RELATIONSHIPS BETWEEN PHYSICO-CHEMICAL PROPERTIES AND ORGANIC CARBON IN MANGROVE SOIL OF XUAN THUY NATIONAL PARK, NORTHERN VIETNAM

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Abstract: *Mangroves are unique environment in which soil usually exist in waterlogging condition. The substrate in mangrove received suspended matters from tidal flushing, the matters in turn provide a special environment for plant development. In this study, we determine the relationships between physico-chemical properties of soil and organic carbon contents. To reach our goal, plots were set up in mono-species mangrove of Kandelia obovata as well as in the adjacent bare land. All the samples of soils and roots were treated in situ and in laboratory by standard methods. Soil characteristics varied considerably among sites, and significant differences (P < 0.05) were detected in some soil properties between mangrove and bare land sites. The results showed significant positive and linear correlations between silt, clay and soil water contents with carbon contents at depth. And negative correlations between sand contents with all parameters (except bulk density) were found . The results confirmed that fine particles (clay and silt) can keep water as well as organic carbon in their structure much better than the larger one (sand), and the inundation may act as an essential role in the process of carbon storage in mangrove soil.*

Keywords: carbon content, physico-chemical properties, mangrove soil.

1. INTRODUCTION

Mangrove forests exist between marine and terrestrial systems with the saline or brackish environments, mainly anoxic due to waterlogging. The tidal water comes into mangroves and bring much suspended matters from upstream river and ocean, these materials were trapped mainly by mangrove root systems. The input nutrition from riverine or marine material may provide organic carbon for plant development; as a result, mangroves are known with high productivity and high carbon storing capacity, with potentially more than 90% of their carbon content stored in their soil. This ability resulted from the waterlogged conditions in soil can limit mineralization of organic matters and also form a special physico-chemical properties in soil. In Viet Nam, there were some studies in mangrove plantation in Xuan Thuy National Park; however these studies only focused on biomass and carbon accumulation in soil. It is still a lack of data concerning physico-chemical properties of soil and the relationships with carbon content for mature planted mangroves. The objectives of this study were, thus, to determine the physico-chemical properties in the substrate of a mature planted *Kandelia obovata* forest of 19 years old, and the relationship with organic carbon sequestration. To reach our goal, the study was conducted in a mangroves and in the adjacent bare land in Xuan Thuy National Park, Northern Viet Nam. The study site is a mix of natural and planted ones, in which most of areas are planted with three main species: *Kandelia obovata, Sonneratia caseolaris* and *Rhizophora apiculata*.

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2. STUDY SITES AND METHODS

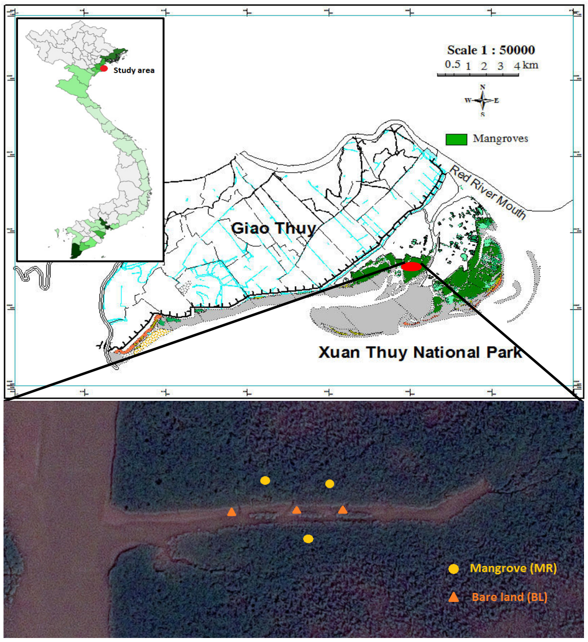

Fig. 1. Map of Xuan Thuy National Park, Nam Dinh Province, Northern Viet Nam with the locations of the core collected

2.1. Study sites

The study site (20°13’37.6” N and 106°31’42.0” E) was set up in the buffer zone of Xuan Thuy National Park (XTNP), which is located on the south bank of Red River Mouth (Ba Lat Mouth) in Gulf of Tonkin, Nam Dinh Province, northern Viet Nam (Fig.1). Mangrove forests in the study area were planted from 1996 to date and dominated by *K. obovata.* The studied site in mangrove forest (*K. obovata*) was planted in 1998.

