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Soil Quality Assessment and Climatic Condition of Selected Forest Reserves in Terengganu, Malaysia

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ABSTRACT

This study was conducted across selected forest reserves in Terengganu, namely Jambu Bongkok, Merchang, Pelagat, and Bukit Kesing, with the aim of addressing the conservation needs of endangered timber tree species, specifically within the Dipterocarpaceae family. The research emphasizes the urgent need for comprehensive data to enhance conservation strategies for Terengganu's valuable timber species. By evaluating the soil quality and its climatic current status, the project provides crucial tools for the Terengganu Forestry State Department to implement effective conservation measures. Soil quality assessments, based on Amacher et al. (2007), indicated that coarse fragment content generally does not adversely affect soil quality in the forest reserves, except for Merchang. Compaction levels were found to be very low across all reserves, consistent with the characteristics of undisturbed tropical forests. The Soil Quality Index (SQI) varied from 15.79% to 26.32%, with Jambu Bongkok exhibiting low SQI due to its sandy soil, low cation exchange capacity, and low water-holding capacity.

Keywords: soil conservation, tropical forest, sustainable forest management

INTRODUCTION

Tropical forests alone have declined at an alarming rate of 0.5% per year, or 120 million hectares between 1990 and 2010 (Karam *et al*., 2022). Consequently, characterizing and managing deforestation remains a pressing environmental challenge in the tropics (Geldmann, 2023; Keenan *et al*., 2015; Gani, 2013). Forest loss is driven by diverse ecological and socio-economic factors, exhibiting significant spatiotemporal variations (Brown *et al*., 2024; Helmi *et al*., 2024; Jiang *et al*., 2023; Hairiah *et al*., 2020).

Terengganu, a state in eastern Peninsular Malaysia bordering Kelantan and Pahang, holds immense economic wealth due to its petroleum and gas reserves. It also harbours numerous valuable and highly endangered timber species. The Terengganu State Forestry Department is entrusted with the preservation, management, and development of the state's forest reserves. Balancing sustainable logging with biodiversity protection is crucial, considering the state's reliance on forestry revenue and the inherent dangers of illegal logging and processing activities to both endangered species and environmental health.

Furthermore, the absence of data on soil quality and climatic conditions impedes sound decision-making by authorities like the Terengganu Forestry State Department regarding forest management practices. Notably, tropical forests exhibit exceptional biodiversity, yet the lack of research on genetic variations leaves us blind to the true extent of this diversity and unprepared for potentially mitigating their loss.

Addressing these urgent knowledge gaps is the core objective of this research. By meticulously documenting the distribution and status of various timber stands within Terengganu's forests, we aim to provide crucial data, including geographical locations, that empowers effective conservation efforts for endangered species. Additionally, evaluating current soil quality and climatic conditions will equip forest managers with the necessary information to develop well-informed rehabilitation and conservation plans for degraded areas. The objective of this research is to document the effects of climate condition and soil quality on the growth of endangered tree species.

MATERIALS AND METHODS

Study area

This research was conducted within select forest reserves managed by the Terengganu Forestry State Department, Malaysia between the month of February till July 2023.

Soil profile

To study the characteristics of the current soil profile at each forest reserve, a 1-meter-deep soil pit was established (**Figure 1**). **Table 1** provides an overview of the study sites and sampled trees. Information meticulously collected from each pit included soil horizon delineation, colour descriptions, consistency assessments, root presence and activity evaluation, aggregate observations, and detailed descriptions of soil structure.

Table 1: Forest reserves

Forest reserves	Species	Location
Jambu Bongkok	*Melaleuca cajuputi* *Shoera materialis*	4°52'50"N 103°22'34"E
Merchang	*Shorea platycarpa*	5°04'21"N 103°14'27"E
Pelagat	*Shorea kuantanensis*	5°35'10"N 102°26'57"E
Bukit Kesing	*Shorea atrinoversa*	5°17'42"N 102°51'40"E

Soil quality samplings and analyses

Composite soil samples were collected from each designated forest reserve at a uniform depth of 0-30 cm. These samples were formed by randomly combining individual soil cores within each reserve. Following collection, the composite samples were stored in polyethylene bags and air-dried under room temperature for 48 hours at the laboratory facility. Standard soil analysis methods were employed to assess various soil parameters, including pH, electrical conductivity (EC), cation exchange capacity (CEC), nutrient content (including carbon, nitrogen, and individual nutrients), texture, bulk density, and moisture content (Gupta, 2007).

Climatic condition

Relative humidity, wind speed, and light intensity were measured at each sampling point using the Environ-meter model Kestrel 0850LBLK Impeller.

Statistical analyses

One-way analysis of variance (ANOVA) using SPSS Statistical Package was performed to compare mean values of soil analysis results between each forest reserve. Significant differences detected were further investigated using Tukey's HSD test. Correlation analyses were also conducted to examine the relationships and contributions of selected soil parameters in this study.

RESULTS AND DISCUSSION

Climatic condition

Table 2 summarizes the climatic conditions recorded at each sampling plot. Relative humidity ranged from 71.5% to 86.4%, indicating a generally humid environment across all research sites. Notably, Jambu Bongkok and Bukit Kesing forest reserves displayed higher light intensity compared to Merchang and Pelagat. This finding may be attributed to the greater openness and sunlight exposure within the former two reserves.

Table 2: Climatic condition

	Jambu Bongkok	Merchang	Pelagat	Bukit Kesing
Relative humidity (%)	83.8	71.5	84.5	86.4
Light Intensity (Lux)	3360	96	1366	3520
Wind Speed (fpm)	6.7	0	0	0
Temperature (°C)	27.4	31.8	27	27.4

Table 3 shows the characterization of soil profile. **Table 4** shows the selected physical and chemical properties of the soil profile. The results shows the class texture, soil acidity and salinity level of the soil. Jambu Bongkok has high sand content when compared to other forest soil. However, since Jambu Bongkok Forest Reserve is located near the seashore, it is expected that the soil are high in sand fractions. The soil type for this forest reserve was determined to be most likely Entisols Order. This is due to there being no visible layers in the soil profile of Jambu Bongkok. This soil might be either Siri Baging, Siri Jambu or Siri Pauh. As for Merchang, Pelagat and Bukit Kesing, the soil can be classed in Ultisols order as it exhibits low pH, which is an important characteristic of tropical weathered soils.

