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Assesstment of soil organic carbon in mangrove area, Pante Bayam-Aceh

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ABSTRACT

Pante Bayam is one of natural mangrove area in Aceh Province. Due to anthropogenic activities such as fishpond, the area become degradated. This study aims to analyze soil organic carbon (SOC) stock based on soil depth and texture characteristics at several observation points in the study area. Data were collected from seven sample locations with four categories of soil depth: 0–15 cm, 15–30 cm, 30–50 cm, and 50–100 cm. The results showed that the highest carbon stock was found at a depth of 50–100 cm, reaching 159.1 Mg C/ha, while the 15–30 cm layer had the lowest carbon stock. This indicates that the subsoil plays a significant role in long-term carbon storage. The distribution of carbon stocks also varied between locations, where PB04 and PB07 showed the highest values, while PB05 and PB06 showed the lowest. Correlation analysis showed a positive relationship between clay content and soil carbon stock, indicating that fine soil texture supports carbon accumulation through the formation of stable aggregates. These findings emphasize the importance of soil management that considers soil depth and physical characteristics to increase the potential for climate change mitigation through sustainable soil carbon storage.
Keywords: Carbon, Coastal Conservation, Fraction, Soil, Texture

1. Introduction

Soil organic carbon (SOC) is one of the key components in the soil system that functions as a primary indicator of soil fertility, aggregate stability, water retention, and cation exchange capacity [1]. In addition, SOC also plays an important role in climate change mitigation due to its ability to store carbon in the long term, thereby reducing the concentration of carbon dioxide (CO_2) in the atmosphere. It is estimated that soils store around 1,500–2,400 Gt C worldwide, which is greater than the carbon stored in the atmosphere and vegetation combined [2].

The distribution of organic carbon in soil is greatly influenced by various factors, including climate, land cover, land use, human activities, and soil physical properties such as texture and depth. Soil texture which consists of sand, silt, and clay fractions plays a role in determining the capacity of the soil to retain organic matter. Clay soils tend to have higher organic carbon content than sandy soils due to their ability to protect organic matter from microbial decomposition through physical and chemical stabilization processes [3]. Conversely, sandy soils generally have lower carbon content due to their high porosity and faster decomposition rates. As global attention to climate change issues increases, various approaches have been proposed to increase soil carbon stocks, including through land restoration, agroforestry, and soil conservation. One important effort to support these strategies is to accurately quantify soil carbon stocks, both vertically (depth) and spatially (between locations). Previous studies in Indonesia have shown that the range of soil organic carbon stocks varies, depending on the type of land use and soil characteristics. For example, a study by [4] showed that soils on peatlands can store more than 100 Mg C/ha, while mineral soils on intensive agricultural lands often only store <30 Mg C/ha in the 0–30 cm layer.

Pante Bayam is a village located in East Aceh Regency, Aceh Province, which has the characteristics of a coastal ecosystem with a combination of agricultural land, swamps, and plantations. This area is inhabited by people who mostly work as farmers and fishermen, with the main land use for dryland agriculture, especially secondary crops and other seasonal crops [5]. Agroecologically, Pante Bayam has significant potential in storing soil organic carbon, due to the presence of fine texture fractions in some parts of the area and the influence of coastal hydrological conditions that create an anaerobic environment for some time, which can slow down the decomposition of organic matter [6]. In addition, the presence of mineral soils with relatively high clay content in several locations makes this area relevant in the context of carbon conservation and sustainable agricultural development [7]. With these conditions, Pante Bayam plays a strategic role in efforts to preserve the local environment and mitigate climate change based on the site, while reflecting the dynamics of traditional production systems that are still strongly influenced by local knowledge and hereditary resource utilization patterns. Therefore, this study aims to analyze the content and stock of soil organic carbon in depth (up to 100 cm) based on soil depth and texture, and evaluate the relationship between texture fraction and organic carbon content. The results of this study are expected to provide scientific contributions in the formulation of sustainable land management strategies and soil-based carbon mitigation planning in tropical areas.