Located in northern Viet Nam, the study area has a typical monsoonal tropical climate with high humidity (80-85% on average). The average annual temperature ranges from 23.4 to 24.5°C. The two coldest months are December and January, with average temperatures ranging from 16.0 to 17.1°C and the hottest month being July, with mean temperatures over 29.4°C. The average annual rainfall is between 1,750 - 1,800 mm, and the two distinct seasons are: wet season from May to October, and dry season from November to April (Nam Dinh Province Statistical Office, 2016). Tidal regime in this area is irregular diurnal, with large amplitude, maximum at 3.54 m and minimum at 0.37 m (Center for Oceanography, 2016).

2.2. Sampling methodology and measurements

The field work was conducted during the dry season in April, 2017. Soil samples up to depth of 100 cm in mangrove and bare land were determined by taking the soil with a non-contaminated core sampler (Geo-slice NM4; Miyagi and Baba 2002). Three geo-slicers were taken randomly in each plot of the planted mangroves (MR1, MR2, MR3); the same procedure was applied for the bare land (without mangrove; BL1, BL2, BL3). In each core, ten soil samples of known volume were collected at 10 cm depth intervals in order to determine soil characteristics, organic carbon contents in soil and in roots. Dead and live roots were eyes sorted separately *in situ* and then put in closed plastic bags as well as placed in ice box before being sent to the laboratory. In total, 180 soil samples were used to determine the soil carbon accumulation and 180 other samples for the determination of the organic accumulation in roots (live and dead roots).

Soil characteristics: bulk density (BD), soil water content (SWC), grain size (sand, silt and clay), carbon content (CC), dry root biomass were measured by different methods.

Bulk density and SWC were determined by gravimetric method. All wet samples were weighed and air-dried at room temperature, then dried in oven at 60°C for 48 hours until constant weight to determine the dry bulk density for each interval. The BD was obtained by the ratio of dry mass per volume of wet sample (known from corer’s manual).

Bulk density (BD in g cm^{-3}) = [dry mass (g)] / [wet sample volume (cm^3)] (1)

Soil water content was obtained by the ratio of water loss per mass of dry sample:

Soil water content (SWC%) = [wet mass-dry mass]/[dry mass]×100 (2)

Grain size was determined in each layer up to depth of 100 in all mangrove and bare land cores. The soil samples were homogenized to < 2mm then digested in hydrogen peroxide until bubbling ceased then analyzed by pipette method to separate the size: > 63 µm; < 63 µm to > 2.0 and ≤ 2.0 µm [Miller, 1987]. All fractions were then dried at 60^{o}C until a constant weight was achieved (~ 48 h). Grain size fractions were calculated as percentage weight of sand (63–500 µm), silt (2.0– 63.0 µm) and clay (≤ 2.0 µm).

Carbon content in soils was determined using Walkley - Black method. In this procedure, excess potassium dichromate (0.4 N $K_2Cr_2O_7$) and concentrated H_2SO_4 were added to the weighed soil to oxidize organic matters. The solution was swirled and let to cool for 18 hours before titration. The reaction of this extraction procedure is as follow:

$$2Cr_2O_7^{2-} + 3C^o + 16H^+ \Rightarrow 4Cr^{3+} + 3CO_2 + 8H_2O$$

The excess $Cr_2O_7^{2-}$ was back titrated with the standard 0.2 N $Fe(NH_4)_2(SO_4)_2.6H_2O$ (ferrous ammonium sulfate) using orthophenanthroline ferrous complex as an indicator until color changed from green to reddish brown. Blank titration of the acidic dichromate with ferrous ammonium sulfate solution was carried out at the beginning of the batch analysis using the same procedure with no soil sample added. Blank sample was done after every four soil samples. One milliliter of 0.2 N $Fe(NH_4)_2(SO_4)_2.6H_2O$ is equivalent to the 0.009807 grams of $K_2Cr_2O_7$ or 0.0006 grams of carbon. Carbon content in the sample was calculated using the following equation:

Carbon content (CC %) in soil = [(B – S) × 0.0006/m] ×100 (3)

Where B is the volume (mL) of ferrous ammonium sulfate used in the blank titration; S is the volume (mL) of ferrous ammonium sulfate used in the sample titration; and m is the mass of soil sample in gram.

