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Teak (*Tectona grandis*) growth as influenced by soil physicochemical properties and other site conditions in Ashanti region, Ghana

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Abstract

Teak, *Tectona grandis* (Verbenaceae), plantations are increasingly established in Ghana because of quick economic returns from its multi-purpose uses. *Tectona grandis* growth is, however, dependent on site conditions, and relationships have been established between various mineral nutrients, other fertility parameters and moisture of soils and teak growth. This study evaluated the influence of site factors, such as parent material, position of slope, gradient, aspect of slope, drainage, groundwater and erosion as well as soil physicochemical properties on teak growth in 10 forest reserves in Ashanti Region, Ghana. From 52 sites with teak age ranging from 3 to 32 years, soil profiles at 100 cm were dug and 20 teak stands that have dominant growth around the soil pit were surveyed. Height and diameters at breast height (DBH) and the site index for each site was determined by calculating the dominant height at the reference age of 18 years. From each site, site factors were surveyed and soil samples were collected at the depths of 0-5, 30-35 and 75-80 cm in the soil profile for physicochemical analysis. The results show that site factors influence and soil pH was not correlated to site index. Volumetric water content and maximum water holding capacity, total carbon, nitrogen, exchangeable Ca and Mg and eCEC showed positive significant correlations with site index. Soil moisture is an important factor for teak growth as soil organic matter contributes to increase the water holding capacity and water content in the soil. Also, nitrogen and exchangeable Ca and Mg are important factors of teak growth in the study sites.

Key words: Teak, *Tectona grandis,* tree growth, site index, site factor, soil physicochemical properties, soil moisture, N, Ca, Mg, Ghana.

Introduction

Large-scale industrial teak, *Tectona grandis* (Verbenaceae), plantations are increasing in Ghana because of the quick economic returns derived form its use for transmission and telephone poles, fence and furniture in Ghana, as well as being exported for foreign exchange [1]. Primary factors affecting teak growth are depth, drainage, texture, moisture status and fertility of both surface and subsurface soils [2]. There is need to select suitable sites for teak growth for an afforestation project.

Among many factors controlling the distribution of teak [3] are edaphic factors which suggests that growth of a teak is influenced by site conditions [4]. Several authors reported that mineral nutrition of soil affects growth of teak in Togo, Benin, Cote d'Ivoire, Liberia and Nigeria [5-8]. In the study of site variables controlling growth of teak in Ghana, Salifu [1] reported that height of teak was negatively correlated with sand content in the soil and was positively correlated with the silt and clay contents and silt and clay improve the nutrient and moisture storage of soils, which is important for teak growth. Also, some authors reported that some mineral nutrients and moisture affect growth of teak in West Africa [5-8]. However, there are few reports on the relationships between various mineral nutrients, other fertility parameters and moisture of soils and teak growth in Ghana. Watanabe *et al.* [9] reported that teak growth was responsive to soil moisture in Ghana. However, site variability of soil nutrient status was very limited, thus the importance of soil nutrient status on growth of teak could not be ascertained. This paper examined nutrient status in relation to teak growth and the influence of site variables controlling yield in order to be able to establish guidelines for the selection of high productive sites in Ghana.

Materials and Methods

***Description of study area and sampling sites*:** This study was carried out in Ashanti region of Ghana, located within 100 km from Kumasi city (6°40'N, 1°37'W). The Ashanti region falls within the equatorial climatic zone with the rainfall regime which is typical of the Moist Semi-deciduous forest zone. The study covered 52 sites in 10 forest reserves including the Forest Research Institute reserve and a private plantation (Fig. 1, Table 1). The study area is characterized by a relative constant temperature over the year with maximum monthly temperature ranging from 28.1 to 34.6°C and minimum monthly temperature between 21.3 and 23.1°C. Annual rainfall ranged from 925.8 to 1477.8 mm (Afram Headwater

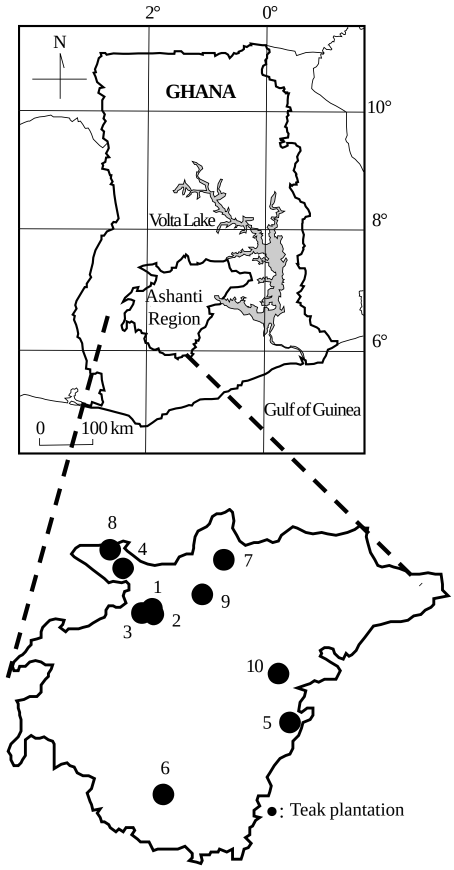


Figure 1. Location of study plantations of teak at the Ashanti region in Ghana.

