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Influencing Factors for Mangrove Soil Organic Matter to Organic Carbon

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Abstract

Degradation and destruction of mangrove forests in many regions have resulted in the alteration of carbon cycling. Objectives of this study were established to answer the question regarding how much soil organic carbon (SOC) is stored in wetland soils in part of the upper northeastern Gulf of Thailand and to what extent SOC is related to organic matter (OM). A total of 29 soil samples were collected in October 2015. Soil physiochemical analyses followed the standard protocol. Spatial distributions were estimated by a kriging method. Linear regression and coefficient were used to determine the suitable conversion factor for mangrove soils. The results showed that surface soil (0–5 cm) contained higher SOC content as compared to subsurface soil (5–10 cm). Considering a depth of 10 cm, this area had a high potential to sequester carbon with a mean ± standard deviation of 5.59 ± 2.24%. The spatial variability of OM and SOC revealed that organic matter and carbon decreased with the distance from upstream areas toward the gulf. Based on the assumption that OM is 50% SOC, the conversion factor of 2 is recommended for more accuracy rather than the conventional factor of 1.724.

Introduction

Since the Industrial Revolution, there has been a speedy increase in atmospheric carbon dioxide (CO2) concentration. Global levels of CO2 already passed above 400 ppm mark in 2015. The natural movement of carbon across the atmosphere, vegetation, soils, and the oceans is the key to mitigate climate change due to elevated CO2. Globally, soils store more carbon, about 3.3 times, than the atmosphere and 4.5 times the bionic pool. Among different ecosystems, wetlands often represent the largest carbon pool because of their anoxic conditions and thus play a vital role in carbon cycles. Of the 1,500 Pg C stored in the Earth's soils, peat-forming wetlands are estimated to contain about 300–600 Pg C. Southeast Asian peatlands account for the most important carbon sink, representing 68.5 Pg C or 77% of global tropical peatlands [1]. Despite accounting for the importance of wetlands to ecosystems and humans, one-third of global wetlands have been lost due to land use change, aquaculture inversion, and wetland degradation. Carbon emissions from mangrove loss are uncertain, but it is estimated that about 10% of all carbon emissions are released by deforestation worldwide. Thailand alone is estimated to have lost approximately 82% of its wetlands. Chonburi Province, Thailand, also has experienced wetland loss as a result of urban sprawl, industrial development, and deforestation. Between 1961 and 2007, its wetland coverage was reduced from 38.2 km^2 to 7.8 km^2, or by about 80%. Wetland conversion directly affects the size of the soil carbon pool. Soil organic carbon (SOC) is part of the carbon stored in soil organic matter (OM). The estimation of SOC has followed various techniques from the oldest to the simplest method [2]. The assumption that OM contains 58% carbon was first established by Sprengel in 1826. Since then, the conversion factor of 1.724 has been repeatedly used as a rough estimate of organic carbon content for universal applications. Other early studies published in

German scientific literature assumed that OM holds 58% carbon and 60% carbon. However, these numbers are considered too low in many areas. The application of 1.9 and 2.5 was recommended to convert OM to SOC for soils in the top and subsurface layers, respectively, worldwide. Soil type and environment result in SOC-to-OM variations. In wetland ecosystems, a factor of 1.842 has been determined for most peats, 1.88 for peat in Wales, and 2.07 and 2.34 for wetlands in England [3]. A recent study has claimed that a factor of 2, based on the assumption that OM is 50% carbon, is more accurate in almost all cases than the conventional factor of 1.724. Soil management can manipulate the balance of carbon sink and source processes. When OM is broken down, some of the SOC can be quickly mineralized and converted to CO_2. Carbon thus disappears from the soil. The high amount of soil organic matter tends to be limited to the soil surface, probably at a depth of 5 to 10 cm [4]. Organic matter often binds to fine particles, particularly clay, and the binding processes further prevent soil carbon loss. The study of SOC and its relationship to OM is important; yet there are research gaps to be filled regarding mangrove soils in Thailand. It is still questionable how much SOC is stored in the wetland soils and to what extent SOC is related to OM. The aim of this study is to spatially investigate the SOC content in mangrove areas at surface and subsurface layers, as well as the association of SOC-to-OM conversion.

Materials and Methods

Site Description

Estuarine mangrove forests along the coast of the Gulf of Thailand are influenced by the open coastal environment during high tide and fresh water flow during low tide. The study area is part of the Nature Education Center for Mangrove Conservation and Ecotourism located in Chonburi Province on the eastern coast of the Gulf of Thailand. The center was established in 2001 for mangrove conservation and education purposes. The conservation area covers approximately 480,000 m^2, but the focus area of interest is limited to the area within and around the wooden walkway due to the constraints of area accessibility [5]. The area within the walkway covers 113,240 m^2 and extends to 220,000 m2 for the study area. The water channel receives runoff from residential communities and industries upstream and then drains through the mangrove conservation area before being discharged into the Gulf of Thailand. Chonburi has a tropical savanna climate and temperatures rise in April, with the average daily maximum at 35.2°C. The presence of poor mangrove growth was near the entrance of the walkway and appears in the southeast center of the study area.