In the laboratory, live and dead roots were weighed before and after being dried in oven at 60°C for 48 hours. Carbon content in roots was analyzed by the L.O.I method (L.O.I – Loss On Ignition). In this method, organic matter was oxidized to carbon dioxide, water and ash at 550ºC during 4 hours. Weight losses associated with water and carbon dioxide evolutions were easily quantified by recording sample weights before and after controlled heating.

Carbon content (CC%) in roots = [OC in roots (g cm^{-3})]/[Bulk density (g cm^{-3})]×100 (4)

2.3. Data analysis

A one-way analysis of variance (ANOVA) was used to compare mean parameters in three geo-slices in each plot of mangroves and bare land (depth × elevation). Organic carbon contents and other parameters in mangroves and bare land were compared by two-way analysis of variance (ANOVA).

3. RESULTS AND DISCUSSIONS

3.1. Soil characteristics

Soil characteristics varied considerably among sites, and significant differences ($P < 0.05$) were detected in some soil characteristics between mangrove and bare land sites. In term of grain size, in both mangroves and bare land site, sand content increased with depth, but the opposite trends were observed for silt and clay contents (Table 1 and Table 3). The significant differences between two sites was found in sand content ($P < 0.01$) and silt content ($P < 0.001$) at depth; however there is no significant difference in clay content ($P= 0.84$). Sand content in bare land is higher than in mangrove in all deep layers, with the lowest value (8.07%) in surface and highest value (62.80%) at the depth 100 cm. The opposite trend was observed in silt proportion, with the highest value on surface (51.83%) and lowest value (31.83%) at 100 cm. A big difference in clay content was found at depth, the values dropped sharply from ~ 40%

in upper layer down to ~ 5% in the deepest one (100 cm). A significant positive correlation was found between distribution of silt content and clay content in soil for the different layers in mangrove (0.98, P < 0.0001) and the same trend was observed for the bare land (0.99, P < 0.0001) (Table 2 and Table 4). The mean values of sand, silt and clay proportions in mangrove soil were 24.96%; 49.81%; and 25.23%, respectively. And for bare land, the values were 32.32%; 42.94%; and 24.73% for sand, silt and clay contents.

Table 1. Variation of sediment compositions and carbon contents (CC) according to the depth of mangrove soil (± SE(standard error) of 3 replications)

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	CC in roots (%)	CC in soil (%)
10	4.77 ± 1.01	57.20 ± 3.51	38.03 ± 2.51	0.08 ± 0.03	1.64 ± 0.10
20	7.53 ± 2.12	56.03 ± 3.40	36.43 ± 1.50	0.17 ± 0.03	2.00 ± 0.09
30	9.60 ± 2.27	56.83 ± 3.73	33.57 ± 1.50	0.22 ± 0.02	2.21 ± 0.22
40	13.47 ± 3.66	54.93 ± 3.64	31.60 ± 0.36	0.29 ± 0.06	2.28 ± 0.11
50	16.47 ± 4.24	52.83 ± 4.73	30.70 ± 1.13	0.31 ± 0.06	2.02 ± 0.04
60	22.40 ± 4.42	50.90 ± 0.78	26.70 ± 4.88	0.18 ± 0.04	1.44 ± 0.14
70	32.23 ± 3.17	48.37 ± 2.84	19.40 ± 5.82	0.10 ± 0.05	1.03 ± 0.21
80	41.00 ± 6.58	44.3 ± 4.76	14.70 ± 8.52	0.07 ± 0.01	0.72 ± 0.08
90	49.23 ± 6.33	39.03 ± 3.29	11.73 ± 7.24	0.03 ± 0.01	0.59 ± 0.08
100	52.87 ± 4.08	37.67 ± 3.94	9.47 ± 3.07	0.05 ± 0.03	0.56 ± 0.07

Table 2. Correlation matrix between physico-chemical properties and carbon contents in mangrove soil at 100 cm depth