Table 1. Brief description of the sampling location, forest and site number.

No.[1]	Location (district)	Forest reserve	n
1	Ofinso	Afram Headwaters	4
2	Ofinso	FORIG Research working circle	6
3	Ofinso	Opro River	3
4	Ofinso	Afrensu Brohuma	9
5	Ashanti-Akim North	South Fomangsu	2
6	Amansie-East	Private plantation	13
7	Sekyedumasi	Awura	4
8	Ofinso	Asubima	3
9	Secyere-East	Aboma	6
10	Ashanti-Akim North	Anum su	2

[1] Teak plantations are shown in numbers in Fig. 1.

forest reserve, FORIG Research Forest and Opro River forest reserve), 945.7-1312.1 mm (Afrensu Brohuma forest reserve), 1011.7-1567.7 mm (South Fomangsu forest reserve), 963.8-2188.7 mm (Private plantation), 925.7-1468.6 mm (Awura forest reserve), 973.2-1278.4 mm (Asubima forest reserve), 917.2-1572.8 mm (Aboma forest reserve) and 1108.8-1616.7 mm (Anum su forest reserve). The main rain season is from mid-March to the end of July, and the minor rainy seasons from September to mid-November. The natural vegetation was classified as moist semi-deciduous forest. The plantations are situated between 134 and 460 m above sea level. The parent materials of the study area are granite, sandstone and Tarkwaian series which consist of quartzite, phyllite, grits, conglomerates, schist and gray to black shady sandstone [10]. The soils of each site were classified Acrisols, Arenosols, Cambisols, Fluvisols, Gleysols, Leptosols and Lixisols [11].

***Field survey*:** Field survey was conducted at 52 selected sites of teak plantations from September 2002 to January 2003. Site factors surveyed included parent material, position of slope, gradient, aspect of slope, drainage, groundwater and erosion, which were classified according to the guidelines for soil description [12]. Soil profile at the depth of 100 cm was dug and prepared for the observation and sampling in each study site. Soil samples were collected from the depths of 0-5, 30-35 and 75-80 cm in the soil profiles for physicochemical analysis, depths of 0-5 and 30-35 cm for maximum water holding capacity analysis and each soil layer in 0-50 cm depth for saturated hydraulic conductivity analysis, a 100 cm^3 core sampler.

On each site, 20 teak stands, which have dominant growth around the soil pit were surveyed. Height and diameter at breast height (DBH) were measured. Dominant height was defined as the mean height of the 20 stands and the ages of the plantation trees used of the study ranged from 2 to 32 years. Site index was determined for each site by calculating the height at the reference age of 18 years, based on the log-log model of Drechsel and Zech[5], with the equation.

Site index = $H\,(18/\mathrm{age})^{0.522}$. The site index refers to the dominant height (H) at the age of 18 years.

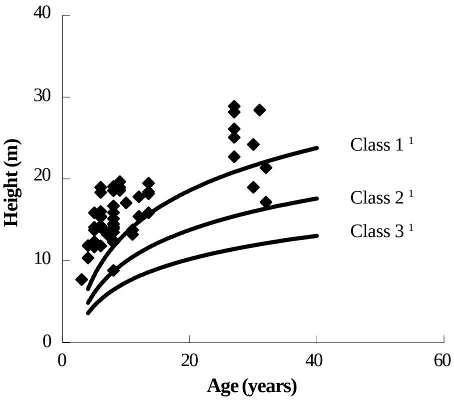
***Laboratory analysis*:** The volumetric water content (VWC) and bulk density of the soil were determined by core samples after they were oven-dried for 24 h at 105°C. Soil core samples were saturated with water for 24 h and the moist and dry weight (24 h 105°C) were obtained to calculate the maximum water holding capacity (MWHC) [13]. Soil core samples were saturated with water for 24 h, and the falling head method was used to determine the saturated hydraulic conductivity [13].

