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Assessment of Physico-Chemical and Biological Properties of Mangrove Soils in Mundrothuruth, Kollam District, Kerala, India

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KEYWORDS
Rhizosphere soil
Micronutrients
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Soil health
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ABSTRACT:

Introduction: Mangrove soils, common in wetland ecosystems, are typically anoxic and rich in organic matter due to waterlogging that slows decomposition. These soils, often comprising less than 35% sand, 40% silt, and 45% clay, influence mangrove forest structure, composition, and productivity through their nutrient content. Despite generally low nutrient levels, soil characteristics vary significantly across ecosystems and within mangrove stands. The present study examines the physico-chemical and biological properties of rhizosphere and non-rhizosphere soils from three sites in the Munrothuruthu wetland, Kerala, India.

Objectives: The present study aims to compare the soil characteristics of rhizosphere and non-rhizosphere soil associated with mangrove vegetation. Also aims to enhance the importance of conserving mangrove ecosystems for their ecological and environmental benefits.

Methods: The present study was conducted in the wetlands of Munroe Island (also known as *Munrothuruthu*) in Kollam District, Kerala. Covering an area of approximately 13.4 km², Munroe Island is a Panchayath situated at the confluence of Ashtamudi Lake and the Kallada River. Over 70% of the Panchayath lies within the delta formed by the Kallada River, and the local population primarily depends on prawn farming for their livelihood. For the present study, soil samples were collected from the selected three locations within Munroe Island. At each location, three soil samples were obtained from non-rhizosphere and rhizosphere by excavating pits to a depth of 30 cm using a spade. Soil samples were collected from two distinct layers; the top layer (0–15 cm) and the sub-surface layer (15–30 cm). Care was taken to prevent any mixing of soil between the layers. The parameters studied included soil pH, electrical conductivity, soil moisture content, water-holding capacity, organic carbon, available phosphorus, available potassium, micronutrients and VAM colonisation studies were carried out employing standard methods.

Results: The soils exhibited acidic conditions, with pH averaging 6.1 in topsoil and 5.6 in subsoil. Electrical conductivity ranged from 0.24 to 0.75 mmhos, while subsoil moisture content exceeded that of topsoil. Organic carbon was highest in non-rhizosphere topsoil (2.7%) and lowest in rhizosphere topsoil (0.4%). Macro and micronutrient availability varied notably. Phosphorus peaked in non-rhizosphere subsoil and was lowest in rhizosphere subsoil. Potassium levels were relatively stable across samples. Calcium ranged from 44.8–51 ppm, magnesium from 22.5–93.5 ppm, and sulphur was highest in non-rhizosphere topsoil (60.57 ppm). Iron and boron concentrations were greatest in rhizosphere subsoil, while zinc and copper were highest in non-rhizosphere soils. Manganese was most abundant in rhizosphere topsoil (44 ppm). Root colonization by Vesicular Arbuscular Mycorrhizal (VAM) fungi was also observed.

Conclusions: The results indicate that soil physico-chemical properties significantly influence the ecophysiology, vegetation, species composition, and forest structure of mangroves.The findings of the study emphasize the vital role of soil properties and mycorrhizal associations in mangrove ecosystem functioning and call for conservation strategies that prioritize soil health and microbial interactions under increasing anthropogenic stress

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1. Introduction

Mangrove soils are typically found in wetlands and are often anoxic, though not usually sulfidic (1,3). These soils generally consist of less than 35% sand, 40% silt, and 45% clay (22, 23, 24). High in organic matter due to waterlogged conditions that slow plant decomposition, mangrove soils support the structure, composition, and productivity of mangrove forests through their nutrient content and availability (20). Despite many mangrove soils having extremely low nutrient levels (13), this can vary greatly across ecosystems and even within individual stands (6). Most are mildly acidic, a trait influenced by certain bacterial activity and naturally occurring clays. While some mangrove soils are both highly reduced and rich in sulfur, this is not a consistent feature across all mangrove environments.

