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Growth Response of Cocoa Seedlings (*Theobroma cacao* L.) to Concentration and Application Interval of Forest Organic Fertilizer

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Abstract: Vegetation plays an essential role in regulating soil fertility through nutrient cycling, organic matter accumulation, and interactions with soil microorganisms. This study aimed to evaluate the chemical characteristics and soil fertility status under vegetation dominated by *Mimosa invisa* L., *Crotalaria anagyroides* L., and *Imperata cylindrica* L. Beauv. in Baitussalam District, Aceh Besar Regency, Indonesia. Soil samples were collected from the 0–20 cm layer using a non-factorial randomized block design with five replications. Soil chemical analyses included pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, calcium, magnesium, sodium, cation exchange capacity (CEC), exchangeable sodium percentage (ESP), and exchangeable hydrogen. Data were analyzed using analysis of variance (ANOVA), followed by the Least Significant Difference (LSD) test at the 5% significance level. The results showed that vegetation type significantly affected available phosphorus and exchangeable calcium but had no significant effects on soil pH, total nitrogen, exchangeable potassium, magnesium, sodium, CEC, ESP, or exchangeable hydrogen. Soils under *Mimosa invisa* generally exhibited higher soil pH, organic carbon, total nitrogen, CEC, and exchangeable calcium than those under *Crotalaria anagyroides* and *Imperata cylindrica*. High exchangeable sodium and ESP values across all vegetation types indicated persistent effects of seawater intrusion following the 2004 Indian Ocean tsunami. These findings demonstrate that vegetation type influences nutrient cycling and selected soil chemical properties, with leguminous vegetation showing greater potential to improve soil fertility. The study provides valuable information for developing sustainable soil management and ecological restoration strategies in tropical coastal ecosystems.

Keywords: *Crotalaria anagyroides*; *Mimosa invisa*; *Imperata cylindrica*; Soil Chemical Properties; Soil Fertility; Vegetation Dominance

Introduction

Cocoa (*Theobroma cacao* L.) is one of the leading plantation commodities that plays an important role in supporting agricultural development and the economy in many tropical countries, including Indonesia. Cocoa cultivation contributes significantly to farmers' income, employment opportunities, and export earnings. Indonesia is recognized as one of the major cocoa-producing countries in the world, and the commodity continues to have strong economic potential due to the increasing global demand for cocoa beans and processed cocoa products (Quiñones-Cabezas et al., 2024). In addition to its economic value, cocoa cultivation also supports rural development and the sustainability of plantation-based agricultural systems. Therefore, efforts to improve cocoa productivity remain an important priority in plantation crop management.

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One of the major factors influencing cocoa productivity is the quality of planting materials used during cultivation (Cahyaningrum et al., 2024). High-quality seedlings are essential for establishing healthy and productive cocoa plantations. Vigorous seedlings generally exhibit better adaptability to field conditions, improved root development, and greater tolerance to environmental stress after transplanting. (Ardiani et al., 2023). Consequently, the nursery stage represents a critical phase in cocoa cultivation because it determines the initial growth and future performance of the plants. Poor seedling quality during the nursery stage may result in weak plant growth, lower productivity, and increased susceptibility to pests and diseases (Oladokun et al., 2022).

The growth and development of cocoa seedlings are affected by several factors, including environmental conditions, water availability, planting media, and nutrient supply (Campos-Vega et al., 2018). Among these factors, nutrient availability plays a particularly important role because nutrients are required for various physiological and biochemical processes in plants. Adequate nutrient availability supports cell division, chlorophyll formation, photosynthesis, root development, and vegetative growth. Therefore, proper fertilization management is necessary to ensure optimal seedling growth during the nursery stage (Arthur et al., 2019).

Fertilization practices in cocoa nurseries commonly involve the use of inorganic fertilizers due to their rapid nutrient availability and ease of application (Zulkarnain et al., 2024). However, the excessive and continuous use of inorganic fertilizers may negatively affect soil quality and environmental sustainability. Long-term application of synthetic fertilizers can reduce soil organic matter content, increase soil acidity, decrease microbial diversity, and contribute to nutrient leaching and environmental pollution (Rahman et al., 2021). These conditions may eventually reduce soil fertility and affect sustainable agricultural production systems. As environmental concerns continue to increase, the use of environmentally friendly agricultural inputs has become an important aspect of sustainable plantation management.