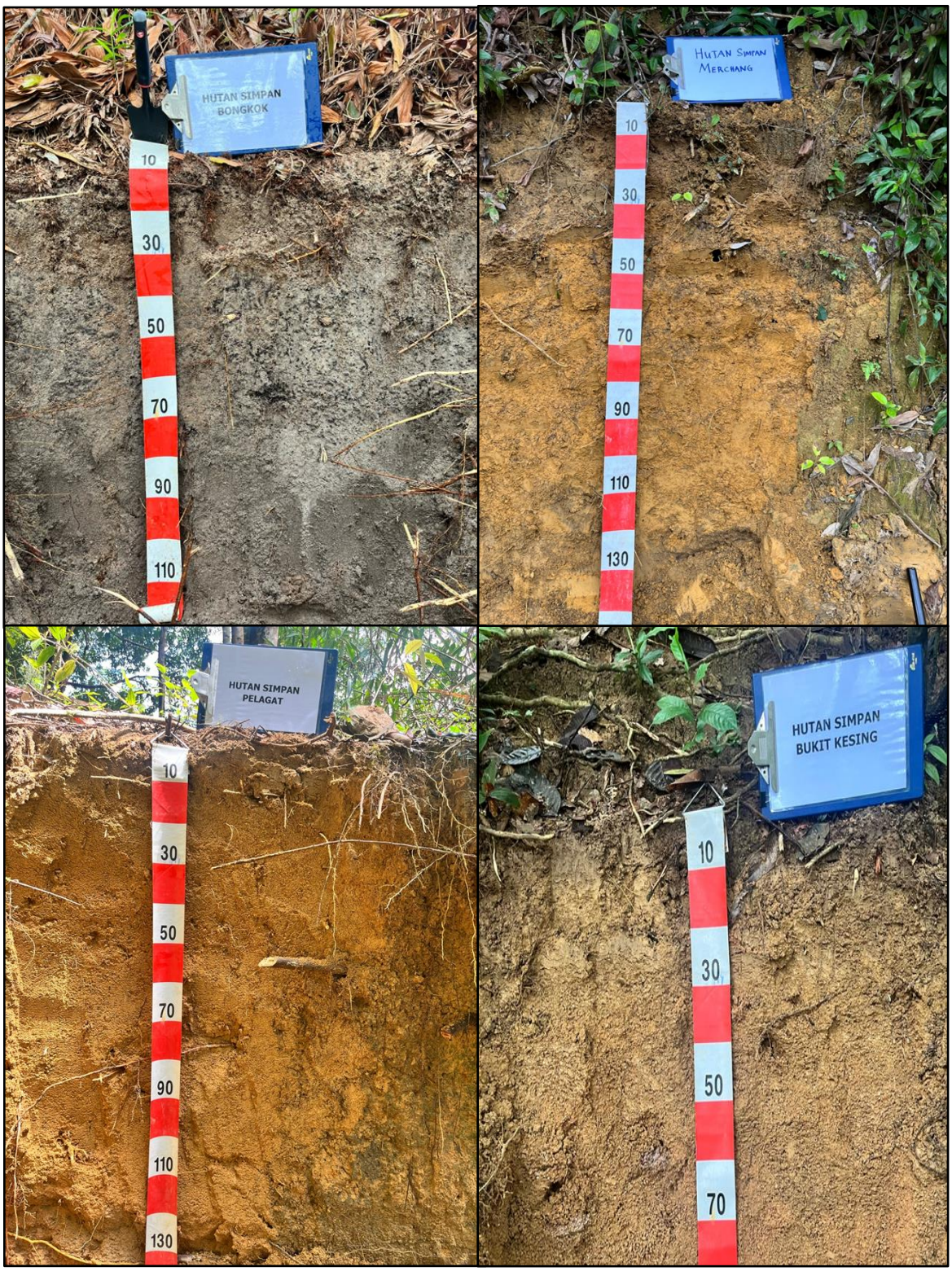


Figure 1: Soil profiles

Table 3: Characterization of the soil profile

Plot	Depth(cm)	Description
Jambu Bongkok	0-28	Light gray (10YR 7/2); sandy; single grained, few to many fine roots; excessively drained
	28-70	Gray (10YR 6/1); sandy; single grained; few to many fine and coarse roots; mottles; excessively drained
	70-118	Gray (10YR 7/2); sandy; single grained; few coarse roots; excessively drained
Merchang	0-9	Dark yellowish brown (10YR 4/6); Hairy roots visible; Sandy clay loam; friable; many coarse roots; wavy boundary
	9-32	Dark yellowish brown (10 YR 4/4); Sandy clay loam; sub-angular blocky; many coarse roots; wavy boundary
	32-85	Brownish yellow (10YR 6/8); sandy clay loam; angular to sub-angular blocky; few coarse roots; abrupt diffuse boundary
	85-130	Yellowish brown (10YR 5/6); sandy clay; subangular blocky; few coarse roots
Pelagat	0-8	Dark yellowish brown (10YR 4/6); Sandy loam; friable; many fine to coarse roots; abrupt diffuse boundary
	8-32	Brownish yellow (10 YR 6/8); Sandy loam; friable; sub-angular blocky; many fine to coarse roots; abrupt diffuse boundary
	32-85	Yellowish yellow (10YR 6/6); sandy loam; friable; angular to sub-angular blocky; many fine to coarse roots; diffuse boundary
	85-105	Brownish yellow (10 YR 6/8); sandy loam; friable; angular to sub-angular blocky; many fine to coarse roots; diffuse boundary
	105-130	Brownish yellow (10 YR 6/8); sandy loam; strong; angular to sub-angular blocky; few fine to coarse roots
Bukit Kesing	0-2	Yellowish brown (10YR 5/4); sandy loam; friable; many fine to coarse roots; clear smooth boundary
	2-10	Yellowish brown (10 YR 5/4); sandy clay loam; friable to sub-angular blocky; many fine roots; clear smooth boundary
	10-32	Yellowish brown (10YR 5/6); sandy clay loam; angular to sub-angular blocky; many very fine roots; diffuse boundary
	32-50	Brownish yellow (10 YR 6/8); sandy clay loam; angular to sub-angular blocky; many very fine roots; diffuse boundary
	50-65	Yellowish brown (10YR 5/8); sandy clay loam; angular to sub-angular blocky; many very fine roots; diffuse boundary
	65-80	Brownish yellow (10YR 6/8); sandy clay loam; moderate; blocky subangular blocky; diffuse boundary
	80-100	Yellowish brown (10 YR 5/8); sandy clay loam; strong subangular blocky; few fine roots

Soil Quality

Table 5 shows the selected physico-chemical properties of soil quality of the forest reserves. The data in **Table 5** is also presented individually in graphic format (**Graph 1-15**). Significant differences were observed in several soil quality parameters among the studied forest reserves. The coarse fragment content was notably higher in Jambu Bongkok A, Jambu Bongkok B, Pelagat, and Bukit Kesing compared to Merchang. This finding may be attributed to the lower organic matter content and waterlogged conditions characteristic of the Merchang sampling site. Similarly, bulk density displayed statistically significant variations, with higher values recorded in Merchang, Pelagat, and Bukit Kesing compared to both Jambu Bongkok plots. This observation likely stems from the higher sand fraction present in Jambu Bongkok soil,

leading to its higher porosity and lower bulk density. Soil pH ranged from 4.60 to 4.92 across all reserves, falling within the typical range for tropical soils (**Graph 3**). This coincides with the dominant presence of Ultisols and Oxisols, well-known for their high degree of weathering. Interestingly, electrical conductivity presented a contrasting pattern, with Merchang and Pelagat exhibiting the highest values among the investigated forests (**Graph 4**). This finding, alongside their proximity to water sources, raises the possibility of salinity issues, especially if electrical conductivity exceeds 4 dS m^{-1}.

