hail and 3.1 Tg for Nikli wetland soils. Bangladesh predominantly consists of Inceptisols and the studied areas belong to Inceptisols as well. Hussain (2002) reported that the SOC stock of Inceptisols in Bangladesh is 1.59 Pg. Eswaran et al. (1993) estimated SOC stock in the total soil of Bangladesh is 2.2 Pg. There is very scanty info on SOC stock in the Sylhet basin soils of Bangladesh. Lal (2004) estimated the SOC pool was estimated in India at 21 Pg at 30 cm depth and 63 Pg at 150 cm depth. He also reported that SOC concentration in most cultivated soils is less than 10 g/kg which is consistent with the present study. The prevalent low levels of SOC concentrations are attributed to excessive tillage, imbalanced fertilizer use and little or no return of crop residue to the soil. It is important to note that carbon sequestration in soils is a slow process and may take centuries to build up a stable stock of organic matter. Nevertheless, increasing SOC stocks in subsoil is still recognized as a promising means to enable substantial C sequestration in soils (Ruppel et al., 2012). Along with these, different afforestation practices may result in significant SOC accumulation in the wetland soils, especially to secure soil organic carbon pools and climate change mitigation as well.

Conclusion

It is deduced from the present study that C stock in basin regions was gradually lessening in greater magnitude which may lead to higher carbonaceous gas emissions due to the very fast decomposition rate of soil organic carbon. The carbon stock was higher in the medium low land sites in contrast to medium high land sites. It might be due to the decrease of inundation level by the predicted climate change, intensification of agricultural practices and other eco-environmental changes. It is widely accepted that manure inputs can improve soil quality with organic carbon stabilization in soil. There is no alternative to adopt the proper management practices for retaining carbon stock. The strategies including reduction in tillage intensity to control surface erosion, change in cropping intensity and systems, adoption of yield promoting practices including high doses of nutrients and amendment, and re-establishment of permanent perennial vegetation like forestry and pasture should be practiced for increasing carbon stock in the basin regions of Bangladesh.
ACKNOWLEDGEMENTS

The financial support from the fellowship fund of Ministry of Science and Technology, Government of the Peoples’ Republic of Bangladesh for carrying out this study is gratefully acknowledged.

Open Access: This is an open access article distributed under the terms of the Creative Commons Attribution NonCommercial 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) or sources are credited.

REFERENCES

Aabbrar, M.M., Xu, H., Aziz, T., Sun, N., Mustafa, A., Aslam, M.W., Shah, S.A.A., Mehmood, K., Zhou, B., Ma, X., Chen, X. and Xu, M. (2020). Carbon, nitrogen, and phosphorus stoichiometry mediate sensitivity of carbon stabilization mechanisms along with surface layers of a Mollisol after long-term fertilization in Northeast China. Journal of Soils and Sediments. https://doi.org/10.1007/s11368-020-02825-7

Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, 47: 4–21. https://doi.org/10.1111/j.1365-2389.1996.tb01386.x

Blake, G.R. and Hartge, K.H. (1986). Bulk density. In: Klute, A.L., Miller, R.H., Keeney, D.R. (Eds). Methods of Soil Analysis. Part 2. Second Edition, Agronomy Monograph 9. American Society of Agronomy—Soil Science Society of America, Madison, pp. 363-382.

Bremner, J.M. and Mulvaney, C.S. (1982). Total Nitrogen. In: Page, A.L., Miller, R.H. and Keeney, D.R. (Eds.). Methods of Soil Analysis. Part 2. Second Edition, American Society of Agronomy—Soil Science Society America, Madison, USA, pp. 595–622.