Organic fertilizers have gained increasing attention as an alternative nutrient source in sustainable agriculture (Yuliana et al., 2023). Organic fertilizers are widely known for their ability to improve soil physical, chemical, and biological properties while supporting environmentally friendly cultivation practices. The application of organic fertilizers can enhance soil structure, increase water-holding capacity, stimulate beneficial microbial activity, and improve nutrient availability in the soil (Lainawa and Rahmi, 2024). In addition, organic fertilizers contribute to the gradual release of nutrients, thereby reducing nutrient losses and improving nutrient use efficiency by plants.

Among the different types of organic fertilizers, liquid organic fertilizers have become increasingly popular in nursery management due to their practical advantages. Liquid organic fertilizers are relatively easy to apply and can be rapidly absorbed by plants through roots and leaves (Kaba at al., 2022). Their liquid form allows nutrients to become more readily available during the vegetative growth stage compared to solid organic fertilizers. Furthermore, liquid organic fertilizers often contain both macro- and micronutrients that are essential for plant growth and development. The balanced nutrient composition in liquid organic fertilizers can support stem elongation, leaf formation, root development, and overall plant vigor (Dwiyanto et al. (2021).

The success of liquid organic fertilizer application is highly influenced by several factors, particularly fertilizer concentration and application interval. Appropriate fertilizer concentration is important to ensure sufficient nutrient supply for plant growth. Low fertilizer concentrations may not adequately fulfill plant nutrient requirements, leading to limited growth responses. Conversely, excessively high concentrations may create nutrient imbalances or osmotic stress around the root zone, which can inhibit nutrient absorption and negatively affect plant growth (Gunawan et al., 2024). Therefore, determining the optimum fertilizer concentration is necessary to achieve efficient nutrient utilization and maximum plant growth response (Dewi et al., 2021).

In addition to concentration, the interval of fertilizer application is another important factor affecting the effectiveness of liquid organic fertilizers (Mailidarni et al., 2024). Application intervals determine the continuity of nutrient availability during plant growth. Frequent fertilizer application at appropriate intervals may maintain nutrient availability in the root zone and improve nutrient uptake efficiency (Gumilar et al., 2023). On the other hand, excessively long intervals may reduce nutrient availability during critical growth periods, thereby limiting vegetative growth responses. The interaction between fertilizer concentration and application interval may also influence plant growth performance because both factors are closely related to nutrient dynamics and plant physiological processes (Sasmita et al., 2017).

Forest organic fertilizer is one type of liquid organic fertilizer that contains essential nutrients required during the early growth stage of plants (Panataria et al., 2022). This fertilizer contains macroelements such as nitrogen, phosphorus, and potassium, as well as micronutrients that support plant metabolic activities (Mailidarni at al., 2025). Nitrogen plays an important role in chlorophyll formation and vegetative growth, phosphorus supports root development and energy transfer processes, while potassium contributes to enzyme activation and water regulation in plant tissues. The availability of these nutrients in balanced amounts is expected to improve cocoa seedling growth during the nursery stage (Dwiyanto et al., 2021).

Several previous studies have demonstrated the positive effects of organic fertilizer application on cocoa seedlings and other plantation crops. Cahyaningrum et al., (2024) reported that liquid organic fertilizer application significantly improved plant height, leaf number, and stem diameter in cocoa seedlings. Similar findings were reported by Gunawan et al. (2024), who found that appropriate doses of liquid organic fertilizers stimulated early vegetative growth and improved seedling vigor. In addition, organic fertilizer application has been reported to enhance nutrient uptake efficiency and improve soil biological activity, thereby supporting sustainable crop production systems.

Although numerous studies have investigated the benefits of organic fertilizers in plant cultivation, information regarding the optimum concentration and application interval of Forest organic fertilizer for cocoa seedlings remains limited. (Munawwarah and Sulaiman, 2023). Most previous studies focused mainly on fertilizer dosage without evaluating the combined effects of concentration and application interval under nursery conditions. As nutrient availability and nutrient absorption efficiency are strongly influenced by these two factors, further research is necessary to determine the most effective fertilizer management strategy for cocoa seedlings (Arthur et al., 2019).

The evaluation of fertilizer concentration and application interval is particularly important during the nursery stage because seedlings require adequate nutrients to support rapid vegetative growth (Putra at el., 2022). Parameters such as plant height, leaf number, and stem diameter are commonly used to assess seedling growth responses because they reflect plant vigor and nutrient utilization efficiency. Improved vegetative growth during the nursery stage is expected to enhance plant establishment and productivity after transplanting to the field (Lainawa and Rahmi, 2024).

