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Soil Organic Matter Status in Mangrove Areas Dominated by *Avicennia Marina* and *Excoecaria Agallocha* at Tambak Oso Village, Waru District, Sidoarjo Regency

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ABSTRACT: This study investigates the status of soil organic matter in mangrove areas dominated by *Avicennia marina* and *Excoecaria agallocha* in Tambak Oso Village, Sidoarjo Regency, Indonesia using purposive random sampling across different vegetation densities (low, medium, high), the research analyzed soil pH, redox potential, organic carbon, and total nitrogen. Results indicate that Avicennia marina areas had higher soil organic carbon due to faster litter decomposition and humification, attributed to lower lignin content. In contrast, *Excoecaria agallocha* soils contained higher total nitrogen, especially under medium vegetation density, likely due to slower litter decomposition providing sustained nitrogen release. Furthermore, vegetation density influenced soil pH and redox potential, where higher density increased pH (towards neutral) and decreased redox potential, promoting anaerobic conditions favorable for carbon stabilization. The dominant soil texture was sandy clay loam, aiding moisture and organic matter retention. These findings highlight the differential contributions of mangrove species and vegetation density to soil nutrient dynamics and have implications for sustainable mangrove restoration and management strategies.

KEYWORDS: Carbon Organic; Soil Acidity; *Excoecaria* ; Mangrove; *Avicennia*

I. INTRODUCTION

The mangrove ecosystem is one of the coastal ecosystems that plays a crucial role in maintaining environmental stability, including protecting shorelines from erosion, serving as a habitat for coastal biota, and acting as a significant carbon sink through the accumulation of organic matter in the soil (Alongi, 2012). One of the key parameters in assessing the ecological function of this ecosystem is the soil organic matter content, which contributes to maintaining soil fertility, supporting soil microbial activity, and promoting vegetation growth. Mangrove species such as *Avicennia marina* and *Excoecaria agallocha* possess different morphological and physiological characteristics in terms of carbon absorption and storage, which may affect the amount of organic matter accumulated in the underlying soil (Kauffman *et al.*, 2011).

Therefore, it is important to conduct a comparative study of soil organic matter content in areas dominated by these two mangrove species to better understand each species' contribution to the carbon cycle. Tambak Oso Village in Waru District, Sidoarjo Regency, is a coastal area with mangrove vegetation cover, including *A. marina* and *E. agallocha*. However, scientific information regarding the soil condition, particularly its organic matter content, remains very limited. This study aims to analyze and compare the soil organic matter content in mangrove areas dominated by *Avicennia marina* and *Excoecaria agallocha* as a foundation for the sustainable management and conservation of mangrove ecosystems in the region.

II. RESEARCH METHODS

A. Study Area

This research was conducted from January to May 2025. Soil sampling took place in Tambak Oso Village, Waru District, Sidoarjo Regency, at two different land uses based on the type of mangrove vegetation (*Avicennia marina* and *Excoecaria agallocha*) and three levels of vegetation density for each land use type. Soil samples were collected using a purposive random sampling method with three replications at each location. Soil chemical content analysis was carried out at the Land Resources Laboratory, Faculty of Agriculture, UPN "Veteran" East Java.