Table 4: Selected physical and chemical properties of the soil profile

Plot	Depth(cm)	Clay (%)	Silt (%)	Sand (%)	pH	EC (dS m^{-1})
Jambu Bongkok	0-28	4.41	2.53	93.05	4.96	57.20
	28-70	2.43	3.34	94.23	5.37	19.47
	70-118	2.65	4.65	92.68	5.10	27.79
Merchang	0-9	29.73	16.92	53.33	4.81	29.65
	9-32	20.12	18.21	61.67	4.88	25.54
	32-85	32.26	16.8	50.8	4.63	14.17
	85-130	37.04	14.96	48.00	4.34	21.15
Pelagat	0-8	16.9	11.57	71.4	5.15	54.20
	8-32	15.83	15.83	9.65	5.25	27.72
	32-85	13.84	9.67	76.4	4.76	37.70
	85-105	18.87	12.56	68.5	4.38	42.30
	105-130	14.70	14.36	70.9	4.86	11.95
Bukit Kesing	0-2	16.01	12.99	70.9	5.01	50.6
	2-10	24.84	20.47	54.64	5.04	48.80
	10-32	30.50	21.07	48.4	4.45	45.10
	32-50	30.72	22.35	46.92	4.69	20.42
	50-65	22.43	20.68	56.85	4.67	20.94
	65-80	23.19	22.99	53.79	4.94	24.68
	80-100	20.7	17.10	62.15	5.15	15.26

Merchang forest emerged as the frontrunner in terms of organic matter content (**Graph 8**), thereby contributing to higher levels of total carbon, total nitrogen, and total sulfur (**Graph 5-7**). This will also have a positive impact on soil microbial population and enzymatic activity (Karam *et al*., 2013). Notably, cation exchange capacity, reflecting the soil's ability to hold exchangeable bases for plant uptake, demonstrated a different trend. Both Jambu Bongkok A and B plots, with their high sand fraction and low clay content, displayed the lowest CEC values compared to other forests (**Graph 9**). This highlights the significant influence of soil texture on CEC, with clay fractions playing a crucial role in retaining exchangeable bases.

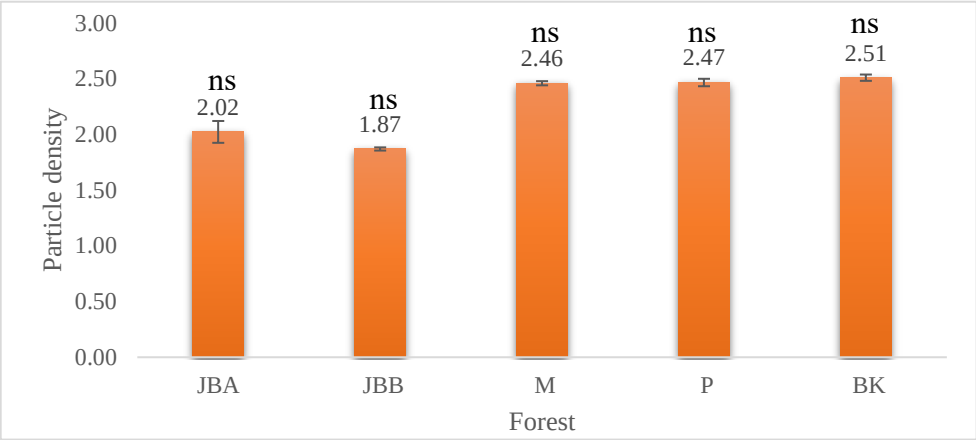
Regarding macronutrients, Pelagat and Bukit Kesing emerged as the leaders in potassium levels, followed by Merchang and then Jambu Bongkok (**Graph 10**). Similarly, calcium and magnesium concentrations peaked in the Pelagat reserve (**Graphs 11** and **12**). However, it's noteworthy that overall macronutrient levels across all forests were relatively low. This expected outcome can be attributed to the combined effects of low pH and limited cation exchange capacity, both common attributes of forest soils compared to those subjected to agricultural practices where fertilization replenishes nutrients. Additionally, it's vital to consider the presence of both available and non-available forms of nutrients within the soil matrix for plant uptake. Interestingly, exchangeable sodium levels deviated from the observed

pattern for other macronutrients. Jambu Bongkok forests exhibited significantly higher Na concentrations compared to the other studied areas (**Graph 13**). This suggests a potential influence of the reserve's coastal location and exposure to sodium-rich seawater. Analysis of aluminium, a non-essential element for plant growth, revealed no significant variations between the forest reserves (**Graph 14**). However, its presence impacts soil acidity and can indirectly affect cation exchange capacity. High levels of aluminium and hydrogen occupying the adsorption sites on soil colloids can limit the binding of exchangeable macronutrient bases, leading to leaching and potential loss. Therefore, monitoring soil pH before fertilizer application is crucial to avoid such wasted efforts and potential ecological risks. In situations where high acidity is detected, liming can be employed as a viable solution to improve the soil's capacity to hold and retain crucial nutrients for plant growth. Finally, phosphorus levels displayed a unique pattern, with Bukit Kesing exhibiting the highest concentration compared to Jambu Bongkok and Merchang, although statistically similar to Pelagat (**Graph 15**).

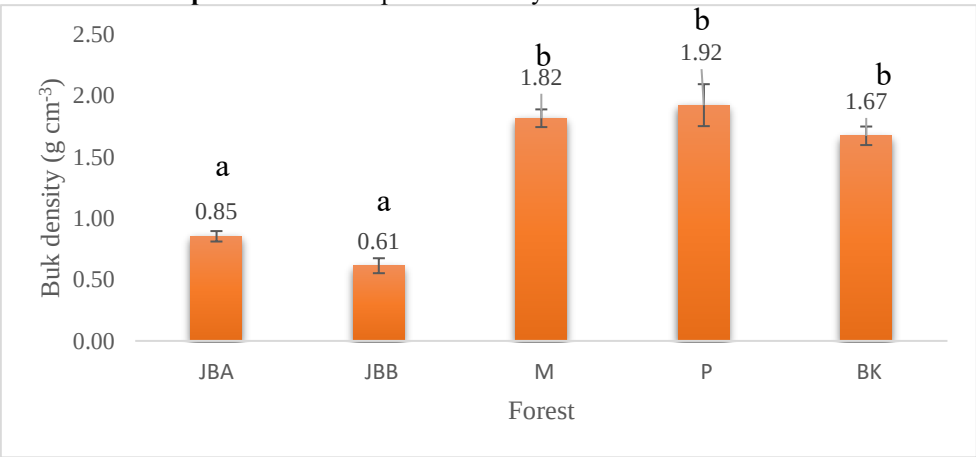
Table 5: Physico-chemical properties of soil quality of forest reserves of northen region in Terengganu