Based on the above considerations, this study was conducted to evaluate the growth response of cocoa seedlings to different concentrations and application intervals of Forest organic fertilizer (Mujayyana at al., 2026). The study aimed to determine the most effective concentration and application interval combination for supporting optimal cocoa seedling growth under nursery conditions (Cahyaningrum et al., 2024). The findings of this research are expected to provide scientific information regarding efficient organic fertilizer management strategies and contribute to the development of sustainable cocoa cultivation practices.

Method

Study Site and Research Period

This study was conducted in Riting Village, Indrapuri District, Aceh Besar Regency, Indonesia, at an altitude of approximately 250 m above sea level. The research was carried out from March 31 to June 28, 2008.

Experimental Design

The experiment employed a factorial Randomized Block Design (RBD) consisting of two factors with three replications. The first factor was the concentration of Forest organic fertilizer, while the second factor was the application interval. The treatments were arranged as follows:

Forest Organic Fertilizer Concentration (F)

F_0 = 0 cc L^{-1} water
F_1 = 1 cc L^{-1} water
F_2 = 2 cc L^{-1} water
F_3 = 3 cc L^{-1} water

Fertilizer Application Interval (I)

L_1 = once every week
L_2 = once every two weeks
L_3 = once every three weeks

The combination of both factors resulted in 12 treatment combinations with three replications, producing a total of 36 experimental units. Each experimental unit consisted of three cocoa seedlings grown individually in polybags, resulting in a total of 108 polybags used in the experiment.

Seed Germination

Cocoa seeds were germinated in a wooden germination box measuring 50 cm × 50 cm × 70 cm filled with fine sand as the germination medium. The seeds were planted with the radicle facing downward until approximately three-fourths of the seed portion was embedded in the sand. The spacing between seeds within rows was 2 cm, while the spacing between rows was 4 cm. Watering was carried out twice daily, in the morning and afternoon, depending on field conditions.

To maintain moisture during germination, the germination box was covered with moist burlap. Seed germination started approximately 8–10 days after sowing, after which the germinated seeds were transferred to polybags.