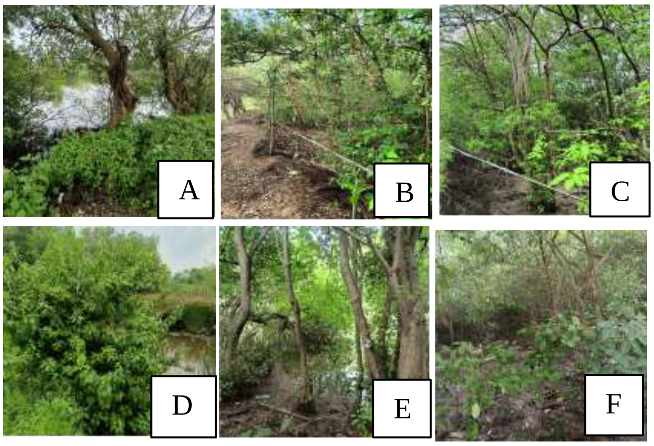

Figure 1. Existing Conditions in 6 Land Use Units at Tambak Oso Village, Sidoarjo. A) RA (Low Density with *Avicennia marina* Mangrove Vegetation); B) SA (Medium Density with *Avicennia marina* Mangrove Vegetation); C) TA (High Density with *Avicennia marina* Mangrove Vegetation); D) RKB (Low Density with *Excoecaria agallocha* Mangrove Vegetation); E) SKB (Medium Density with *Excoecaria agallocha* Mangrove Vegetation); F) TKB (High Density with *Excoecaria agallocha* Mangrove Vegetation)

B. Land Climatology Analysis

The climatological analysis included the classification of temperature and humidity regimes using soil and air temperature data, as well as soil and air humidity data, and the classification of climate conditions using the Schmidt and Ferguson method based on rainfall data from the sampling locations. Climatological data were obtained from the NASA Power Data Access Viewer website. All climatological data used were from the last five years (2020–2024).

C. Soil Chemical and Physics Analysis

Analysis of soil acidity

Soil pH analysis is conducted using the conductometric method. A soil sample weighing 10 grams is placed into a shaking bottle, then 20 ml of ion-free water (H_2O) solution is added. Subsequently, the sample is shaken using an electric shaker for 30 minutes. The pH suspension measurement is performed using a pH meter.

Analysis of soil organic carbon

Soil organic carbon analysis is conducted using the Walkey and Black method. A soil sample passing through a 0.5 mm sieve, weighing 0.25 grams, is placed into a 100 ml volumetric flask, then 5 ml of $K_2Cr_2O_7$ and 10 ml of concentrated sulfuric acid are added, and then homogenized. After 1 hour, distilled water is added up to the mark and homogenized, then left to reach room temperature. Absorbance is measured using a spectrophotometer with a wavelength of 560 nm.

Soil Redox Analysis

Weigh 10 grams of air-dried soil and place it into a plastic bottle then add 20 ml of deionized water. Shake the mixture using an electric shaker for 30 minutes. Measure the redox of the suspension using a multimeter.

Soil Total Nitrogen Analysis

- Destruction of Soil Samples

Soil samples with a size of <0.5 mm are placed into a digestion tube. Added 1 g of selenium mixture and 3 ml of concentrated sulfuric acid, destroyed until temperature 350°C (3-4 hours). Destruction is complete when white steam is released and a clear extract is obtained (approximately 4 hours). The tube is lifted, cooled, and then the extract is diluted with ion-free water to exactly 50 ml. Shake until homogeneous, let it sit overnight for the particles to settle. The extract is used for N measurement by distillation.

- Measurement of Nitrogen by distillation

Quantitatively transfer the entire sample extract into the boiling flask (use deionized water and a wash bottle). Add a small amount of boiling stone powder and aquades until half the volume of the flask. A container for the released NH_3 is prepared, which is an Erlenmeyer flask containing 10 ml of 1% boric acid, supplemented with three drops of Conway indicator (red in color), and connected to a distillation apparatus. With a beaker, add 10 ml of 40% NaOH into the boiling flask containing the sample and seal it immediately. Distilled until the receiver volume reaches 50-70 ml (green in color). The distillate is titrated with 0.050 N H_2SO_4 until a pink color appears. Record the titration volume of the sample (Vc) and the blank (Vb).

Soil Texture (Three Fractions Method)

- Sample Preparation

Weigh 10.000 g of <2 mm soil sample and place it into an 800 ml glass beaker. Add 50 ml of 10% H_2O_2 and leave it overnight. The next day, add 25 ml of 30% H_2O_2 and heat until foaming ceases. Then, add 180 ml of deionized water and 20 ml of 2N HCl. Boil the mixture on an electric heater for approximately 10 minutes. Remove from the heat and allow to cool slightly, then dilute with deionized water to a total volume of 700 ml. Wash the sample using deionized water with a Berkefeld filter or by decantation until it is acid-free. Then, add 10 ml of 4% sodium pyrophosphate ($Na_4P_2O_7$) solution as a dispersing agent.