Parameters	Jambu Bongkok A	Jambu Bongkok B	Merchang	Pelagat	Bukit Kesing
Coarse fragment (%)	27.59 ± 5.43a	27.59 ± 5.43a	2.91 ± 0.27b	46.82 ± 0.98c	36.91 ± 3.63ac
Particle density (Dp)	2.02 ± 0.10ns	1.87 ± 0.01ns	2.46 ± 0.02ns	2.47 ± 0.03ns	2.51 ± 0.03ns
Bulk density ($g\ cm^{-3}$)	0.85 ± 0.04a	0.61± 0.06a	1.82 ± 0.07b	1.92 ± 0.17b	1.67 ± 0.08b
pH_w	4.60 ± 0.03a	4.69 ± 0.04ab	4.84 ± 0.11bc	4.88 ± 0.09c	4.92 ± 0.02c
EC ($dS\ m^{-1}$)	27.68 ± 0.65a	27.70 ± 1.07a	35.13 ± 1.49b	31.27 ± 0.86ab	19.47 ± 0.85c
TC[a] (%)	0.79 ± 0.09a	0.81 ± 0.08a	3.49 ± 0.19c	0.91 ± 0.01a	1.40 ± 0.14b
TN[b] (%)	0.01 ± 0.00a	0.01 ± 0.1a	0.14 ± 0.01c	0.02 ± 0.01a	0.05 ± 0.01b
S(%)	0.004 ± 0.00a	0.0014 ± 0.00a	0.015 ± 0.00c	0.002 ± 0.00a	0.005 ± 0.00b
C/N Ratio	55.83 ± 3.23a	84.02 ± 17.62a	24.63 ± 2.38b	49.78± 12.88ab	29.44 ± 1.23bc
C/S Ratio	204.10 ± 20.72ns	615.52 ± 90.85ns	235.00 ± 7.27ns	564.05 ± 224.39ns	282.43 ± 31.18ns
Organic matter (%)	1.02 ± 0.12a	1.05 ± 0.10a	4.52 ± 0.24b	1.18 ± 0.02a	1.82 ± 0.18c
CEC[d] ($cmol_c\ kg^{-1}$)	8.51 ± 0.37a	8.53 ± 0.34a	11.90 ± 0.52b	11.53 ± 0.69b	12.55 ± 0.74b
K ($cmol_c\ kg^{-1}$)	0.12 ±0.01a	0.12 ±0.01a	0.16 ± 0.02a	0.27 ± 0.05b	0.28 ± 0.03b
Ca ($cmol_c\ kg^{-1}$)	0.06 ± 0.01a	0.08 ± 0.01a	0.21± 0.03b	0.27 ± 0.00b	0.36 ± 0.03c
Mg ($cmol_c\ kg^{-1}$)	0.07 ± 0.01a	0.08 ± 0.02ac	0.15 ± 0.02 bc	0.14 ± 0.02ac	0.23 ± 0.01d
Na ($cmol_c\ kg^{-1}$)	15.07 ± 1.61a	17.33 ± 0.82a	8.75 ± 0.13b	8.03 ± 0.12b	7.64 ± 0.14b
Al ($cmol_c\ kg^{-1}$)	10.72 ±0.77ns	11.74 ± 1.40ns	12.77 ± 1.14ns	11.55 ± 0.79ns	9.45 ± 1.80ns
P mg kg^{-1}	15.05 ± 0.92a	13.47 ± 0.59a	14.73 ± 0.67a	17.40 ± 0.35b	19.07 ± 1.01c

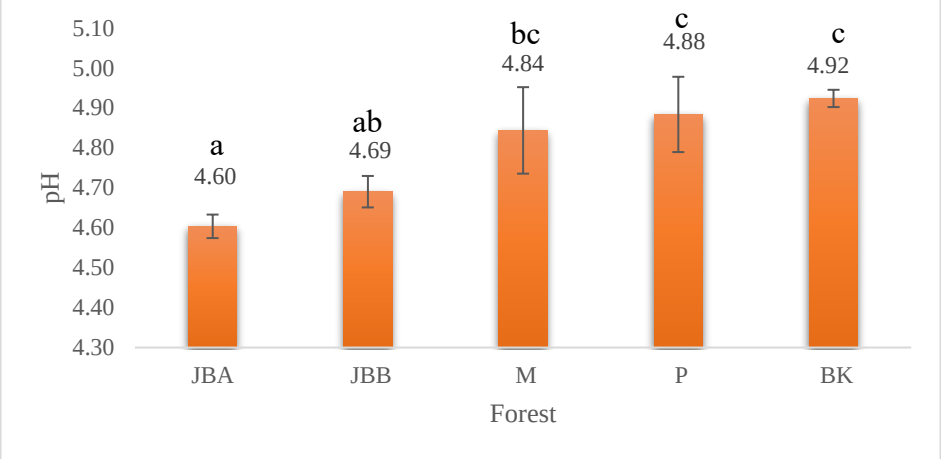
Note: Means with different letters indicate significant difference at $p<0.05$ between plots at the same soil depth using the Independent Student's *t*-test; TC[a], total carbon; TN[b], total nitrogen; EC[c], electrical conductivity; CEC[d], cation exchange capacity;



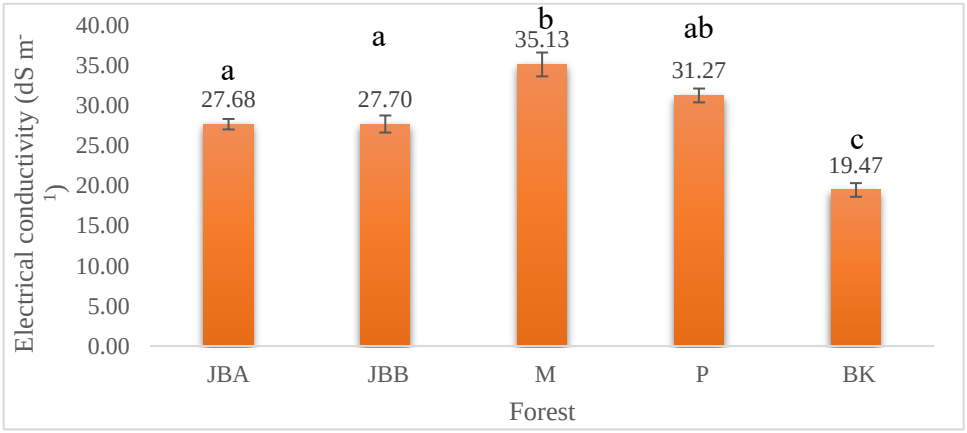
Graph 1: Total mean particle density of selected forest reserves.



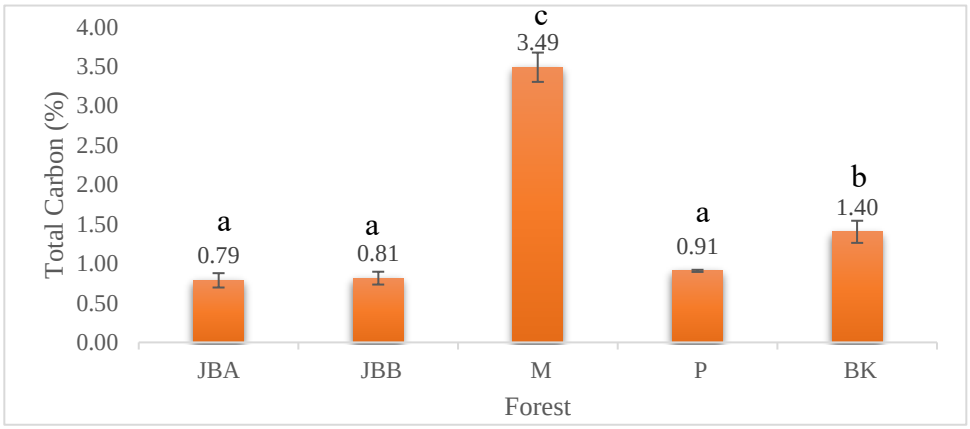
Graph 2: Total mean bulk density of selected forest reserves.



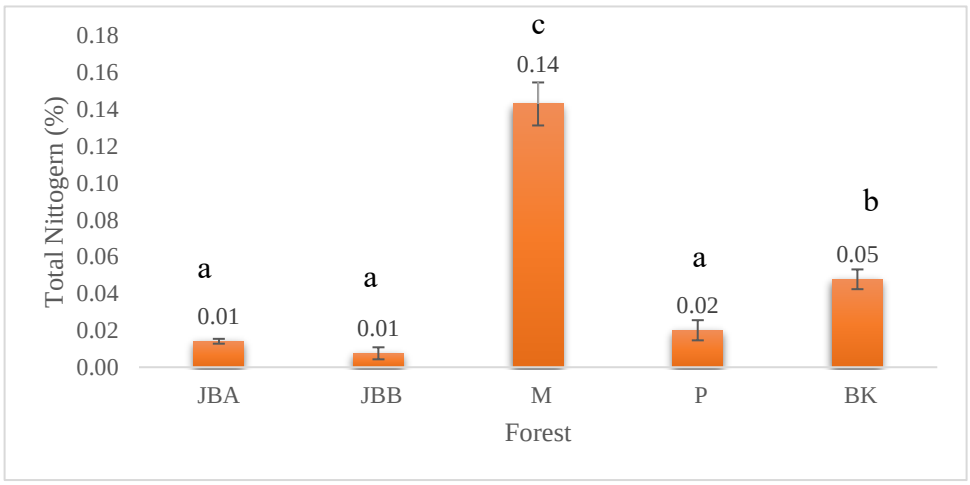
Graph 3: Total mean pH of selected forest reserves.