The nutrient content and availability in mangrove soils are key factors influencing the composition, structure, and productivity of mangrove forests (20). Although many mangrove soils exhibit extremely low nutrient levels (13), nutrient availability can vary significantly between different mangrove ecosystems and even within individual stands (6). Among the primary factors shaping mangrove structure, nutrient availability is considered one of the most influential (24). Mangrove soils are often characterized by nutrient limitations, particularly in nitrogen (N) and phosphorus (P), which are critical for plant growth and ecosystem function (21, 13).

Mangrove soils are typically anoxic but are not always sulfidic (3, 1). Nutrients generated by primary producers are transferred through the food web and eventually enter the detrital pool via the decomposition of leaf litter and woody material. Also mangrove ecosystems play a vital role in the hydrological cycle and provide a wide range of essential ecosystem services, including flood mitigation, water quality improvement, carbon sequestration, wildlife habitat provision, and buffering against high water events. However the structural complexity of mangrove root systems, combined with their unique position at the land-sea interface, makes them critical habitats for a diverse array of species (10). Additionally, mangroves act as natural filters, trapping sediments carried by runoff and river water before it reaches adjacent ecosystems. This function reduces water turbidity and enhances light penetration, which is crucial for the health of nearby aquatic habitats.

The present investigation aims to characterize the soils associated with mangrove and adjacent vegetation in Munrothuruth, Kollam District, Kerala, India. Mangroves are complex and dynamic ecosystems with diverse soil properties that support a rich array of biodiversity. However, these ecosystems are increasingly threatened by urbanization and industrial development. The degradation of mangrove habitats can lead to significant ecological imbalances due to the vital functions they perform.

A particular emphasis of this study is on the role of Vesicular Arbuscular Mycorrhizal (VAM) fungi, which form symbiotic associations with plant roots. These fungi facilitate the uptake of essential nutrients such as phosphorus and water in exchange for carbohydrates from the host plant. Their presence is crucial for maintaining soil health and enhancing plant growth, making them indispensable components of mangrove ecosystems. Despite their ecological significance, there has been limited research on the soil characteristics of mangrove ecosystems in this region. Mangroves contribute significantly to coastal protection by stabilizing shorelines, preventing erosion, and buffering inland areas from storm surges. They also act as sediment traps, promoting the accumulation of coastal sediments. The present study seeks to address existing research gaps by investigating the physico-chemical and biological properties of soils within a representative mangrove ecosystem in Kerala. Specifically, it aims to compare the soil characteristics of rhizosphere and non-rhizosphere zones associated with mangrove vegetation. By enhancing our understanding of these soils, this research underscores the importance of conserving mangrove ecosystems for their ecological and environmental benefits.

2. Study area and Methods

The present study was conducted in the wetlands of Munroe Island (also known as *Mundrothuruthu*) in Kollam District, Kerala. Covering an area of approximately 13.4 km², Munroe Island is a Panchayath situated at the confluence of Ashtamudi Lake and the Kallada River. Over 70% of the Panchayath lies within the delta formed by the Kallada River, and the local population primarily depends on prawn farming for their livelihood. The island was formed as part of land reclamation efforts during the tenure of Colonel John Munro, who oversaw the development of this region. In recognition of his contributions, the reclaimed land was named Munroe Island. The region surrounding Munroe Island forms a part of the Ashtamudi estuary, which is a significant geological component of the South Indian

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Peninsular Shield. The estuary comprises both crystalline rocks and tertiary sediments (12). According to the classification by the Department of Soil Survey and Soil Conservation, the topsoil of Munroe Island is categorized as acidic saline soil. This soil type is typically found in low-lying marshes, waterlogged zones, and poorly drained areas near rivers and streams that are exposed to tidal influences. The intrusion of sea and backwater tides contributes to the salinity of these soils. However, during the monsoon season, the influx of rainwater and freshwater from rivers helps to partially leach the salinity. The soil texture in the region varies widely, ranging from sandy loam to clay, and is generally characterized by a dark grey to black color. For the present study, three sites were selected within Munroe Island: Mundrothuruth, Pattamthuruth, and the boat jetty area of Mundrothuruth. At each site, three mangrove plants were selected for analysis. The species studied include *Sonneratia caseolaris, Rhizophora apiculata*, and *Avicennia marina.*