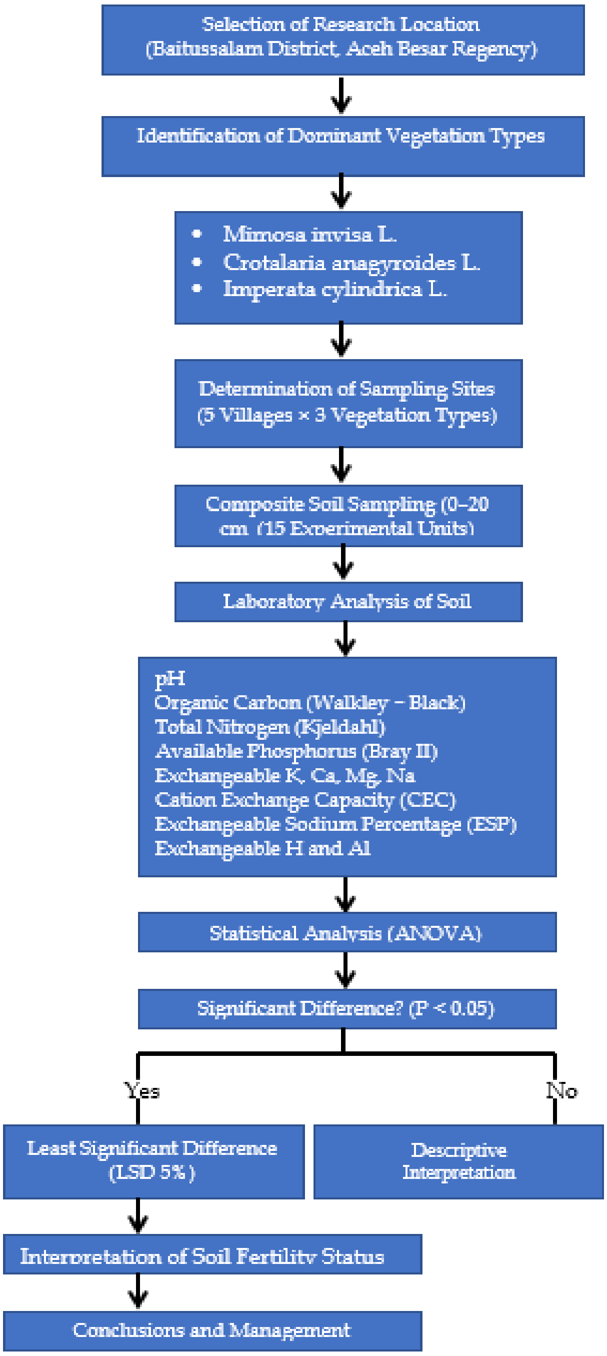

Figure 1. Research Flow Chart

Nursery Preparation and Transplanting

Topsoil was used as the planting medium for seedling growth. The soil was air-dried and sieved using a 5-mesh sieve before being placed into polybags. One day before transplanting, the planting media in the polybags were watered to ensure adequate moisture conditions.

Eight-day-old germinated cocoa seeds were then transplanted into the prepared polybags. The polybags were arranged at a spacing of 20 cm × 20 cm with a distance of 50 cm between rows. The arrangement of the polybags followed the experimental layout according to the treatment combinations.

Plant Maintenance

Routine maintenance activities included watering, weeding, fertilization, and pest and disease management. Watering was carried out twice daily in the morning and afternoon to maintain adequate soil moisture. Weeding was conducted manually by removing weeds growing inside the polybags.

Application of Forest organic fertilizer began 15 days after transplanting according to the assigned treatment concentrations and application intervals. To prevent pest and disease attacks, cocoa seedlings were sprayed once a month with Sevin 85 SP and Dithane M-45 at a concentration of 2 cc L^{-1} water.

Observation Parameters

Several growth parameters were observed during the study, including plant height, leaf number, and stem base diameter. Observations were conducted at 30, 60, and 90 days after transplanting (DAT).

Plant Height

Plant height was measured from 1 cm above the soil surface to the highest growing point of the seedling using a measuring ruler. Measurements were recorded at 30, 60, and 90 DAT.

Number of Leaves

The number of leaves was determined by counting fully opened leaves from the first leaf to the youngest fully expanded leaf. Observations were conducted at 30, 60, and 90 DAT.

Stem Base Diameter

Stem base diameter was measured using a micrometer screw gauge at approximately 1 cm above the soil surface. Measurements were performed at 30, 60, and 90 DAT.

Statistical Analysis

Data obtained from the observations were analyzed using analysis of variance (ANOVA) based on the factorial Randomized Block Design. When the treatments showed significant effects, mean comparisons were further analyzed using the Honestly Significant Difference (HSD) test at the 5% significance level.

Result and Discussion

Effect of Forest Organic Fertilizer Concentration on Cocoa Seedling Height

The analysis of variance showed that the concentration of Forest organic fertilizer had no significant effect on cocoa seedling height at 30 days after transplanting (DAT), but significantly affected seedling height at 60 and 90 DAT. The average cocoa seedling height under different fertilizer concentrations is presented in Table 1.

Table 1. Effect of Forest Organic Fertilizer Concentration on Cocoa Seedling Height.

Forest Organic Fertilizer Concentration	30 DAT (cm)	60 DAT (cm)	90 DAT (cm)
F0 (0 cc L^{-1} water)	18.67	24.54 a	27.45 a
F1 (1 cc L^{-1} water)	19.12	27.87 ab	31.22 ab
F2 (2 cc L^{-1} water)	19.85	30.12 b	34.12 b
F3 (3 cc L^{-1} water)	18.94	26.45 ab	29.76 ab
HSD 0.05	ns	3.21	3.87

Note: Means followed by the same letter within the same column are not significantly different according to the HSD test at the 5% significance level. ns = not significant; DAT = days after transplanting.

The results indicated that the application of Forest organic fertilizer at a concentration of 2 cc L^{-1} water (F2) produced the highest seedling height at both 60 and 90 DAT. At 90 DAT, seedlings treated with F2 reached an average height of 34.12 cm, which was significantly different from the other treatments. Meanwhile, the control treatment (F0) resulted in the lowest seedling height throughout the observation period.

The increase in cocoa seedling height observed in treatment F2 was presumably associated with the adequate availability of nutrients required for vegetative growth. Liquid organic fertilizers generally contain essential macro- and micronutrients that support physiological processes such as photosynthesis, cell division, and tissue formation. Nitrogen, in particular, plays an important role in stimulating stem elongation and leaf development. Adequate nutrient supply may improve metabolic activity and promote more vigorous plant growth.