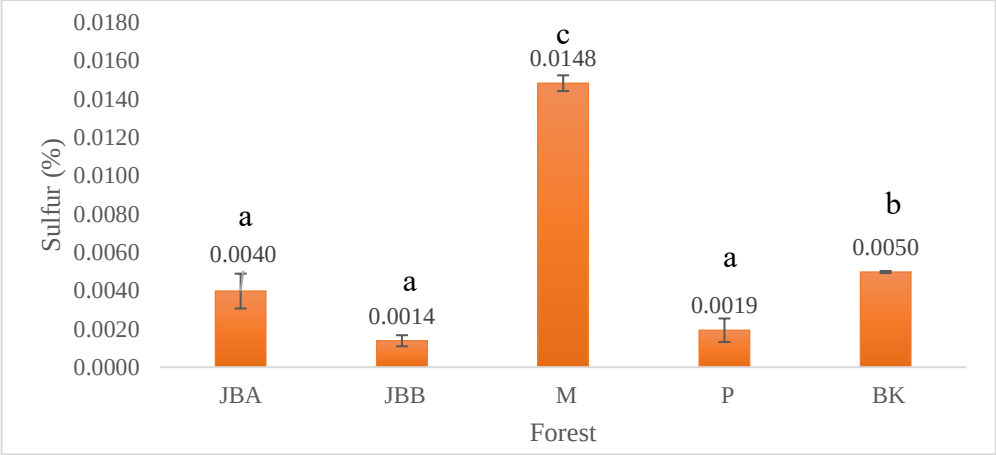
Graph 4: Total mean electrical conductivity (CEC) of selected forest reserves.



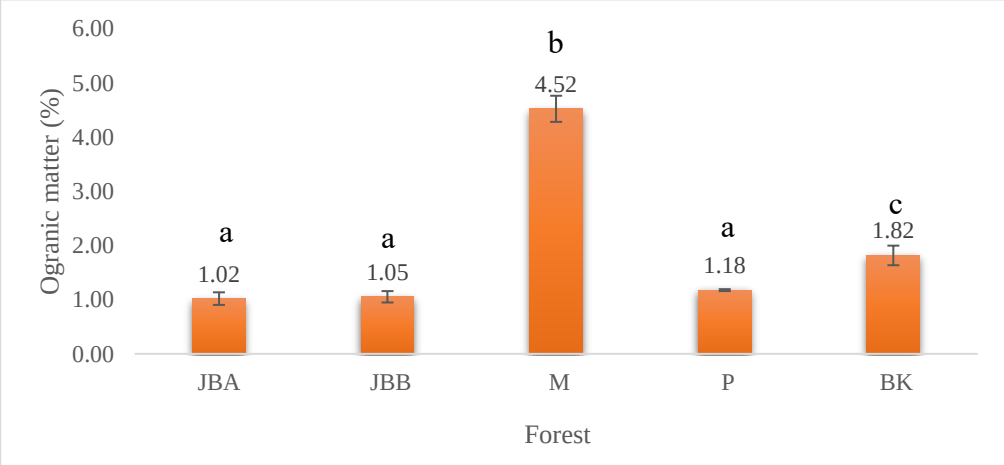
Graph 5: Total carbon mean of selected forest reserves.



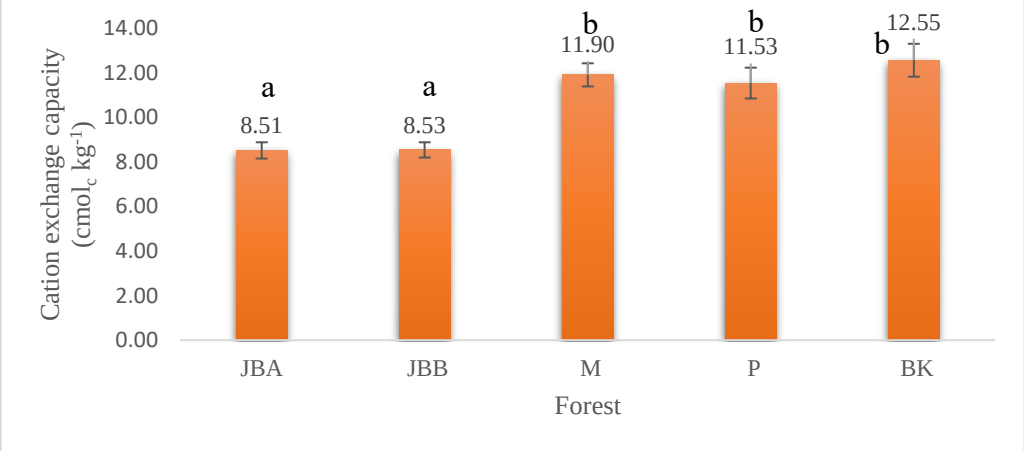
Graph 6: Total nitrogen mean of selected forest reserves.



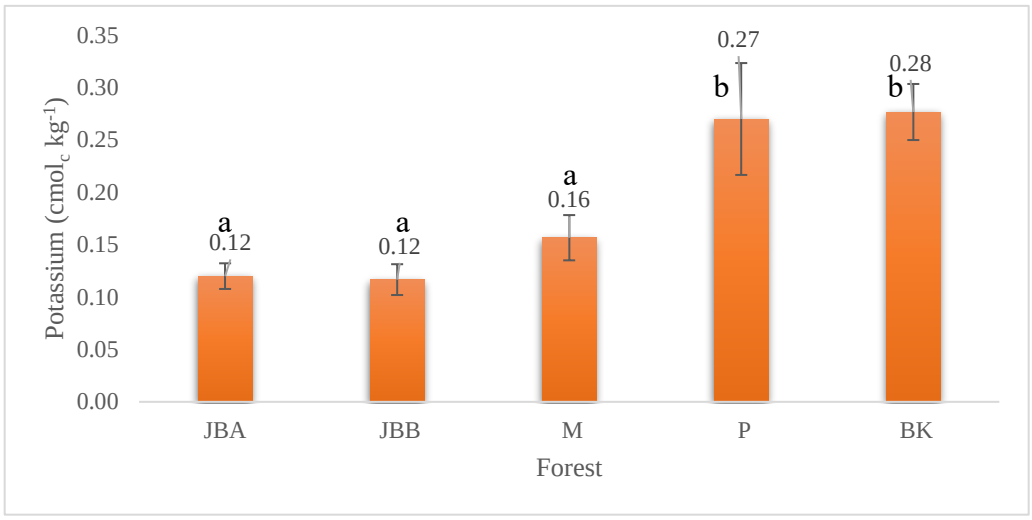
Graph 7: Total mean sulfur of selected forest reserves.