Sampling Design

The sampling site was marked by a handheld GPS on site. The boundary of the area was mapped using Google Earth imaginary layout. The geographic coordinate system used was WGS84 before being projected to the UTM Zone 47N system for consistent data analysis. The spatial sampling sites were planned on the grid-based sampling design with a cell size of 80 m × 80 m. From an initial grid design providing 35 soil samples covering the entire area, a total of 29 soil samples from the surface across the study area were available for analysis due to limited accessibility**.** Soil samples were collected in October 2015. All the samples were collected during low tides; thus a hand collection technique was implemented. To collect samples, a 10 × 5 cm^2 soil core was used from each designated location within a square grid. The collected sediments were cut into two layers: surface and subsurface. All samples were kept at 4°C at the sampling moisture content for laboratory processing [6].

Analysis of Soil Characteristics

The physiochemical sediment properties, that is, texture, pH, salinity, electrical conductivity (EC), total dissolved solid (TDS), and soil texture, were analyzed. After air-dried samples were prepared, the percentages of sand, silt, and clay in the sediments were determined by hydrometer testing and then compared with a soil texture triangle to identify soil texture. The ratio of soil to water was 1: 2.5 as suggested by Jackson. The measurement of pH was determined by a pH meter. Salinity, EC, and TDS were analyzed by a portable handheld EC meter [7].

Results

Soil Organic Carbon and Physiochemical Characteristics at 0-5 cm and 5-10 cm Depths.

Sandy clay loam covered the majority of the surface soil, followed by sandy loam and loam. On the other hand, clay texture was dominant in the subsurface soil, followed by sandy clay loam and clay loam. Low salinity with mean values of 2.04 ppt in surface soil and 2.22 ppt in subsurface soil was influenced by strong water inflow from the estuary to the seaside because the data collected in this study was taken during low tides. These values were consistent with average EC values of 3.66 mS/cm and 3.96 mS/cm which indicated moderately saline condition and sea water was diluted by the fresh water. Its salinity, the mixture of saline and fresh water, ranged from 1.00 to 3.52 ppt [8]. According to the salinity classification of Levinton, mangrove soil in this area was considered under brackish and slightly alkaline condition with an average pH above 7. Descriptive statistics of SOC content and related parameters are summarized in **(Table 1)**. The measured values of SOC were equally alike to the amount of TC, indicating very low inorganic carbon forms in this area.

The surface soil exhibited a higher SOC content than the subsurface layer. The results show that, vertically, SOC content decreased with increasing depth. The mean observation with standard deviation SOC was 3.08 ± 1.25% and 2.51 ± 1.47% for the surface and subsurface soils, respectively. Thus surface soils with higher productive mangroves in this area retain a greater amount of SOC input. Local topography and soil drainage are considered important drivers in determining carbon storage. Since the mangrove area in this study was generally flat, the erosion process to transport carbon from topsoil to the bottom of the slopes was difficult. The water-logged condition in the mangrove forest could promote depositional rates and inhibit decomposition rates [9]. It can be observed that the disturbance of soil surface from tillage, dredging, or other aquaculture activities was extremely low in the conservation area compared to agricultural space. Less soil disturbance contributed to a net positive SOC storage of estuarine wetlands. The different amount of carbon deposits along depths was largely influenced by vegetation. In an area with similar decomposition rates, carbon inputs greatly depend on primary productivity. This may be explained by the size of fraction SOC inputs and decomposition rates. Since a large fraction comes from root turnover, the variability of root inputs is an influential factor in carbon storage.

Carbon Storage (0–10 cm)

At a depth of 10 cm, SOC varied across vegetation species and areas. The Nature Education Center for Mangrove Conservation and Ecotourism in this study, heavily dominated by Avicennia Alba Bl., stored SOC at about 5.59% and OM 11.12%. Observed organic matter ranged from 6.14 to 17.34% with a mean ± standard deviation of 11.12 ± 2.23%. Soil organic matter ranged from 2.26 to 9.80% with a mean ± standard deviation of 5.59 ± 2.24% **(Table 2).**

Discussion

Looking back at **Table 2** we can see that the results were comparatively equal

Table 1: Descriptive statistics of total carbon, soil organic carbon, soil inorganic carbon contents, and soil characteristics in surface and subsurface soils

Parameters	Surface soil (0–5 cm) (n=29)				Subsurface soil (5–10 cm) (n=29)		
	Max	Min	Mean	SD	Max	Min	Mean
Total carbon (%)	6.2	0.02	3.09	1.25	5.08	0.02	2.5
Soil organic carbon (%)	6.2	0.02	3.08	1.25	5.01	0.02	2.5
Soil inorganic carbon (%)	0.06	0	0.01	0.02	0.23	0	0
pH	8.01	6.95	7.38	—	8.12	7.35	7.8
Salinity (ppt)	3.04	1	2.04	0.47	3.52	1.2	2.2
EC (mS/cm)	5.28	1.88	3.66	0.78	6.06	2.24	4
TDS (g/L)	2.64	0.94	1.83	0.39	3.03	1.12	2

Table 2: Descriptive statistics of organic matter (OM) obtained by loss on ignition (LOI) and soil organic carbon (SOC) obtained by gas analyzation for the 0–10 cm layer.