	Sand(%)	Silt(%)	Clay(%)	BD (g cm^{-3})	SWC (%)	CC in root(%)	CC in soil(%)
Sand(%)	1						
Silt(%)	-0.992***	1					
Clay(%)	-0.996***	**0.979*****	1				
BD (g cm^{-3})	**0.986*****	-0.974***	-0.986***	1			
SWC (%)	-0.956***	**0.924****	**0.969*****	-0.968***	1		
CC in root (%)	-0.657	0.673	0.642	-0.705	*0.682*	1	
CC in soil(%)	-0.918**	**0.918****	**0.911****	-0.939**	**0.930****	**0.871****	1

Note: *** P < 0.0001; ** P < 0.01; * P < 0.05

Bulk density (BD) increased with soil depth in both mangrove and bare land sites. In mangrove soil, BD increased from 0.84 in the surface layer to 1.45 at depth of 100 cm; the same trend was observed in the bare land, with the lowest value at top soil layer (BD = 1.11) and the highest value in the bottom one (BD = 1.30). The mean values of BD up to depth 100 cm in mangroves were lower than in bare land, with 1.08 g cm^{-3} and 1.21 g cm^{-3}, respectively.

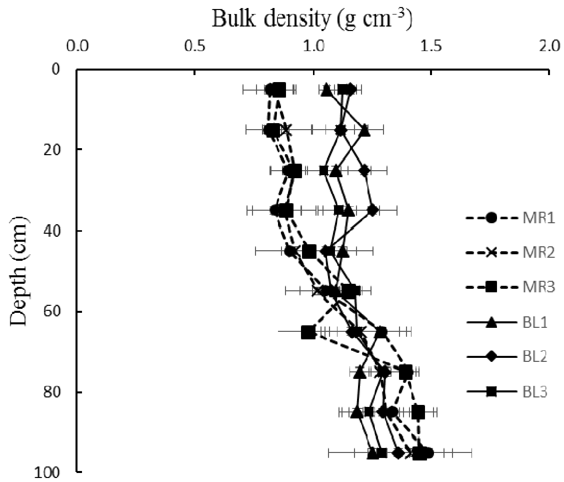

Fig. 2. Vertical distribution of bulk density of mangrove and bare land soils in Northern, Viet Nam (Bars indicate standard error (SE) of 3 replications)

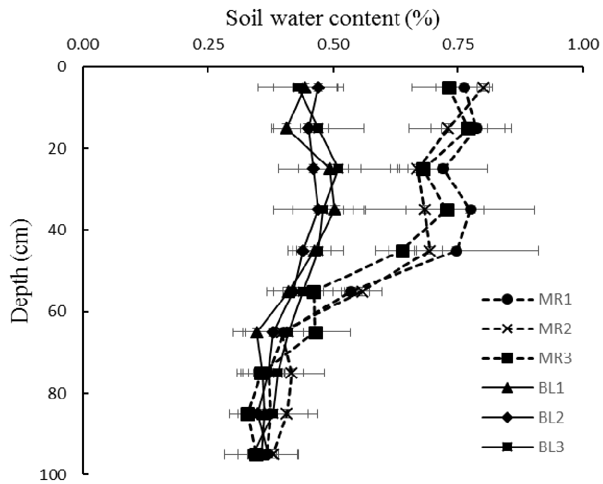

Fig. 3. Vertical distribution of soil water content (SWC) in mangrove and bare land soils in Northern, Viet Nam (Bars indicate standard error (SE) of 3 replications)

The results of BD had very close relationship with sand proportion, and a significant positive and linear correlation between sand contents and BD was found in mangrove soil (0.99, $P < 0.0001$) and bare land soil (0.87, $P < 0.001$) (Table 2 and Table 4).

There was a significant difference of BD in the upper 50 cm depth ($P < 0.01$); below this depth, however, no significant difference ($P = 0.27$) was found. The difference of BD in the upper soil layers of the mangrove and bare land proved that the root systems can make more porous in the soil, as a result, the BD in this site smaller than in bare land. Moreover, at the deeper layers, both mangrove and bare land sites had the same substrate before mangrove plantation.