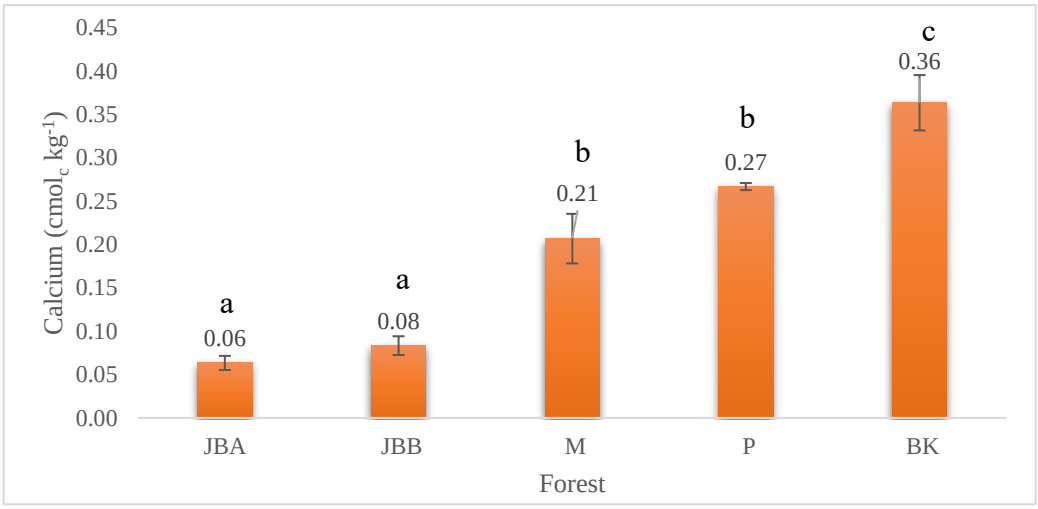
Graph 8: Total mean organic matter of selected forest reserves.



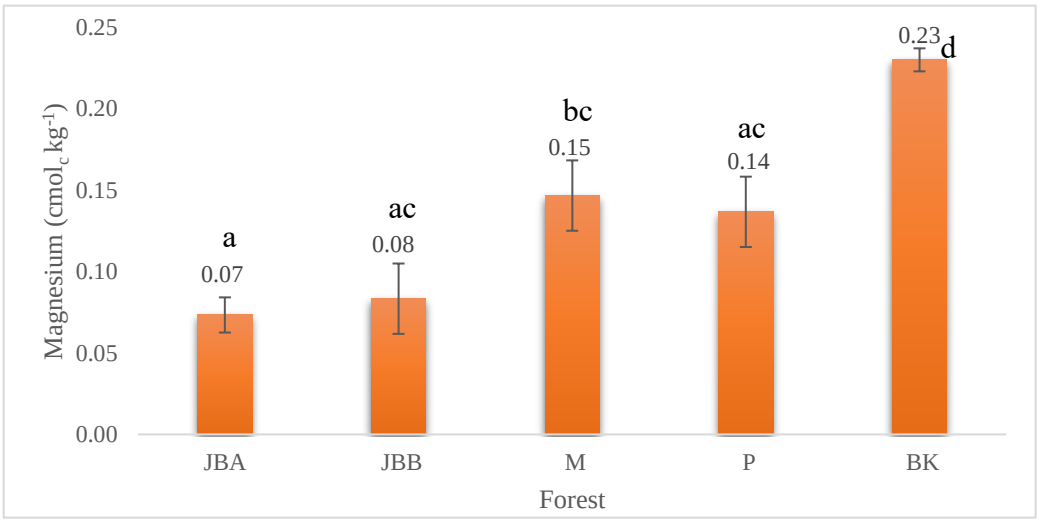
Graph 9: Total mean cation exchange capacity (CEC) of selected forest reserves.



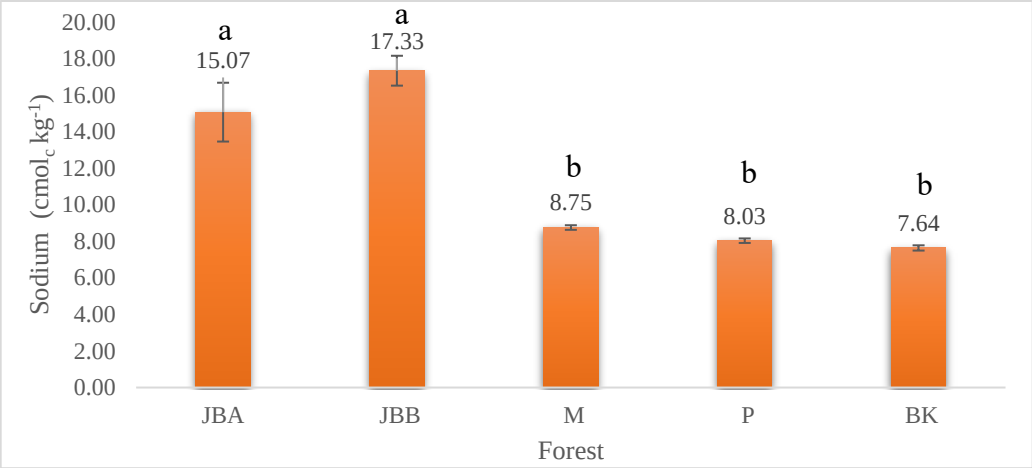
Graph 10: Total mean potassium of selected forest reserves.



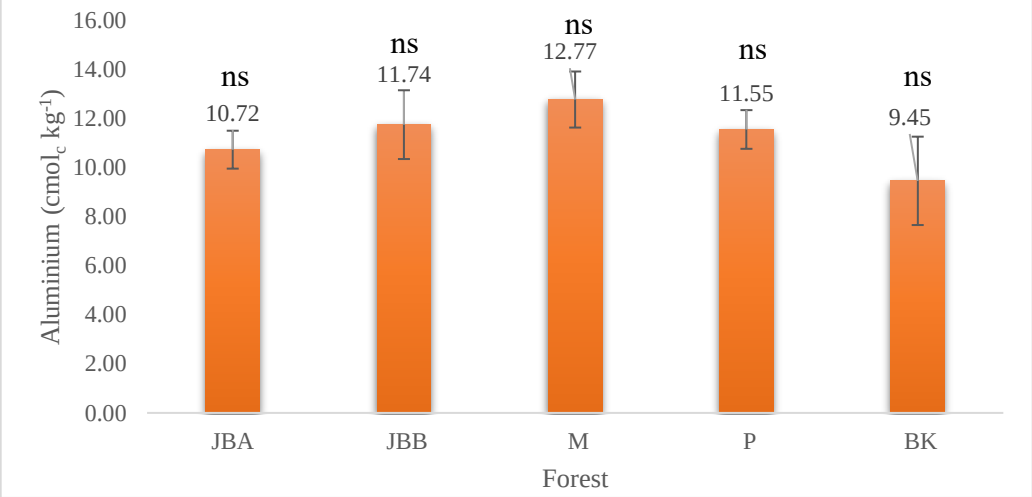
Graph 11: Total mean calcium of selected forest reserves.