2. Method

The study was conducted in the Pante Bayam, Madat, East Aceh, which is a coastal conservation area dominated by natural and artificial mangrove vegetation (Figure 1). The location was chosen because of its potential as a soil carbon store and exposure to anthropogenic pressure. A total of 28 soil samples were collected from seven observation points (PB-01 to PB-07) at four different depths: 0–15 cm, 15–30 cm, 30–50 cm, and 50–100 cm. Samples were taken compositely using a soil drill and stored in labeled plastic bags for laboratory analysis.

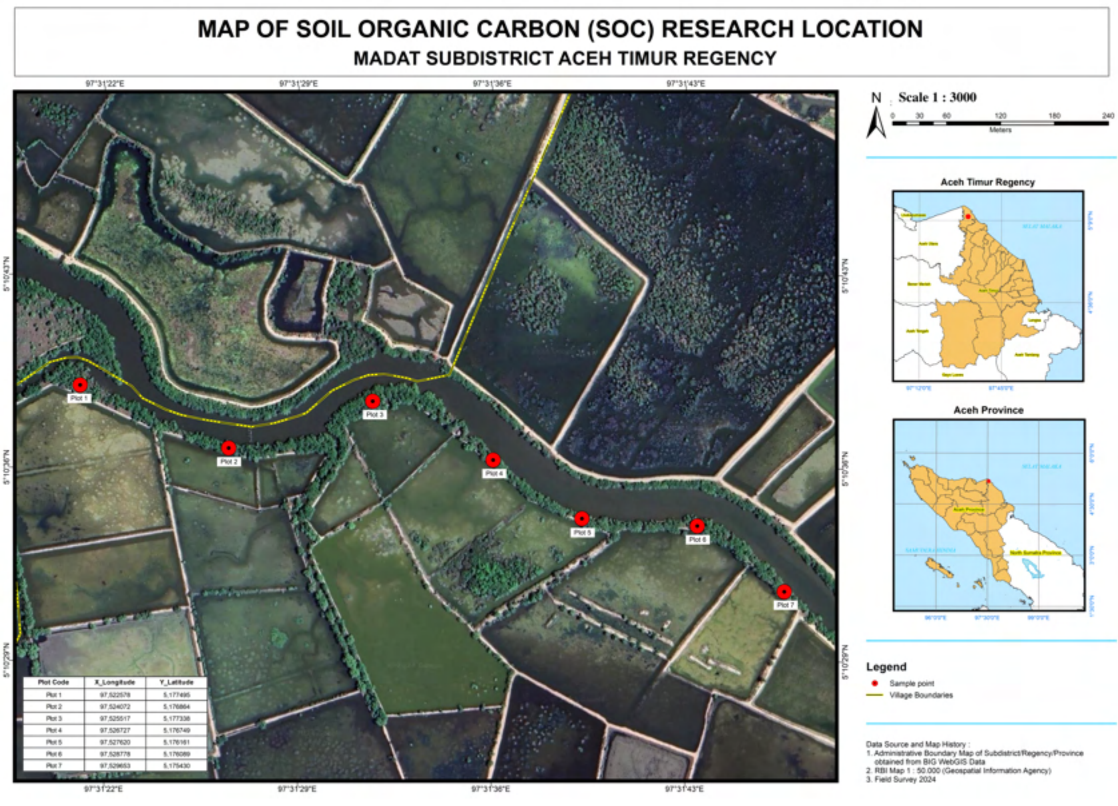

Figure 1. Research location in Pante Bayam Aceh

Laboratory analysis was conducted at the Pusat Penelitian Kelapa Sawit (PPKS) Medan Laboratory, which is accredited by Komite Akreditasi Nasional (KAN). The parameters tested included soil texture (sand, silt, and clay fractions) using the Bouyoucos method [8] and organic carbon content (%C) using the Walkley and Black method [9]. Texture was classified based on USDA standards. Data were analyzed descriptively quantitatively, with the calculation of the average and distribution of values based on depth and location. Graphic visualization was used to show the vertical distribution of carbon and the relationship with texture fractions. Correlation analysis was conducted to evaluate the relationship between sand fractions and organic C content. Soil organic carbon stock (SOC stock) was calculated for each depth layer using the standard formula [6]. Analysis of the relationship between texture fractions (sand, silt, and clay) and organic carbon content was conducted using the simple linear regression method. Scatter plot values were visualized with the addition of a regression line to see the direction of the relationship.