Table 3. Variation of sediment compositions and carbon contents at depth of bare land soil (± SE(standard error) of 3 replications)

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	CC in bare land (%)
10	8.07 ± 0.60	51.83 ± 1.32	40.43 ± 0.75	0.89 ± 0.04
20	10.43 ± 0.70	51.00 ± 2.02	38.57 ± 1.50	0.93 ± 0.06
30	11.53 ± 0.92	51.50 ± 4.07	36.63 ± 3.59	0.81 ± 0.11
40	18.00 ± 0.50	49.13 ± 2.87	32.87 ± 2.41	0.88 ± 0.05
50	19.67 ± 2.47	46.77 ± 5.11	33.57 ± 3.11	0.70 ± 0.09
60	32.50 ± 2.50	43.00 ± 6.24	24.50 ± 3.91	0.75 ± 0.04
70	42.63 ± 2.51	39.23 ± 3.28	18.13 ± 1.21	0.65 ± 0.03
80	56.73 ± 1.00	33.30 ± 2.78	9.97 ± 1.79	0.68 ± 0.05
90	60.87 ± 0.64	31.83 ± 0.58	7.30 ± 0.61	0.61 ± 0.05
100	62.80 ± 0.61	31.83 ± 0.15	5.37 ± 0.51	0.63 ± 0.10

Soil water content in both sites decreased with depth (Fig. 3). The soil water content in mangrove soil dropped sharply from 76.65% at the surface layer to only 36.42% at the depth of 100 cm, while SWC in bare land showed a small decline, from 44.78% in the top layer to 35.54% at depth of 100 cm. A significant difference between SWC in mangrove and bare land ($P < 0.05$) was found in all layers; however, when considering the soil depth from

0 - 60 cm, the difference in both sites was much higher (P < 0.001) and there was no significant difference in the deeper ones (down to 60 cm, P = 0.15). This demonstrates that, mangrove root systems and porous in soil played an important role in keeping water in the soil substrate.

Table 4. Correlation matrix between physico-chemical properties and carbon contents in bare land (BL) soil at 100 cm depth

	Sand(%)	Silt(%)	Clay(%)	BD (g cm^{-3})	SWC (%)	CC in BL (%)
Sand(%)	1					
Silt(%)	-0.997***	1				
Clay(%)	-0.999***	**0.993*** **	1			
BD (g cm^{-3})	**0.874** **	-0.857*	-0.882*	1		
SWC (%)	-0.922**	**0.934** **	**0.912** **	-0.826*	1	
CC in BL (%)	-0.880*	**0.886** **	**0.874** **	-0.609	**0.786***	1

Note: *** P < 0.0001; ** P < 0.01; * P < 0.05

3.2. Carbon content in roots and in soil

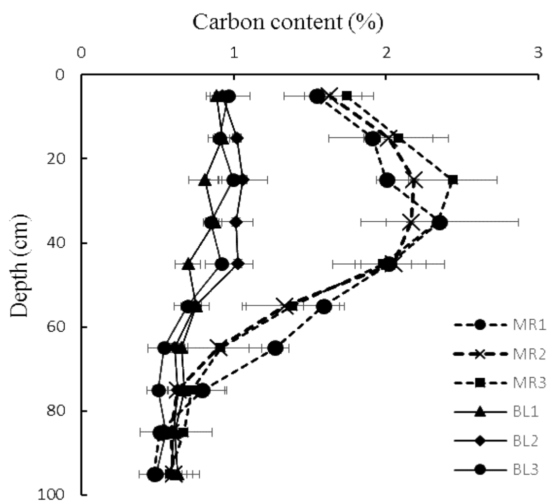

Fig. 4. Vertical distribution of carbon content in bare land and mangrove soil of K. obotava planted mangroves in Northern, Viet Nam (Bars indicate standard error (SE) of 3 replications)

The highest root densities were observed between 20 and 60 cm depth, and the lowest values were found in the bottom layers (70 - 100 cm). The carbon content in roots varied with depth and ranged from 0.05 to 0.31%, with a mean value of 0.15%. Carbon content increased quickly from 0.08% in the upper layer (10 cm) to 0.31% in the layers between 10 and 50 cm depth, and then declined sharply by nearly ten times to 0.03 % at 90 cm depth (Fig. 4). The upper layers (0 - 60 cm depth) accounted for 84% of root biomass, suggesting that roots distribution were scarce in the depth soil layers. This result reinforced our choice of determining carbon contents not deeper than 100 cm depth taking into account that we were interested in the carbon enrichment of the soil with mangrove plantation.