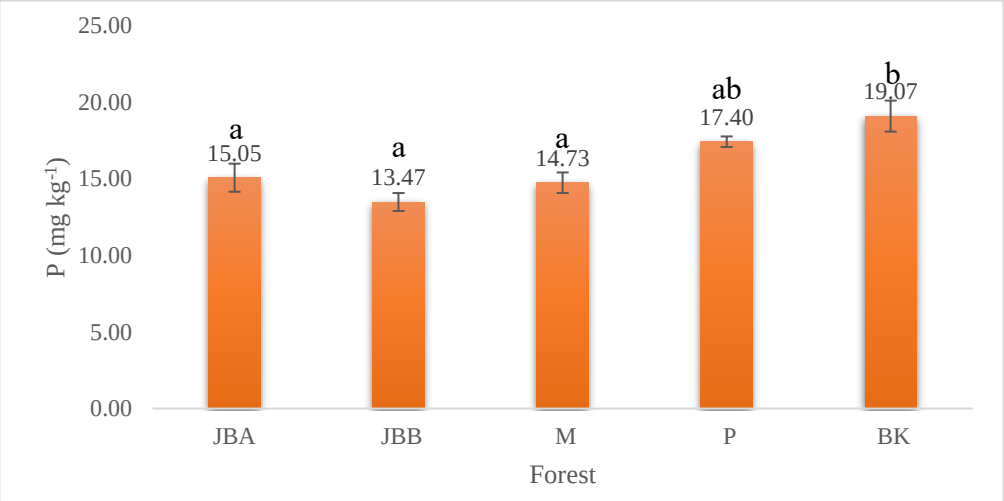
Graph 12: Total mean magnesium of selected forest reserves.



Graph 13: Total mean sodium of selected forest reserves.



Graph 14: Total mean aluminium of selected forest reserves.



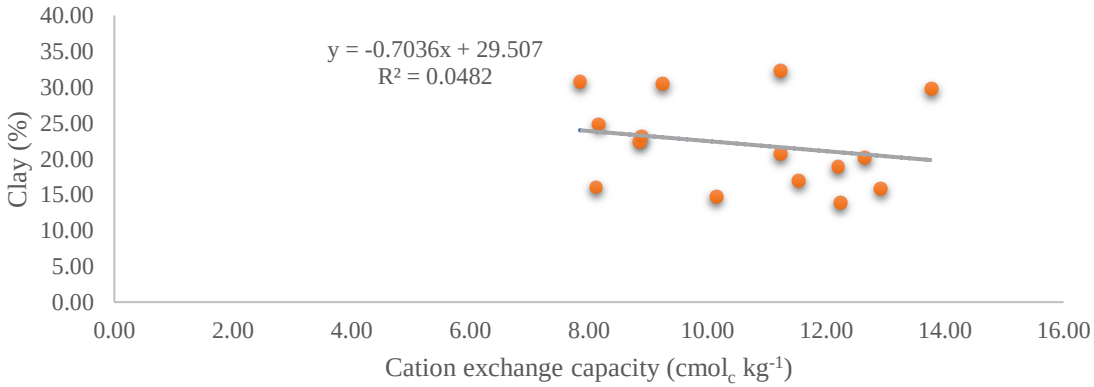
Graph 15: Total mean phosphorus of selected forest reserves.

Note: Different letters are significantly different following One Way ANOVA and Tukey post-hoc test ($p<0.05$). Note: JBA, Jambu Bongkok A; JBB Jambu Bongkok B; M, Merchang; P, Pelagat; BK, Bukit Kesing.

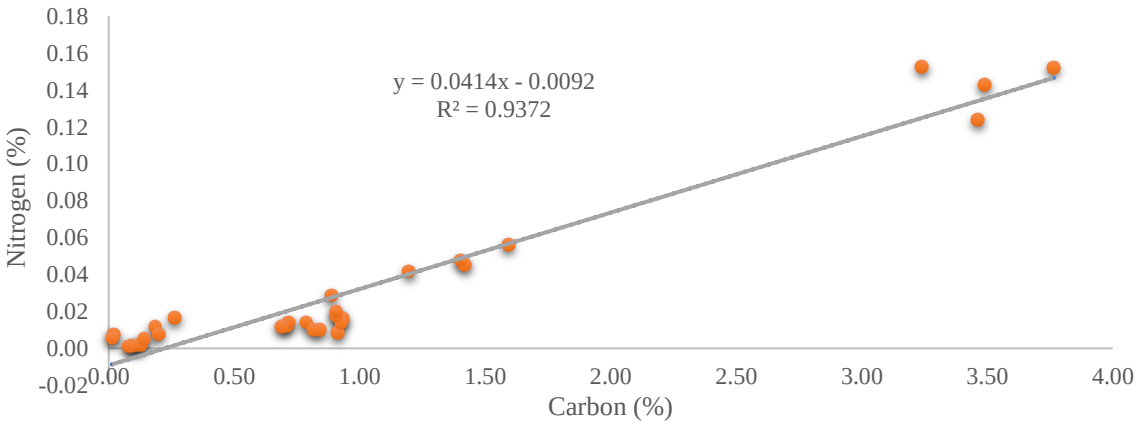
Correlation analyses

Correlation analyses were conducted to explore the relationships between three key soil parameters: clay fraction, organic carbon, and soil pH, with a focus on their influence on cation exchange capacity (CEC). This approach aimed to reveal how changes in one parameter might affect another, providing a deeper understanding of soil dynamics within the studied forest reserves. **Graph 16** depicts the relationship between clay fraction and CEC. Interestingly, the analysis revealed no clear positive or negative correlation between these variables. This unexpected finding could be attributed to several factors. Firstly, non-linear distribution of clay content across the reserves might be playing a role. Notably, Jambu Bongkok exhibits considerably lower clay content compared to the other forests with significantly higher fractions. Additionally, the inherently low CEC values observed in most of the studied soils could be influencing the observed linear regression pattern in the clay fraction-CEC correlation. Further investigation beyond clay content might be necessary to fully elucidate the factors governing CEC in these forest soils. Exploring the combined influence of clay with other significant soil components, such as organic matter and sesquioxides, could provide more insightful results.

The ratio of carbon and nitrogen plays important role in showing the rate of immobilization and mineralization of nutrients in the soil. Lower carbon and nitrogen ratio is good for soil fertility as carbon nitrogen ratio lower than 20 shows high mineralization of nutrients in the soil. It is recommended to maintain carbon and nitrogen ratio between the ratio of 20-30, where the rate of immobilization and mineralization is balanced. **Graph 17** shows that the correlation analyses between carbon and nitrogen show strong positive linear relationship the R^2 value of 0.9372 ($0 = R^2 = 1$). Increase in carbon significantly increase the nitrogen content (Halim *et al*., 2024; Khasanah *et al*., 2015). It is normal for nitrogen value to be less that carbon. Malaysian soils is highly weathered. The hot and humid tropical weather speed up the weathering and degradation of rocks and soils. **Graph 18** shows that there was positive relationship between pH and cation exchange capacity. The level of cation exchange capacity is highly influenced by pH level. Increase in pH level will increase cation exchange capacity.



Graph 16: Relationship between clay fraction and CEC at selected forest reserves.



Graph 17: Relationship between carbon and nitrogen at selected forest reserves.