For the present study, soil samples were collected from the selected three sites within Munroe Island. At each location, three soil samples were obtained from non-rhizosphere and rhizosphere by excavating pits to a depth of 30 cm using a spade. Soil samples were collected from two distinct layers: the top layer (0–15 cm) and the sub-surface layer (15–30 cm). Care was taken to prevent any mixing of soil between the layers. Approximately 500 grams of soil from each layer were collected, placed in clean polyethylene bags, properly labeled, and transported to the laboratory for further analysis. In the laboratory, the soil samples were processed to remove stones, roots, and other debris. The cleaned samples were then divided into 10-gram subsamples, which were used for physical and chemical analyses and root colonization studies. From each study sites rhizosphere soil samples of the selected mangrove species also collected and processed.

The parameters studied included soil pH and electrical conductivity described by Jackson, (9). Soil moisture content, water-holding capacity, organic carbon percentage were analysed with the standard method (17). Percentage of available Phosphorus in the soil samples was determined using Bray No.1methode (4) and modified by FAO (5). Available potassium (K) was extracted using the method by Madaras and Koubova (15). Sulphur availability in the soil was determined using the method of Motsra and Roy (17). Soil micronutrient like iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and boron (B) levels were determined by using the above method. Available calcium (Ca) and magnesium (Mg) was determined by shake 5 g soil with 25 ml neutral normal ammonium acetate for 5 minutes and filter immediately through Whatman No. 42 filter paper. First few ml of the filtrate may be discarded. From soil extract Ca and Mg can be estimated by atomic absorption spectrophotometer. For Vesicular Arbuscular Mycorrhizal (VAM) root colonization studies on collected root samples with a diameter of less than 0.2 mm were thoroughly washed under running tap water to remove any adhering soil particles. The cleaned roots were then cut into 1 cm segments using a sterile blade. These root segments were placed in a small beaker containing 10% potassium hydroxide (KOH) solution and left for approximately 60 minutes to clear the tissue. For staining, a modified method developed by Vierheilig et al. (25) was adopted, using a solution of Pelikan Blue ink diluted in 5% acetic acid. The root samples were immersed in this staining solution and kept for several days to allow adequate staining. Following staining, the roots were destained using 50% glycerol to enhance visibility of internal structures. Finally, the stained root segments were placed on clean microscopic slides, gently squashed, and observed under a microscope to examine the colonization of Vesicular Arbuscular Mycorrhizal (VAM) fungi. The percentage of root colonization was calculated with the formula :

$$\text{Percentage of root colonization} = \frac{\text{Number of root bits with infection}}{\text{Total number of root bits examined}} \times 100$$

3. Results and Discussion

The present study analysed the physical, chemical, and biological properties of rhizosphere and non-rhizosphere soil samples collected from three sites within the Munrothuruthu wetland. The findings revealed that the soil pH at all study sites was acidic, with average values of 6.1 in the topsoil and 5.6 in the subsoil (Fig. 1). Soil pH, which indicates the level of acidity or alkalinity, is an important factor influencing nutrient availability and microbial activity. Studies on tropical mangrove forests globally have reported a wide pH range, with values varying from acidic to alkaline. For instance, previous research has documented soil pH ranging from 2.87 to 6.40 in mangrove ecosystems (11, 19, 23, 24).

Soil electrical conductivity (EC), an indicator of salinity influenced by factors such as soil texture and organic

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matter content, also varied among the study sites (Fig. 2). The highest EC was recorded in non-rhizosphere topsoil (0.75 mmhos), while the lowest was in rhizosphere topsoil (0.24 mmhos). The Electrical conductivity values of coastal line soils vary widely at different season depending on precipitation and evaporation (26). Here the electrical conductivity of mangrove shows slight variations which ranges from 0. 24 – 0. 75 mm hos.