Dahiyia, L.S., Kersbaem, K.C. and Richter, J. (1984). Spatial variability of some nutrient constituents of an Alfisol from loess: I. Classical statistical analysis. Zeitschrift für Pflanzenernährung und Bodenkunde, 147: 695-703. https://doi.org/10.1007/BF02307526

De Stefano, A. and Jacobson, M.G. (2018). Soil carbon sequestration in agroforestry systems: a meta-analysis. Agroforestry Systems, 92(2): 285-299. https://doi.org/10.1007/10457-017-0147-9

Eswaran, H., Vanden, B.E. and Reich, P. (1993). Organic carbon in soils of the World. Soil Science Society of America Journal, 57(1): 192-194. https://doi.org/10.2136/ssaj1993.03615995005700010034x

FAO-UNDP (1988). Land resources appraisal of Bangladesh. Technical report 2. Agro-ecological regions of Bangladesh. Food and Agricultural Organization, Rome, pp. 570.

Grace, P.R., Antle, J., Aggarwal, P.K., Ogle, S., Paustian, K. and Basso, B. (2012). Soil carbon sequestration and associated economic cost for farming systems of the Indo-Gangetic plain: a meta-analysis. Agriculture, Ecosystem and Environment, 146: 137-146.

Guo, J., Wang, B., Wang, G., Myo, S.T.Z. and Cao, F. (2020). Effects of three cropland afforestation practices on the vertical distribution of soil organic carbon pools and nutrients in eastern China. Global Ecology and Conservation, 22: e00913.

Hussain, M.S. (2002). Distribution of organic carbon and its sequestration in the soils of the Bengal Delta. The Delta Research Centre. Department of Geology, University of Dhaka, pp. 28.

Krull, E.S., Skjemstad, J.O. and Baldock, J.A. (2004). Functions of soil organic matter and the effect on soil properties. Cooperative Research Centre for Greenhouse Accounting, Australia.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304(5677): 1623-1627.

Nelson, D.W. and Sommers, L.W. (1982). Total carbon, organic carbon and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds). Methods of Soil Analysis. Part 2. Second Edition, American Society of Agronomy—Soil Science Society America, Madison, USA, pp. 595–622.

Patrick, M., Tenywa, J.S., Ebanyat, P., Tenywa, M.M., Mubiru, D.N., Basambaand, T.A. and Leip, A. (2013). Soil Carbon thresholds and nitrogen management in tropical agro-ecosystems: concepts and prospects. Journal of Sustainable Development, 6(12): 32-43. https://doi.org/10.5539/jsd.v6n12p31

Rumpel, C. and Kögel-Knabner, I. (2011). Deep soil organic matter—a key but poorly understood component of terrestrial C cycle. Plant Soil, 338: 143–158.

Rumpel, C., Chabbi, A. and Marschner, B. (2012). Carbon Storage and Sequestration in Subsoil Horizons: Knowledge, Gaps and Potentials. In: Lal et al. (Eds.). Recarbonization of the Biosphere. Dordrecht, The Netherlands: Springer, pp. 445-464.

Schmidt, M.W.I., Torn, M.S., Aliven, S., Dittrmar, T., Guggenberger, G., Janssens, I.A., Kleber, M., Kögel-Knabner, I., Lehmann, J., Manning, D.A.C., Nannipieri, P., Rasse, D.P., Weiner, S. and Trumbore, S.E. (2011). Persistence of soil organic matter as an ecosystem property. Nature, 478(7367): 49–56. https://doi.org/10.1038/nature10386

Sparling, G.P. and Schipper, L.A. (2002). Soil quality at a national scale in New Zealand. Journal of Environmental Quality, 31(6): 1848–1857.

SRDI (2010). Land and soil statistical appraisal book of Bangladesh. Soil resource Development Institute, Ministry of Agriculture, Dhaka, Bangladesh, pp. 1-24.

Uddin, M.J., Hooda, P.S., Mohiuddin, A.S.M., Smith, M. and Waller, M. (2019). Land inundation and cropping intensity influences on organic carbon in the agricultural soils of Bangladesh. Catena, 178: 11-19.

Wang, S., Huang, M., Shao, X., Mickler, R.A., Li K. and Ji, J. (2004). Vertical distribution of soil organic carbon in China. Environmental Management, 33: 200–209.