Soil quality index

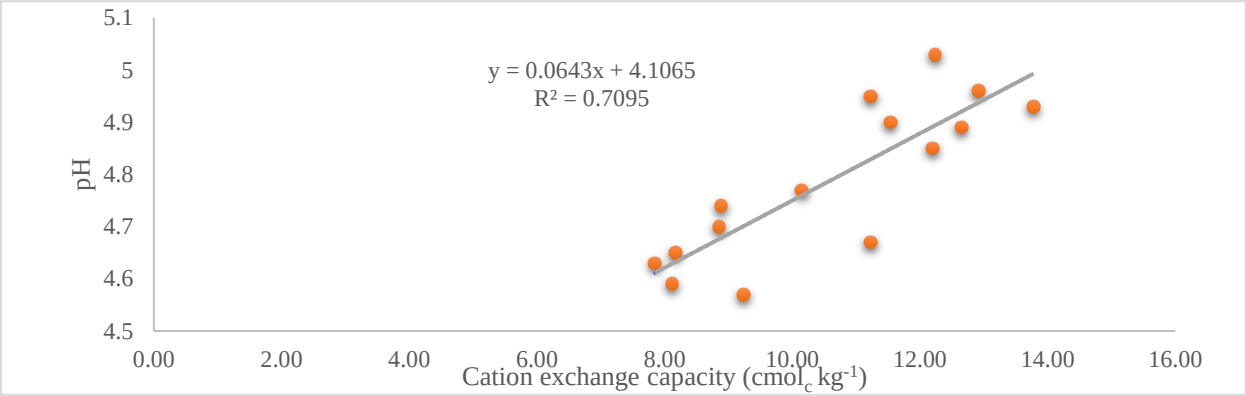
To assess the overall soil quality within the examined forest reserves, the Soil Quality Index (SQI) developed by Amacher et al. (2007) was employed. This index, created by the Forest Inventory and Analysis (FIA) in collaboration with the US Department of Agriculture's Forest Service, held specific appeal for our study due to its applicability in both tropical and temperate climates. While the standard SQI recommends evaluating 19 physical and chemical parameters, we adapted the methodology to accommodate available resources and analytical equipment limitations. **Table 6** presents the SQI scores calculated for the selected forest reserves in northern Terengganu.

Total SQI = ∑ individual soil property index values
SQI, % = (total SQI/maximum possible total SQI for properties measured) x 100

Based on the interpretations provided by Amacher *et al.* (2007) for the Soil Quality Index (SQI), the coarse fragment content is unlikely to have adverse effects on soil quality in any of the studied forests, except for Merchang. Similarly, the compaction levels across all reserves are very low and do not pose a significant threat. This finding aligns with the expected characteristics of undisturbed tropical forests (Karam *et al*., 2022; Aditya *et al*., 2020; Arifin *et al*., 2012). **Graph 19** shows the soil quality index ranges for all of the forest was between 15.79 up to 26.32%. Jambu Bongkok has low SQI which could be due to the nature of the soil properties which high in sand percentage and low cation exchange capacity, low nutrients and low water holding capacity.

Concerning soil pH, all reserves exhibited values categorized as moderately acidic, which falls within the typical range observed in Malaysian forests (Karam *et al*., 2012; Karam *et al*., 2011). Total carbon content varied across the reserves, with Merchang showcasing the highest level compared to the others. Forests in Jambu Bongkok, Pelagat, and Bukit Kesing presented total carbon values below 1, potentially indicating organic carbon loss through surface runoff or erosion processes. Notably, total nitrogen levels across all reserves were found to be low, suggesting a lack of organic nitrogen or potential nitrogen loss through leaching. Examining the macronutrients, potassium, magnesium, calcium, and sulfur levels were deemed insufficient in all studied forests (Aiza *et al*., 2022; Liu *et al*., 2024; Yamashita *et al*., 2015). Phosphorus levels displayed some variation, with moderate levels observed in

Jambu Bongkok A, Pelagat, and Merchang. In contrast, Jambu Bongkok B and Merchang exhibited deficient phosphorus levels in their soils.

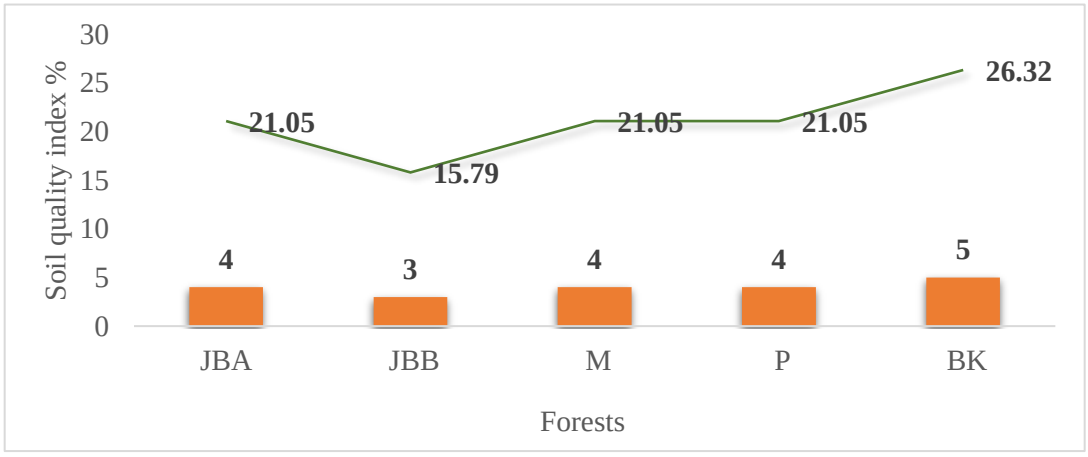


Graph 18: Relationship between pH and cation exchange capacity (CEC) at selected forest reserves.

Table 6: Soil Quality Index scores for each forest reserve

Parameters	JB A	JB B	M	P	BK	Maximum Total SQI
Coarse fragment	1	1	0	1	1	1
Bulk density	1	1	1	1	1	1
Soil pH	1	1	1	1	1	2
Total carbon	0	0	1	0	1	2
Total nitrogen	0	0	1	0	0	2
Potassium	0	0	0	0	0	2
Calcium	-1	-1	-1	-1	-1	2
Magnecium	0	0	0	0	0	2
Aluminium	1	1	1	1	1	2
Sulfur	0	0	0	0	0	1
Phosphorus	1	0	0	1	1	1
Sodium	0	0	0	0	0	1
Total	4	3	4	4	5	19
SQI%	21.05	15.79	21.05	21.05	26.32	

Note: JBA, Jambu Bongkok A; JBB Jambu Bongkok B; M, Merchang; P, Pelagat; BK, Bukit Kesing.



Graph 19: Soil quality index of selected forest reserves.
Note: JBA, Jambu Bongkok A; JBB Jambu Bongkok B; M, Merchang; P, Pelagat; BK, Bukit Kesing.

CONCLUSION

This report presents a preliminary assessment of soil quality and analyses for four forest reserves in northern Terengganu: Jambu Bongkok, Merchang, Pelagat, and Bukit Kesing. The investigations reveal that all four soils exhibit limited fertility, as characterized by low pH, cation exchange capacity (CEC), and nutrient content. These characteristics are consistent with highly weathered tropical soils, as evidenced by the classification of most samples as Ultisols, except for Jambu Bongkok which falls under the Entisols order. Furthermore, variations in carbon-nitrogen ratios suggest a greater extent of nutrient immobilization within the studied soils. Lower C/N ratios generally indicate higher rates of nutrient mineralization, favoring plant uptake. For instance, the high C/N ratio observed in Jambu Bongkok can be attributed to its low nitrogen content and dominance of sandy soil texture. Consequently, the calculated Soil Quality Index (SQI) values for these reserves are relatively low. This can be attributed to the combined effects of soil acidity, which limits nutrient availability, and low CEC, which restricts the soil's ability to retain essential elements. However, it's important to acknowledge that the soil samples were collected from undisturbed forest reserves, where a significant portion of nutrients may be bound within organic matter or unavailable for immediate plant uptake. This potentially underestimates the true fertility potential of these soils.

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