The distribution of root biomass is in broad agreement with several studies in mangrove forests that showed the highest root densities were observed in the upper soil horizons [4]. For instance, in natural and planted mangroves, the root biomass was the highest in the upper 20 cm of forests (*Rhizophora mucronata* Lamarck, *Avicennia marina* (Forsk.) Vierh and *Sonneratia alba* J. Smithin) in Gazi bay, Kenya [5], in the upper 50 cm depth in a secondary mangrove forest (*Ceriops tagal* (Perr.) C.B. Rob.) in Satun Province, southern Thailand (Komiyama et al. 2000), and in the upper 45 cm of *Rhizophora mangle* (L.), *Avicennia ger- minans* (L.), *Laguncularia racemosa* (L.), and *Conocarpus erectus* (L). mangroves in the Everglades, USA [6]. These authors also demonstrated that root density as well as their carbon content not only varied with depth but also with mangrove species and stand ages.

Carbon content in mangrove soil shared the same trend with carbon content in roots. The carbon contents in soil increased from top layer (1.64%) to the depth of 40 cm (2.28%) then decreased to only 0.56% at the depth of 100 cm. However, in the bare land, the highest concentration of carbon was recorded at the depth of 30 cm with 0.96% and the lowest value was 0.57% in the bottom layer. The carbon contents in both sites were the same at the bottom layer, but the mean value of carbon content of all the samples up to depth of 100 cm in mangrove soil (1.45%) was almost twice the one of the bare land (0.77%). The results about carbon content in soil and in roots in this study was in trend with our results in the same sites in 2016 [7]. This confirmed that roots are an essential source of organic carbon accumulation in mangrove soils and the distribution of roots in deeper layers are negligible.

3.3. Relationships between physico-chemical properties and carbon contents

Table 2 and Table 4 showed the correlation between physico-chemical properties and carbon contents in soil (in both sites) at depth. When compare the CC% and SWC%, the results showed that these parameters were quite in line. Soil water contents were positively correlated with carbon contents in mangrove and bare land with the correlation were 0.93 ($P < 0.01$) and 0.79 ($P < 0.05$), respectively (Fig. 5). This means that, the inundation may act as an essential role in the process of carbon storage in mangrove soil.

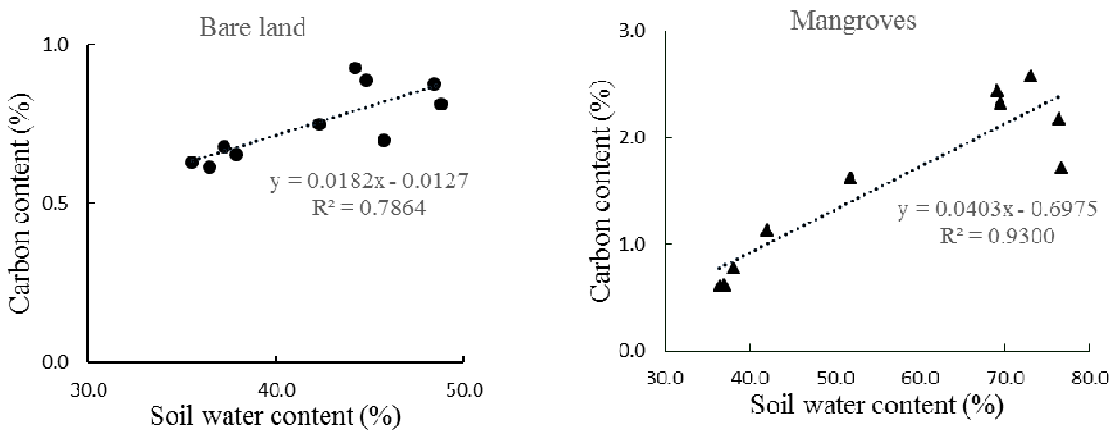

Fig. 5. Relationship between carbon contents and water contents in soil for different layers of the K. obotava mangrove plantations and bare land in Northern, Viet Nam