However, increasing the fertilizer concentration to 3 cc L^{-1} water (F3) tended to reduce seedling height compared to the F2 treatment. This result suggests that excessive fertilizer concentration may create nutrient imbalance or osmotic stress around the root zone, thereby reducing nutrient absorption efficiency and inhibiting plant growth. Similar findings were reported by Gunawan et al. (2024), who stated that the effectiveness of liquid organic fertilizer depends greatly on the appropriate dosage and concentration applied to the plant.

Recent studies have demonstrated that vegetation composition strongly influences soil chemical properties through litter deposition, root exudation, and nutrient cycling. Mahmood et al. (2024) reported that land-use change significantly altered soil organic carbon storage and phosphorus fractions in tropical soils, indicating that vegetation plays a fundamental role in maintaining soil fertility. Similarly, Guillaume et al. (2017) found that changes in vegetation cover significantly modified phosphorus availability and distribution in highly weathered tropical soils. The results of this study indicate that the application of Forest organic fertilizer at an appropriate concentration can improve cocoa seedling growth during the nursery stage. The optimum concentration observed in this study was 2 cc L^{-1} water, which provided the most favorable conditions for vegetative growth.

Effect of Forest Organic Fertilizer Concentration on Leaf Number

The analysis of variance also revealed that Forest organic fertilizer concentration significantly affected the number of leaves at 60 and 90 DAT. Cocoa seedlings treated with 2 cc L^{-1} water (F2) consistently produced a higher number of leaves compared to the other treatments.

Table 2. Effect of Forest Organic Fertilizer Concentration
on Number of Leaves of Cocoa Seedlings

Forest Organic Fertilizer Concentration	30 DAT (leaves)	60 DAT (leaves)	90 DAT (leaves)
F0 (0 cc L^{-1} water)	5.12	7.45 a	9.12 a
F1 (1 cc L^{-1} water)	5.67	8.34 ab	10.45 ab
F2 (2 cc L^{-1} water)	6.02	9.76 b	12.23 b
F3 (3 cc L^{-1} water)	5.43	8.02 ab	10.11 ab
HSD 0.05	ns	1.22	1.67

Note: Means followed by the same letter within the same column are not significantly different according to the HSD test at the 5% significance level.

The increase in leaf number may be related to the improved availability of nutrients involved in leaf formation and chlorophyll synthesis. Nitrogen is an essential component in chlorophyll molecules and contributes directly to photosynthetic activity and vegetative growth. Adequate nitrogen supply supports the development of new leaves and increases photosynthetic efficiency, which subsequently enhances plant growth. Leguminous vegetation has been widely recognized for its ability to improve soil fertility through biological nitrogen fixation and high-quality organic residue inputs. Sukitprapanon et al.

(2020) reported that residues from leguminous plants significantly increased available nitrogen, phosphorus, and exchangeable bases in tropical sandy soils. Likewise, Zhang et al. (2020) demonstrated that organic inputs derived from plant biomass improved soil fertility more effectively than synthetic fertilizers by enhancing soil organic matter and nutrient retention.

Leaf formation is an important indicator of seedling vigor because leaves function as the primary site of photosynthesis. Increased leaf production may enhance carbohydrate synthesis and provide sufficient energy for plant growth and development Wanger, T. C., at al., 2021). Therefore, the greater number of leaves observed in treatment F2 indicates improved physiological activity and nutrient utilization efficiency in cocoa seedlings.

In contrast, the highest fertilizer concentration (F3) did not significantly improve leaf number and tended to produce lower growth responses compared to F2. This result confirms that excessive nutrient application does not always promote better plant growth. Nutrient imbalance caused by excessive fertilizer concentration may negatively affect physiological processes and reduce vegetative growth performance.

Effect of Fertilizer Application Interval on Cocoa Seedling Growth

The application interval of Forest organic fertilizer also influenced cocoa seedling growth. Seedlings receiving fertilizer applications at shorter intervals generally showed better vegetative growth than those treated at longer intervals. Frequent fertilizer application likely maintained more stable nutrient availability during the nursery period, thereby supporting continuous growth processes.