- Sand Fraction Separation

The soil suspension with the dispersing agent is sieved using a 50-micron sieve while rinsing with deionized water. The filtrate is collected in a 500 ml cylinder for silt and clay separation. The particles retained on the sieve are transferred to a pre-weighed aluminum dish using a wash bottle with deionized water. Dry the sample in an oven at 105°C until moisture-free, cool it in a desiccator, and weigh it (sand weight = A g).

- Silt and Clay Fraction Separation

Dilute the filtrate in the cylinder to a total volume of 500 ml, stir for 1 minute, and immediately pipette 20 ml into an aluminum dish. Dry the filtrate in an oven at 105°C (usually overnight), cool in a desiccator, and weigh (silt + clay + dispersing agent weight = B g).

For clay separation, stir the solution again for 1 minute and let it stand for 3 hours and 30 minutes at room temperature. Pipette 20 ml of the clay suspension at a depth of 5.2 cm from the liquid surface and transfer it to an aluminum dish. Dry the suspension in an oven at 105°C, cool in a desiccator, and weigh (clay + dispersing agent weight = C g).

D. Data Analysis

The obtained data is tabulated and analyzed using Microsoft Excel and SPSS software. Data analysis includes descriptive analysis, ANOVA, HSD test (Tukey), and regression analysis. The resulting data is then presented in the form of graphs and tables.

III.RESULT AND DISCUSSION

Table 1. HSD Test at 5% Level of Soil Chemical Parameters

Land Uses	Parameters				
	Soil Acidity	Redox (mV)	SOC (%)	Total Nitrogen (%)	C/N Ratio
RA	6,14 a	20,67 a	4,60 b	0,25 a	19,28 cd
SA	6,61 b	16,00 a	**6,60 d**	0,32 b	**21,58 d**
TA	**6,80 b**	10,33 a	4,28 ab	0,27 ab	16,95 c
RKB	6,53 ab	**22,00 a**	3,94 ab	0,41 c	10,33 a
SKB	6,57 b	13,67 a	5,61 c	**0,43 c**	13,66 b
TKB	6,69 b	9,33 a	3,61 a	0,32 ab	12,32 ab
HSD 5%	*	ns	*	*	*

Notes: RA (Low Density with *Avicennia marina* Mangrove Vegetation), SA (Medium Density with *Avicennia marina* Mangrove Vegetation), TA (High Density with *Avicennia marina* Mangrove Vegetation), RKB (Low Density with *Excoecaria agallocha* Mangrove Vegetation), SKB (Medium Density with *Excoecaria agallocha* Mangrove Vegetation), TKB (High Density with *Excoecaria agallocha* Mangrove Vegetation). * (significantly different), ns (not significantly different). Values followed by the same letter indicate no significant difference based on the HSD test at 5% level.

Soil pH values at the study site ranged from 6.01 to 6.80, indicating a slightly acidic to neutral condition (Eviati *et al.*, 2023). This pH range is optimal for most microbial activities that support organic matter decomposition (Sayara et al., 2011). Our findings reveal that areas with lower vegetation density tend to exhibit more acidic soils, while higher vegetation density correlates with higher (more neutral) pH levels. This is consistent with studies by Jing *et al.* (2020) and Ren *et al*. (2018), which found that dense vegetation can enhance soil pH buffering capacity through increased organic inputs and microbial stabilization.

The soil pH at each sampling location indicates that areas with low vegetation density tend to have the lowest pH values. Conversely, the higher the vegetation density at a sampling site, the higher the soil pH. This pattern is supported by a study by Jing *et al.* (2020) published in the *Forest Journal*, which found a significant positive correlation between planting density and soil pH. Areas with higher vegetation density generally have higher (less acidic) soil pH, while those with lower vegetation density tend to have lower (more acidic) pH levels. This is likely due to reduced microbial activity, which plays an important role in acid neutralization through the decomposition of organic matter.