3. Results and Discussion

3.1. Soil Organic Carbon Content and Stock

The results of the visualization of soil organic carbon stock (SOC) data based on the depth and location of the samples in Pante Bayam, East Aceh, show quite significant vertical and spatial variations (Figure 2). In general, the SOC value increases with increasing depth in most samples. For example, in sample PB01, the carbon stock increases sharply from around 5.8 Mg C/ha at a depth of 0–15 cm to 22.2 Mg C/ha at a depth of 50–100 cm, indicating carbon accumulation in the subsoil layer. The same pattern is seen in PB03 and PB05, which also show the highest SOC values in the deepest layers, indicating the great potential of the lower horizon as an organic carbon reservoir. On the other hand, several samples such as PBO4 and PB07 show a more even distribution of carbon stock between depths. This may be due to more homogeneous soil characteristics, active soil biota activity throughout the profile, or due to minimally disturbed land use systems such as natural vegetation or shrubs that allow stable carbon decomposition and accumulation [10]. In contrast, the overall low SOC value in the PBO5 sample (a total of only around 6.3 Mg C/ha) reflects degraded soil conditions or minimal organic matter input, which can occur due to agricultural intensification, land conversion, or erosion.

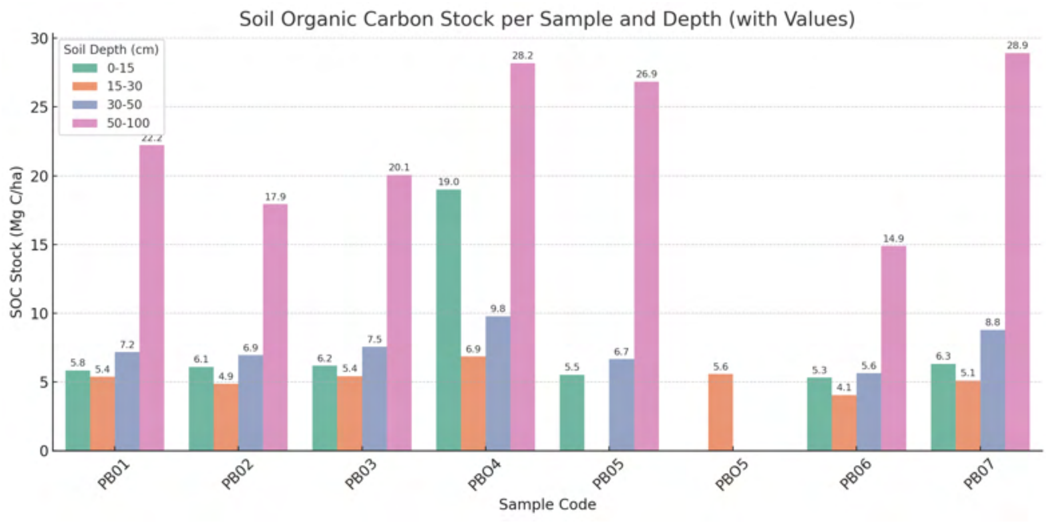

Figure 2. Soil Organic Carbon per Sample and Soil Depth

In terms of texture, clayey and silty soils generally have a higher carbon binding capacity due to their large specific surface area and ability to form organo-mineral complexes [8]. The bulk density estimation in this study, which was calculated based on the percentage of clay and silt, strengthens the effect of texture on SOC variations. Soils with clay content >25% such as PB03 and PB07 tend to have lower bulk density (1.05–1.1 g/cm³) and store higher carbon, compared to highly sandy soils such as PBO5 which have higher bulk density and lower carbon content [13]. This finding is in line with global studies showing that more than 60% of soil carbon stock can be found in layers >30 cm, but is often overlooked in conventional carbon inventories [14]. Thus, a depth-based approach such as the one used in this study is essential to obtain more accurate carbon stock estimates and support soil-based climate change mitigation strategies [15].