However, soil moisture content, a critical factor for plant growth and microbial activity, also showed variability across the sites (Fig. 3). The highest average soil moisture was observed in rhizosphere subsoil (8.93%), while the lowest was found in non-rhizosphere topsoil (8.4%). In a study Mc Donald, *et al.* (16) states that wide variation in mangrove forest structure has been correlated with variation in soil moisture content. The present study reveals that the moisture content is higher in the down layer than top layer and which ranges from 7. 05 – 9. 05%. While soil organic carbon (Fig.4), which is vital for soil microbes, resulted highest in non-rhizosphere topsoil (2.7%) and lowest in rhizosphere topsoil (0.4%). Less than one percent organic carbon reported by Sah, *et al* (22) and Hossain, *et al* (8) indicates the poor nutritional content of the soils of some mangrove soils. The present study supports their view.

The percentage of soil phosphorus content showed notable variation across the three study sites. The highest phosphorus content was observed in the non-rhizosphere subsoil (295.8 kg/ha), while the lowest was recorded in the rhizosphere subsoil (82.6 kg/ha). Overall, site one exhibited the highest phosphorus content across samples, while site three had the lowest levels, as illustrated in Fig.5. The average available potassium content in rhizosphere topsoil was 535.6 kg/ha and non-rhizosphere topsoil was 537.6 kg/ha (Fig. 6).

The present study found that the highest soil available calcium content was 51 ppm in the non-rhizosphere down soil (Fig. 7), while the lowest was recorded in the rhizosphere down soil (44.8 ppm). In case of available sulphur, an essential protein ingredient and helps in maintaining green colour of leaves, the highest average was recorded in non-rhizosphere top soil, (60.57 ppm) and least by rhizosphere top soil, 9. 24 ppm (Fig. 8). The available iron content was highest in the rhizosphere down soil (Fig. 9). Zinc availability was greatest in the non-rhizosphere down soil (5.51 ppm) and lowest in the rhizosphere down soil (Fig. 10). In the case of available manganese (Mn), an important plant mineral nutrient playing a crucial role in several physiological processes, mainly photosynthesis, it was observed that highest average manganese content recorded in rhizosphere top soil, which is about 44 ppm and least by non-rhizosphere top soil, 3.41 ppm (Fig 11). Similarly, the highest copper concentration was observed in the non-rhizosphere down soil (5.58 ppm), with the lowest (3.53 ppm) in the rhizosphere down soil (Fig.12).

Boron levels were highest in the rhizosphere down soil (0.705 ppm) and lowest (0.441 ppm) in the non-rhizosphere down soil (Fig. 13). Magnesium, plays an important role in photosynthesis and building block of chlorophyll, was found to be highest (93.5 ppm) in the non-rhizosphere down soil (Fig. 14). Similar observations were reported by Muhibbullah et al (18) in the Sundarban mangrove ecosystem, where calcium content ranged from 1900–4500 mg/g and magnesium from 420–1500 mg/g. In the present study, calcium content ranged from 44.8–51 ppm, and magnesium from 22.5–93.5 ppm.

Regarding phosphorus, the highest average available content was recorded in the non-rhizosphere soil: 262.6 kg/ha in the topsoil and 82.6 kg/ha in the subsoil. In contrast, the rhizosphere soil showed lower phosphorus values: 59.16 kg/ha in the top layer and 19.07 kg/ha in the bottom layer. The dual role of micronutrients such as copper, iron, manganese, calcium, boron, zinc, and magnesium—as either essential or potentially toxic elements in mangrove ecosystems—has been documented by several researchers (14, 2). The current findings further support the varying influence of these elements on mangrove vegetation.

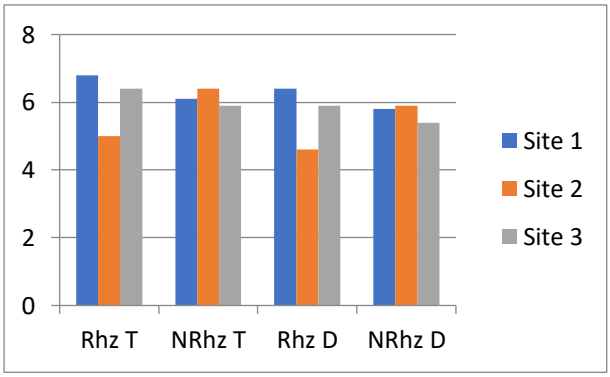

Fig. 1: Soil pH from study sites.
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