Unlike soil pH, the redox value results at the research location have values that are opposite to the soil pH values. The higher the vegetation density, the lower the redox value. High vegetation density increases the accumulation of organic matter in the soil through the increase of litter and root exudates. This accumulation can lower the soil redox potential (Eh) create anaerobic conditions that slow down the decomposition of organic matter and promote the humification process. In low redox conditions, the activity of aerobic microorganisms decreases, allowing the accumulation of complex organic compounds such as lignin and phenol, which then undergo transformation into humus.

Recent research by (Fiard *et al.*, 2024) highlighted that anthropogenic pressures such as urban and agricultural activities significantly alter microbial communities and sediment quality in mangrove ecosystems. Their study revealed that contamination from pesticides and trace metals affects microbial biomass and diversity, even in areas with high organic matter. This supports our findings that while organic inputs and vegetation density can enhance microbial activity and reduce redox potential, pollution may suppress microbial resilience. The identification of specific microbial taxa as bioindicators underscores the importance of integrating microbial parameters into mangrove monitoring to detect early signs of ecological stress.

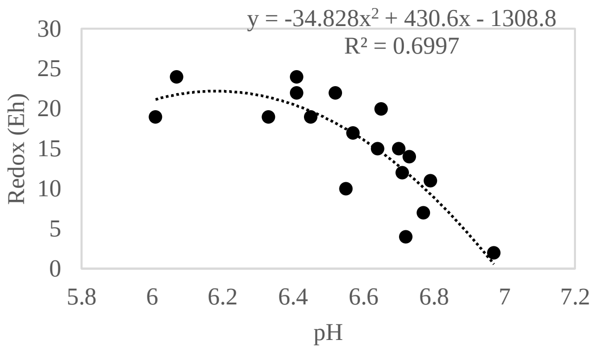

Figure 2. Relationship Between Soil pH and Redox

According to (Husson, 2013), Eh and pH are the main drivers in the soil/plant/microorganism system, influencing the physiology of plants and microorganisms as well as soil genesis. Low Eh conditions, which often occur in soils with high vegetation density, can alter microbial dynamics and biochemical processes in the soil, including humification. Breavington *et al.* (2025) found that soil redox potential directly influences carbon fluxes. Lower Eh values due to high organic inputs led to suppressed CO_2 emissions and stimulated CH_4 release. These dynamics are consistent with our study, which observed that redox stratification shaped carbon storage patterns and microbial function in mangrove soils.

Furthermore, according to a study conducted by Xu & Tsang (2022), soil organic carbon (SOC) has significant redox capacity, influencing the redox transformation of potential toxic elements in the soil. The interaction between organic carbon and redox chemical components of the soil such as O_2, Fe, and Mn can produce reactive oxygen species (ROS) and Fe(II), which contribute to redox transformations including the humification process.

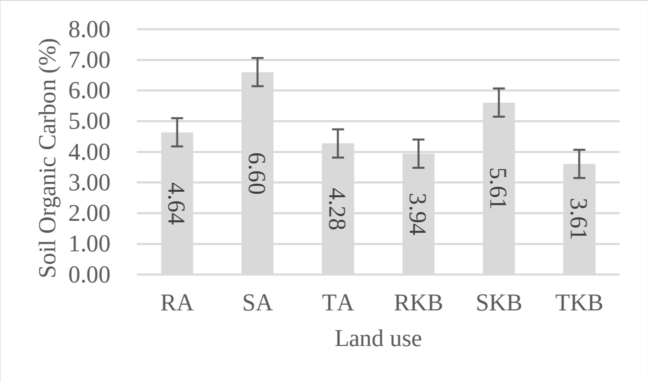

Figure 3. Percentage of Soil Organic Carbon

The results of the soil organic matter measurements at the research site indicate that the soil organic carbon content in areas with Avicennia marina mangrove vegetation is higher than in areas with *Excoecaria agallocha* mangrove vegetation. The difference in soil organic carbon levels between *Avicennia* and *Excoecaria* mangrove areas can be attributed to several factors, including differences in litter production, decomposition rates, and the physicochemical characteristics of the soil influenced by the dominant type of mangrove vegetation. *Avicennia* mangrove species generally produce litter that is more easily decomposed and undergoes humification more quickly compared to *Excoecaria agallocha*. This is due to the lower lignin and phenolic compound content in *Avicennia* leaves, allowing soil microorganisms to decompose its litter more quickly. Additionally, the litter of *Excoecaria* contains toxic compounds (such as dipterenoids and latex) that can slow down decomposition and humification. As a result, the humification rate in *Avicennia* mangrove areas is higher, leading to the formation of more stable organic carbon and resulting in a higher soil organic carbon content compared to Excoecaria mangrove areas (Alongi, 2012; Kristensen *et al.*, 2008).