Variable	Min	Max	Mean	Median	SD	Skewness
OM (%)	6.14	17.34	11.12	11.04	2.23	0.59
SOC (%)	2.26	9.8	5.59	5.98	2.24	0.15

as compared to carbon content under dominance of Rhizophora mangle but were lower when compared to dominance of Avicennia schaueriana in Brazil. In Indonesia, soils under Avicennia forest and Ceriops forest showed mean ± SD SOC contents of 3.96 ± 0.18% and 11.40 ± 0.64% at a depth of 20 cm, respectively. Published results early in the twentieth century showed that 1.8 was a suitable OM-to-SOC factor for the marine sediment. Later, the simulated model of OM and nutrients in mangrove wetland soils located in the Shark River estuary of south Florida showed OM: SOC ratios from 1.81 to 2.10 with a mean value of 1.98 based on four mangrove sites. Robinson et al. Ponomareva and Plotnikova, and Pribyl advocated 2 as the recommended factor for accurate conversion [10]. The SOC-to-OM conversion factor of 2 is, thus, considered to provide better accuracy for estimating the carbon content in mangrove environments or similar types of wetland. Our results coincided with the study from Everglades National Park, Florida, in which OM concentrations decreased from 82% to 30% in upstream locations down to marine sites. The recent study mentioned two sources of variability in any estimated factor: first, the different methods used to measure OM and SOC and, second, and the diversity in soil composition. In this study, the methods used to estimate OM and SOC were consistent; thus natural factors played a dominant role. The natural setting of the coastal area can reflect differences in carbon content of OM that, in this study, showed higher conversion factors of SOC to OM in the mangrove environment further from shore. In nature, mixed origins of organic matter in mangrove soil can be very diverse and complex. The near-ocean area showed a high density of mangrove plants that can gain soil OM from fallen detritus decomposition. On the contrary, near shore areas potentially receive OM sources from land via human activity as it is closer to the community. Therefore, the rate and source of organic matter input affect microbial reactions as well as nutrient availability. Continued production and slow decomposition can lead to very large OM content in soil with long periods of water saturation, but raised OM decomposition occurs in more aerated or less anoxic conditions. However, the speed and ease of carbon mineralization depend on the OM fraction in which it resides; for example, humus-carbon mineralizes slowly when compared to plant residue, particulate OM, and soil microbial biomass. The tidal process is one factor driving a great influx of SOC content and turnover in mangrove forests. Coastal mangroves act as a barrier to any fresh water and tidal flows; this buffer zone often develops suspended matter including OM and SOC in the directions parallel to the coast [11]. Areas further from shore with a high density of mangroves have a vertical mixing of water caused by strong waves and tides which tend to circulate suspended matter; thus OM and SOC usually remain in this zone. Estimates of OM : SOC in soil vary from site to site and may be affected by other factors such as types of vegetation cover, clay in the soil, degree of decomposition, and soil composition, which are out of the study scope.

Conclusions

The Nature Education Center for Mangrove Conservation and Ecotourism under dominance of mixed natural and planted Avicennia alba Bl. showed a great potential to sequester carbon in soils with high amounts of SOC stored in the top 10 cm. Surface soil (0–5 cm) contained an average ± standard deviation in SOC of 3.08 ± 1.25% which is greater when compared to subsurface soil (5–10 cm) with 2.51 ± 1.47%. Considering the ecosystem in the study area, the origins of the carbon inputs were derived from primary productivity such as leaf debris and plant roots. The spatial variability of OM and SOC demonstrated the decreasing pattern from land to sea or upper to lower tidal zones. Besides the influence of the tides, we summarized that a substantial load of dissolved and particulate organic matter comes from canals and the community upstream. In terms of the strength of the spatial autocorrelation, the nugget-to-sill ratio of 0.41 for SOC was stronger than 0.58 for OM yet indicated moderate spatial dependency for both variables. The use of the factor of 2 in different types of wetlands was also recommended by considerable supporting evidence. However, this number is not for universal purposes but rather for rough estimation. The conversion factor may vary depending on vegetation cover, temperature, soil type, soil depth, and the technique used to analyze OM and SOC.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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