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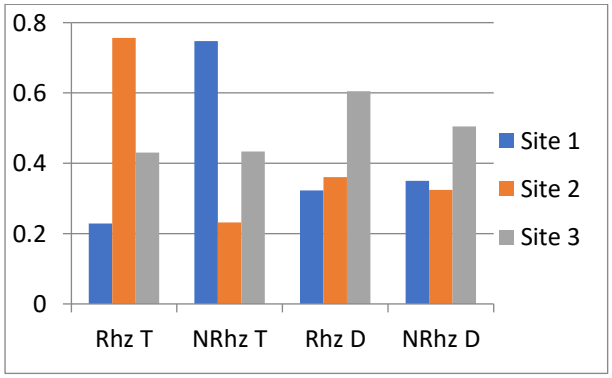

Fig. 2. Electrical conductivity
(RhzT:-Rhizosphere Top soil, NRhz T:- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

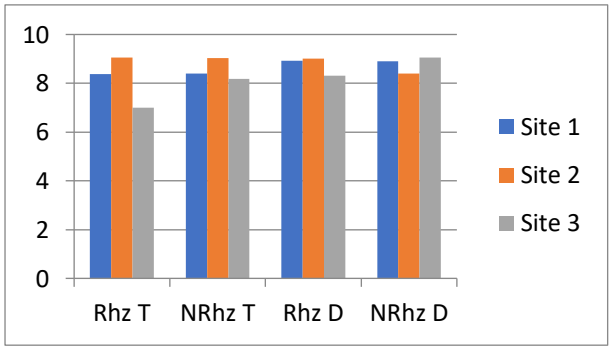

Fig. 3: Soil Moisture Content
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

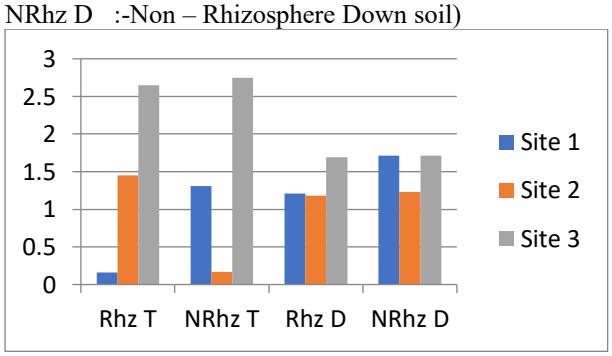

Fig.4: Percentage organic carbon
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D, :-Non – Rhizosphere Down soil)

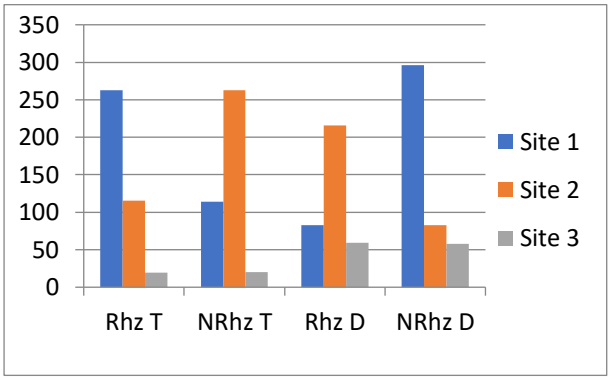

Fig.5: Soil Phosphorous content
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

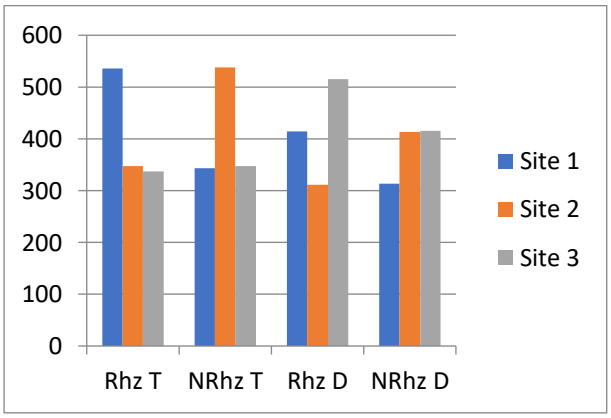

Fig. 6: Available Potassium content
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