Silt and clay contents in both sites were correlated with carbon contents at depth. A significant positive correlation was found between distribution of silt content and carbon content in soil for the different layers in mangrove (0.92, $P < 0.001$) and the same trend was observed for the bare land (0.89, $P < 0.01$). Clay contents were also positively correlated with carbon contents in mangrove and bare land with the correlation were 0.91 ($P < 0.01$) and 0.87 ($P < 0.01$), respectively (Table 2 and Table 4). Moreover, sand contents were negative correlated with all parameters (except BD) in both sites. This was reinforced by negative correlation between BD and CC (0.939 and 0.609) for mangroves and bare land, respectively. Ranges of BD and CC% were close to those measured in other Asian mangroves, in China [8][9], and in Thailand [10]. These authors also noticed that BD and CC% showed opposite trends with depth in mangrove soils. All the results proved that fine particles (clay and silt) can keep water as well as organic carbon in their structure much better than the larger one (sand). In general, the higher the percentage of silt and clay sized particles, the higher the water holding capacity. The fine particles (clay and silt) have a much larger surface area than the larger (sand) particles. This large surface area allows the soil to hold a greater quantity of water. As a results, the amount of organic carbon in a soil also influences the water holding capacity. As the level of organic matter increases in a soil, the water holding capacity also increases, due to the affinity of organic matter for water. The results confirmed that, mangrove root systems can keep more grain size particles in water column from tidal currents and distribute the main proportion for carbon accumulation in mangrove soil.

4. CONCLUSIONS

When combine all the physico-chemical parameters and carbon contents of soil, the results showed that there were strong relationships with the each others. The significant positive and linear correlations between silt, clay and soil water contents with carbon contents, and negative correlations between sand contents with all parameters (except bulk density) were found at depth. Mangrove substrate accelerates follow the time and mangrove roots can keep more fine particles (clay and silt) than the larger one (sand). The results also proved that both mangrove forests and bare land originally had equivalent sedimentary substrate, and that the bare land can be considered as a reference for soil properties before planting mangroves. Moreover, root systems as well as porous in soil play an important role in enriching of organic carbon in soil and keeping water in the soil substrate.

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Tóm tắt:

MỐI QUAN HỆ GIỮA TÍNH CHẤT LÝ HÓA CỦA ĐẤT VÀ CARBON HỮU CƠ TRONG ĐẤT RỪNG NGẬP MẶN TẠI VƯỜN QUỐC GIA XUÂN THỦY, MIỀN BẮC VIỆT NAM

Rừng ngập mặn là một hệ sinh thái đặc biệt, hình thành và phát triển ở các vùng đất ngập nước vùng cửa sông ven biển. Vùng đất ngập mặn nhận được lượng phù sa bồi tụ từ các dòng nước triều, lượng vật chất này cung cấp các dưỡng chất đặc biệt cho sự phát triển của cây ngập mặn. Trong nghiên cứu này, chúng tôi tập trung xác định mối liên hệ giữa các tính chất lý hóa của đất và hàm lượng carbon tích lũy. Để đạt được mục tiêu đề ra, các ô nghiên cứu được thiết lập trong đất rừng Trang và vùng đất trống bìa rừng. Các mẫu đất và rễ thực vật được thu thập, xử lý và phân tích theo các phương pháp chuẩn. Tính chất lý hóa của đất biến đổi đa dạng giữa hai địa điểm nghiên cứu, và có sự khác biệt rõ ràng giữa đất rừng Trang và đất trống ($P < 0.05$). Kết quả phân tích cho thấy có sự tuyến tính và tương quan thuận giữa hàm lượng sét, limon và hàm lượng nước trong đất với hàm lượng carbon theo độ sâu. Và mối tương quan nghịch giữa hàm lượng cát với tất cả các thông số còn lại (ngoại trừ dung trọng đất). Kết quả chứng minh các hạt có kích thước nhỏ (sét và limon) có khả năng giữ nước và carbon hữu cơ trong cấu trúc của chúng tốt hơn so với các hạt có kích thước lớn (cát), và tình trạng ngập nước đóng vai trò thiết yếu trong quá trình lưu giữ carbon trong rừng ngập mặn.

Keywords: hàm lượng carbon, tính chất lý hóa, đất rừng ngập mặn.

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