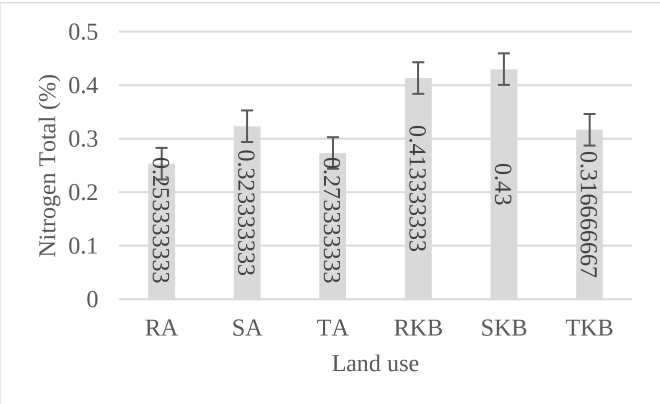

Figure 4. Percentage of Total Nitrogen

It can be observed that in areas with moderate vegetation density, the total nitrogen content of the soil is higher compared to areas with low or high vegetation density. This indicates that vegetation restoration significantly increases soil nitrogen content. In the early to mid-restoration stages, the increase in vegetation density contributes to nitrogen accumulation through the enhancement of litter and soil microbial activity. However, at the advanced restoration stage, the rate of nitrogen increase tends to decline due to ecosystem stabilization. This indicates that the density of vegetation is optimally contributing to the increase in soil nitrogen content (Song *et al.*, 2021). In addition, it can be seen in the graph above that the soil under the canopy of *Excoecaria agallocha* has a higher nitrogen content compared to Avicennia. This is suspected because *Excoecaria* has a moderate to dense canopy density and vegetation cover, producing a lot of litter that decomposes slowly but provides a long-term supply of nitrogen. *Avicennia* tends to grow more dispersed or in areas with higher aeration, producing litter that decomposes quickly, but with a faster loss of soil nitrogen contribution (leaching or uptake). Mangrove species with dense canopies and slow-decomposing litter provide a long-term nitrogen supply to the soil (Alongi, 2014; Liu *et al.*, 2021; Liu *et al.*, 2022).

Next, the soil texture analysis in table 4.2 shows that the texture class across all land uses is dominated by the sandy clay loam class. This can be linked to the organic carbon content across all land uses. Soils with a clayey dusty texture have a high ability to retain moisture and organic matter. The dominant clay and silt fractions can enhance the adsorption capacity for organic matter and reduce the decomposition rate due to anaerobic conditions, especially in tidal areas such as mangrove ecosystems. Mangrove ecosystems are highly effective carbon sinks, especially in the form of soil organic carbon. The organic carbon content of mangrove soil is influenced by various factors, including soil texture, vegetation type, and anthropogenic activities.

The texture of clayey soil with dust plays an important role in the carbon storage process. Soils with high clay and silt fractions are able to bind organic matter more effectively compared to coarse-textured soils like sand. This is because clay particles have a larger surface area, allowing them to adsorb and protect organic matter from microbial decomposition (Alongi, 2014).

Research by Harahap & Siregar (2023) shows that sediments beneath natural mangrove stands, including the species *Avicennia marina*, have higher carbon storage compared to other mangrove species. This is related to the high accumulation of organic matter and the dominant clayey soil texture that supports carbon stability. Mangrove soil with a clay texture also has a neutral to acidic pH and high organic matter content, supporting long-term carbon storage capacity. He also mentioned that vegetation such as *Avicennia marina* affects soil characteristics through the accumulation of litter and roots, enriching the soil's organic matter.