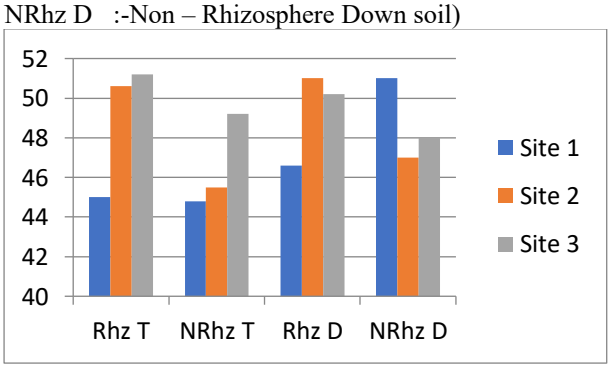

Fig. 7: Available Calcium
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

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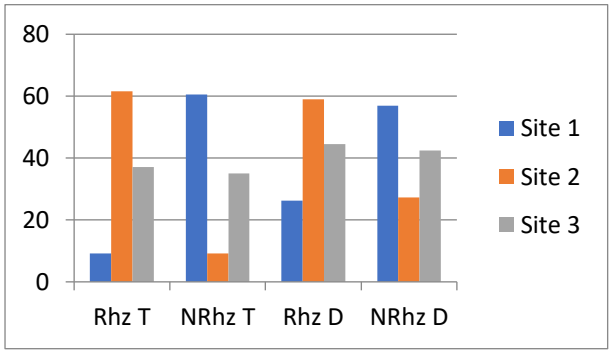

Fig. 8 Available Sulphur
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

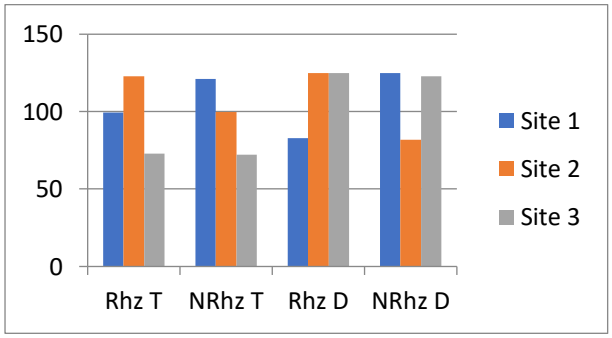

Figure 9: Available Iron content
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

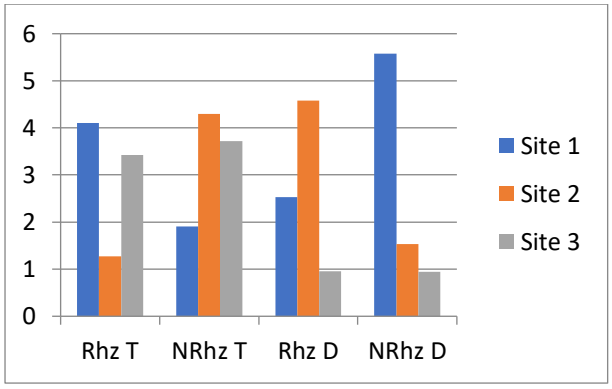

Fig. 10: Available Zinc content
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

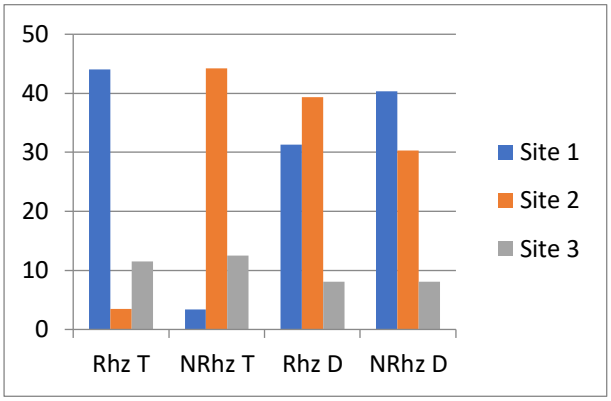

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Fig. 11: Available Manganese content
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