3.2. Organic Carbon Stock at Each Depth

Figure 3 depicting the total stock of soil organic carbon at various soil depths shows significant variations between shallow and deep soil layers (Figure 3). At a depth of 0–15 cm, the SOC value was recorded at 54.3 Mg C/ha, which generally reflects the high input of organic matter from litter and surface biological activity. However, this value actually decreased at a depth of 15–30 cm to 37.3 Mg C/ha, which was likely due to limited accumulation of organic matter and increased decomposition. Interestingly, at a depth of 30–50 cm, the SOC value increased to 52.5 Mg C/ha, and the most striking increase occurred in the deepest layer (50–100 cm) with 159.1 Mg C/ha, indicating that the subsoil layer stores a very large stock of organic carbon.

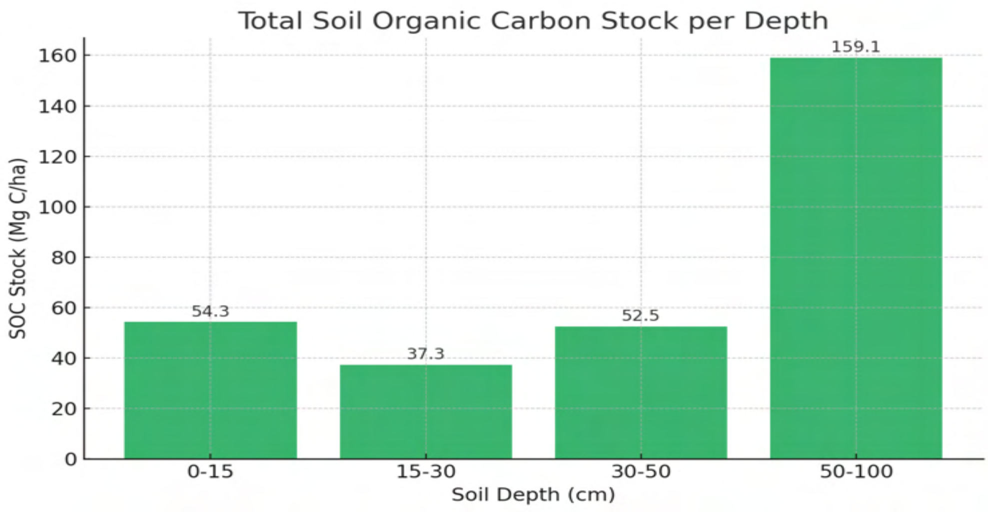

Figure 3. Soil Carbon Stock in Different Soil Depth

Scientifically, these findings indicate that soil organic carbon is not only accumulated in the upper layer, but can also be trapped and stabilized in large quantities in the lower layer. This is in line with the results of the study by [14], which emphasized the importance of the deep soil layer (subsoil) as a long-term carbon store due to physical and chemical conditions that support carbon stabilization, such as interactions with clay minerals and iron oxides. Furthermore, a study by [16] showed that around 50% of the total global soil organic carbon can be found below 30 cm depth, supporting the findings of this visualization. In addition, [17] some finding also showed that soil carbon measurements do not stop at a depth of 30 cm, because the great potential for carbon storage is up to 1 meter or more in the soil profile. From the perspective of climate change mitigation, these results reinforce the importance of soil conservation to greater depths, especially in tropical areas such as Pante Bayam, East Aceh, which has great potential for storing soil organic carbon. The availability of carbon in this subsoil suggests that land restoration and sustainable soil management efforts must encompass the entire soil profile to achieve optimal results in carbon storage and long-term ecosystem stability.

In general, the total accumulation of carbon stocks up to a depth of 1 meter from all samples reached more than 550 Mg C/ha, which is relatively high compared to mineral soils in tropical areas with moderate disturbance intensity. For comparison, research by [4] showed that soil carbon stocks in agricultural lands in Sumatra ranged from 80–230 Mg C/ha at a depth of 0–60 cm. Meanwhile, [6] stated that carbon stocks in tropical forest soils can reach 300–500 Mg C/ha at a depth of 0–100 cm depending on soil conditions and land management. This means that the stock value in this study can be categorized as moderate to high, depending on the initial soil conditions, vegetation types, and land use history. The increasing vertical carbon stock distribution in the lower layers also indicates great untapped potential in the context of climate change mitigation and soil carbon restoration. Many studies and policies still focus on the 0–30 cm layer, whereas the lower layers store most of the total soil carbon [14]. The carbon content in the lower layers also tends to be more chemically stable and more resistant to decomposition due to lower microbial activity and anaerobic conditions that commonly occur at depths greater than 50 cm. Thus, the results of this study support the importance of a vertical approach in calculating soil organic carbon stocks and show that estimates limited to the upper layers can underestimate the capacity of the soil to store carbon. In addition, soil management that can increase carbon flow to the lower layers, such as deep root systems, biochar use, and organic matter conservation, can be an important strategy in maintaining and increasing overall soil carbon stocks [17].