(Ratul *et al.*, 2022) demonstrated that mangrove restoration strategies—particularly species selection and planting design (monoculture vs. mixed)—significantly influence blue carbon sequestration rates in coastal ecosystems. Their study in Xiatanwei, China, found that monoculture plantations of *Kandelia obovata* yielded higher vegetation carbon accumulation than mixed plantations with *Sonneratia apetala*. Nevertheless, soil carbon stocks increased across all vegetation types, emphasizing the crucial role of belowground biomass and litterfall in long-term soil carbon stabilization. These findings align with our study, which similarly observed that vegetation density and organic inputs from mangrove species enhance soil carbon and nitrogen content. This highlights the importance of adaptive restoration strategies and appropriate species selection to maximize ecosystem functions and carbon storage potential in mangrove systems.

Table 2. HSD Test at 5% Level of Soil Texture Parameters

Land Use	Fractions			Class
	Sand	Silt	Clay	
	(%)			
RA	51,67 b	21,33 a	27,00 a	Sandy Clay Loam
SA	56,00 bc	21,00 a	23,00 a	Sandy Clay Loam
TA	**56,33 c**	20,33 a	23,33 a	Sandy Clay Loam
RKB	52,67 bc	16,00 a	31,33 a	Sandy Clay Loam
SKB	42,00 a	**24,33 a**	**33,33 a**	Silty Loam
TKB	54,00 bc	22,67 a	23,67 a	Sandy Clay Loam
HSD 5%	*	ns	ns	

Notes: RA (Low Density with *Avicennia marina* Mangrove Vegetation), SA (Medium Density with *Avicennia marina* Mangrove Vegetation), TA (High Density with *Avicennia marina* Mangrove Vegetation), RKB (Low Density with *Excoecaria agallocha* Mangrove Vegetation), SKB (Medium Density with *Excoecaria agallocha* Mangrove Vegetation), TKB (High Density with *Excoecaria agallocha* Mangrove Vegetation). * (significantly different), ns (not significantly different). Values followed by the same letter indicate no significant difference based on the HSD test at 5% level.

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These findings confirm that beyond vegetation type and density, soil texture, redox dynamics, and pH are critical in shaping nutrient retention and organic matter stabilization. As highlighted by (Brockerhoff *et al.*, 2017), moderate vegetation density offers an ecological balance, optimizing litter input and microbial processing. Additionally, Fu *et al.* (2019) emphasized that microbial biomass and activity are closely tied to vegetation structure and organic resource availability, which in turn influence soil fertility and carbon dynamics in coastal systems.

The texture of clayey soil with dust plays an important role in the carbon storage process. Soils with high clay and silt fractions are able to bind organic matter more effectively compared to coarse-textured soils like sand. This is because clay particles have a larger surface area, allowing them to adsorb and protect organic matter from microbial decomposition (Alongi, 2014). Research by Tahir *et al*. (2023) shows that sediments beneath natural mangrove stands, including the species *Avicennia marina*, have higher carbon storage compared to other mangrove species. According to Cai *et al*. (2016), soils with high clay and silt content offer greater surface area for organic matter adsorption, thereby supporting long-term carbon storage.

CONCLUSIONS

This study found that mangrove species and vegetation density significantly affect soil chemical and physical properties. *Avicennia marina* showed a higher ability to increase soil organic carbon (SOC) due to its easily decomposed litter that accelerates humification. In contrast, *Excoecaria agallocha* contributed more to soil nitrogen content, especially at moderate vegetation density, due to its slower-decomposing litter providing a sustained nitrogen supply.

Vegetation density also influenced soil pH (higher density = more neutral pH) and reduced redox potential, creating anaerobic conditions that support carbon storage. The dominant soil texture was sandy clay loam, which enhances moisture and organic matter retention. Overall, *Avicennia marina* is more effective for carbon storage, while *Excoecaria agallocha* plays a key role in nitrogen accumulation. These findings are valuable for sustainable mangrove conservation and restoration strategies.

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