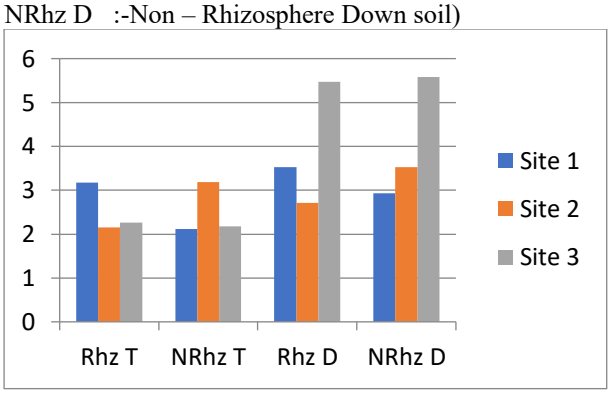

Fig. 12: Available Copper content
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

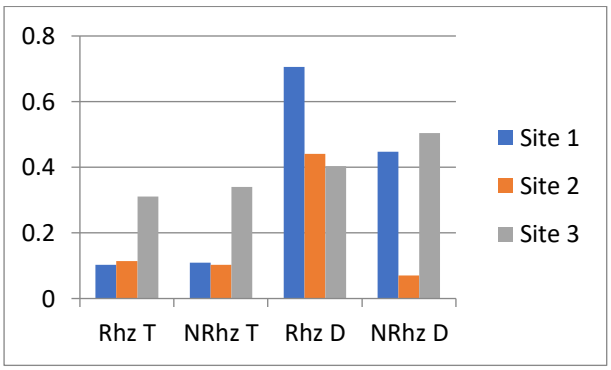

Figure 13: Available Boron content
(RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

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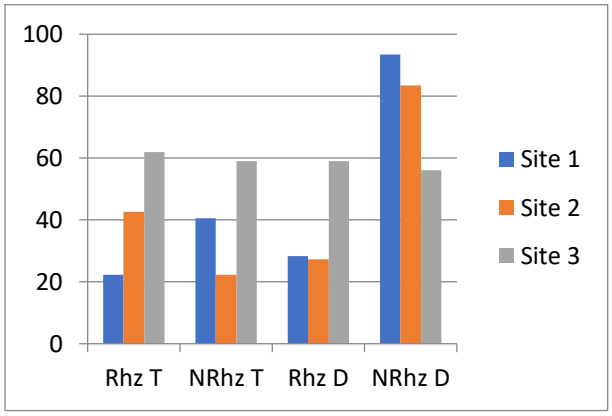

Figure 14: Magnesium content (RhzT:-Rhizosphere Top soil, NRhz T :- Non – Rhizosphere Top soil, Rhz D- Rhizosphere Down soil, NRhz D :-Non – Rhizosphere Down soil)

From the three sites selected for study maximum percentage of root colonization by VAM fungi were seen in site 1, and least population is seen in site 3 (Table 1).

Table 1: Presence of root colonization of VAM fungi from study sites

VAM	Site 1		Site 2		Site 3	
	Top soil	Down soil	Top soil	Down soil	Top soil	Down soil
Vesicles	+	_	_	_	+	+
Arbuscules	_	_	_	_	+	_

(+ presence, - absence)

The present study concludes that soil characteristics play a critical role in shaping the structure and growth of mangrove ecosystems. The findings indicate that the physico-chemical properties of the soil, along with root colonization by vesicular-arbuscular mycorrhizal (VAM) fungi, significantly influence the eco-physiology, species composition, vegetation patterns, and forest structure of tropical mangroves. This underscores the ecological importance of mycorrhizal associations in mangrove environments. Moreover, the study highlights a clear research gap, suggesting the need for further investigation into the interactions between soil properties and mycorrhizal fungi. Understanding these relationships is essential for the effective conservation and restoration of mangrove ecosystems, as well as for enhancing plant growth under stressed conditions.

4. Acknowledgement

All authors contributed equally

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