Table 3. Effect of Forest Organic Fertilizer Application Interval on Cocoa Seedling Growth

Application Interval	Seedling Height at 90 DAT (cm)	Number of Leaves at 90 DAT (leaves)
I1 (once every week)	33.21 b	11.87 b
I2 (once every two weeks)	31.12 ab	10.54 ab
I3 (once every three weeks)	28.45 a	9.34 a
HSD 0.05	2.87	1.12

Note: Means followed by the same letter within the same column are not significantly different according to the HSD test at the 5% significance level.

Appropriate fertilizer application intervals are important because nutrient demand increases continuously during seedling development. Regular nutrient supply may improve nutrient uptake efficiency and maintain active physiological processes such as photosynthesis and protein synthesis. Similar observations were reported by Lainawa and Rahmi (2024), who found that proper organic fertilizer application intervals improved vegetative growth in plantation crop seedlings.

However, excessively frequent fertilizer application may also lead to nutrient accumulation in the planting media. Therefore, determining the appropriate balance between concentration and application interval is necessary to achieve efficient fertilizer utilization and optimal seedling growth. Phosphorus availability is highly influenced by vegetation type, microbial activity, and organic matter decomposition. Li et al. (2025) showed that microbial functional shifts significantly enhanced phosphorus transformation under long-term nitrogen and water inputs. Likewise, studies by Mahmood et al. (2024) indicated that vegetation change altered phosphorus fractions and availability in tropical ecosystems.

Soil organic matter is a key determinant of nutrient availability and cation exchange capacity. Li et al. (2023) demonstrated that long-term organic matter accumulation significantly increased soil carbon and nitrogen pools while improving nutrient retention. Similarly, Tiefenbacher et al. (2023) emphasized that increasing subsoil organic carbon contributes to improved soil structure, nutrient storage, and long-term soil fertility.

Interaction Effect between Fertilizer Concentration and Application Interval

The interaction between fertilizer concentration and application interval showed varying effects on the observed growth parameters. Certain treatment combinations produced better growth responses compared to others, indicating that cocoa seedling growth was influenced by the combined effects of nutrient concentration and application frequency.

The best growth performance was generally observed in seedlings treated with 2 cc L^{-1} water combined with moderate fertilizer application intervals. This finding suggests that balanced nutrient availability and proper application timing are important factors in supporting vegetative growth during the nursery stage (Prasetyo, A., at al, 2020).

The interaction effect observed in this study demonstrates the importance of integrated nutrient management in cocoa seedling production (Yuliana, A.I., at al., 2023). Proper fertilizer concentration combined with suitable application intervals may improve nutrient use efficiency, enhance seedling vigor, and support sustainable nursery management practices.

Although numerous studies have examined the relationships between vegetation and soil fertility, limited information is available regarding the comparative effects of naturally dominant vegetation such as *Mimosa invisa*, *Crotalaria anagyroides*, and *Imperata cylindrica* on soil chemical properties in post-tsunami tropical coastal ecosystems. Consequently, this study aims to fill this knowledge gap by evaluating soil chemical characteristics and fertility status under these dominant vegetation types in Aceh, Indonesia.

Overall, the results of this study indicate that Forest organic fertilizer has considerable potential to improve cocoa seedling growth when applied at appropriate concentrations and intervals. The use of organic fertilizers may therefore serve as an environmentally friendly alternative for supporting sustainable cocoa cultivation systems.

Conclusion

This study demonstrated that dominant vegetation influenced several soil chemical properties and soil fertility status in the coastal soils of Baitussalam, Aceh Besar. Among the three vegetation types, *Mimosa invisa* generally exhibited more favorable soil chemical characteristics, including higher soil pH, organic carbon, total nitrogen, cation exchange capacity, and exchangeable calcium, whereas *Crotalaria anagyroides* showed the highest available phosphorus content and *Imperata cylindrica* was generally associated with lower soil fertility indicators. Vegetation type significantly affected available phosphorus and exchangeable calcium but had no significant influence on exchangeable potassium, magnesium, sodium, cation exchange capacity, exchangeable sodium percentage, or exchangeable hydrogen. The consistently high exchangeable sodium and exchangeable sodium percentage observed across all vegetation types indicate the persistent influence of seawater intrusion in the study area. Overall, the findings demonstrate that vegetation composition contributes to nutrient cycling and soil fertility development, with leguminous vegetation showing greater potential to improve soil quality. These results provide useful scientific information for sustainable soil management, vegetation-based land rehabilitation, and the restoration of tropical coastal ecosystems.

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Author Contributions
The author contributed fully to the conceptualization, experimental work, data analysis, manuscript preparation, and final approval of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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