3.3. Correlation between soil texture and soil organic carbon

The relationship between soil texture fractions and soil organic carbon content shows complex dynamics, as illustrated in three regression graphs between sand, silt, and clay fractions against organic carbon (Figure 4). The results of visual analysis show that the sand fraction has a weak negative relationship with organic carbon, where increasing sand content tends to be followed by a decrease in organic carbon levels. This is in line with the findings of [12], which stated that sandy soil has large pores and low moisture retention, making it less able to stabilize organic matter, accelerate decomposition, and increase carbon loss through leaching and microbial respiration. In contrast, the silt fraction shows a weak positive correlation, but with high variability, reflecting an inconsistent contribution to organic carbon stabilization [18].

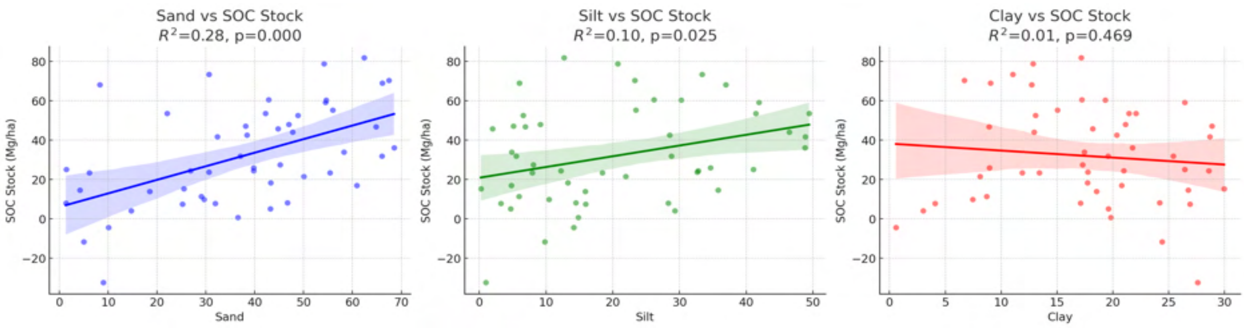

Figure 4. Correlation between soil textur and carbon stock

Although silt can be a bridge between clay fractions and organic matter in forming stable aggregates [19] its role is still less dominant than the clay fraction. The figure of the relationship between clay and organic carbon shows the most consistent and significant trend, with a positive regression line and a relatively narrow confidence band, indicating that the higher the clay content, the higher the soil organic carbon. The clay fraction is known to play a major role in forming organo-mineral complexes that protect organic matter from microbial degradation and oxidation, thereby extending the residence time of carbon in the soil ([20]. This is also supported by the study of [21], which shows that fine-textured soils (high clay) tend to store carbon in stable forms that are more resistant to environmental changes. Therefore, soil texture fractions, especially clay, play an important role in soil carbon conservation strategies and climate change mitigation, especially in the context of sustainable land management.

4. Conclusions

The results of the study on the content and stock of soil organic carbon in the Pante Bayam area, East Aceh, show that the soil in this area has great potential as a carbon store. The results showed that the highest carbon stock was found at a depth of 50–100 cm, reaching 159.1 Mg C/ha, while the 15–30 cm layer had the lowest carbon stock. Analysis of the relationship between soil texture and organic carbon content showed that the clay fraction had a significant positive relationship with carbon content. These findings indicate that the soil in Pante Bayam has a significant contribution to mitigating carbon emissions through storing carbon in organic form in the soil. Therefore, soil conservation, management of crop residues, and protection against land degradation are important keys in maintaining and increasing the potential of this carbon stock for the sustainability of ecosystem functions and agriculture in the future.

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