Air-dried soil samples were ground and passed through a 2 mm sieve for laboratory analysis. The glass electrode method (H_2O and KCl) was used to evaluate soil pH with a soil to solvent ratio of 1:2.5. Total carbon and total nitrogen contents were determined using a CN corder (MT-700; J-Science, Kyoto, Japan). Exchangeable base cations (exchangeable Ca, Mg, K and Na) were extracted from the soil in 1 M ammonium acetate [14]. Exchangeable Ca and Mg were determined by Inductively Coupled Plasma Emission Photometry (ICPS-2000; Shimadzu, Kyoto, Japan) and exch. K and Na were determined using an atomic absorption spectrophotometer (AS 680; Shimadzu, Kyoto, Japan). Exchangeable acidity was determined by titrating the 1 M KCl extract with NaOH [14]. Effective cation exchangeable capacity (eCEC) represents the sum of the amount of exchangeable bases and the exchangeable acidity. Available P was extracted using the Bray-1 method and determined by colorimetry using an UV/VIS spectrophotometer (V-530; Jasco, Tokyo, Japan)[15].

Data analysis: The analyses were performed with a statistical package SPSS Ver.11.0. Differences among site factors were compared using Tukey's least significant difference test and nonparametric test. Pearson's correlation coefficients were calculated to examine the relationship between the site index and the soil physicochemical properties. The concentration of exch. Ca, Mg, K, Na and acidity, eCEC and Bray-1 P exhibited skewed distribution, logarithmic transformation of their concentrations were used in correlation coefficients as recommended by Dahl *et al.* [16]. For the bulk density, VWC, MWHC, pH (H_2O and KCl), total carbon and nitrogen untransformed concentrations were used. To examine the relationship among the soil physicochemical properties, data were analyzed by the average values among the depths of 0-5, 30-35 and 75-80 cm.

Results

Tree growth: The plantation age, mean values for DBH, dominant height and site index are shown in Table 2. The comparison of the dominant height and the growth curves of site classes in northern Ghana [17] are shown in Fig. 2. Among the 52 sites, at 46 sites trees were higher than in Class 1, while at remaining 6 sites height was between Class 1 and Class 2.



[1] Class 1 to 3 according to Nunifu and Murchson [17].

Figure 2. Dominant height in the study sites, and regional site index curves in northern Ghana.

***Site factors*:** The comparisons of teak site index values by site factors are shown in Table 3, and the results show that there were no significant differences in the site index due to different parent material, position, gradient, aspect of slope, drainage, groundwater, erosion and soil classification.

Soil physicochemical properties: Soil physicochemical properties at different soil depth are shown in Table 4. Bulk density and VWC increased with increasing soil depth. Soil pH was slightly acidic, becoming increasingly acidic with increasing depth, while total C and N, exch. Ca, Mg and K were concentrated in surface soil. The comparison of soil chemical properties in the surface soil of the sites and plantations in other countries [4,6,18] are shown in Table 5. Soil pH, Bray-1 P and exch. Ca content of this study were comparable to other regions. Total N content of the study sites was lower than in other regions. Exchangeable Mg content was lower than in Tanzania and Eastern Java and similar to that in Liberia and Southern Sumatra. Exchangeable K content was lower than in Tanzania, Eastern Java and Southern Sumatra, and similar to that of Liberia.

The correlation between soil physicochemical properties at depths of 0-5, 30-35 and 75-80 cm and the site index are shown in Table 6. The VWC (depth of 0-5 and 75-80 cm) and the MWHC (depth of 0-5 cm) showed a positive significant correlation at 5 and 1% level, respectively. Total C (depth of 30-35 and 75-80 cm) and especially N (depth of 0-5, 30-35 and 75-80 cm) showed a positive significant

Table 2. Plantation age, mean DBH and dominant height, site index of teak in each study site.

Forest plot	Age yrs	Mean DBH (cm)	Dominant Height (m)	Site Index
1. Afram Headwaters Forest Reserve				
Ah1	5	15.0 ± 2.5	12.3 ± 1.3	24.1
Ah2	5	17.9 ± 3.2	15.6 ± 1.3	30.9
Ah3	5	16.9 ± 3.7	13.2 ± 1.9	26.8
Ah4	5	14.6 ± 2.3	12.2 ± 1.2	22.8
2. FORIG Research Forest				
Fr1	6	12.3 ± 3.2	11.8 ± 1.0	20.9
Fr2	6	14.7 ± 1.8	14.1 ± 1.2	25.0
Fr3	11	12.0 ± 2.7	12.8 ± 1.8	17.1
Fr4	11	11.3 ± 2.1	13.8 ± 1.3	17.8
Fr5	12	18.4 ± 2.9	17.7 ± 1.4	22.0
Fr6	12	19.3 ± 3.8	15.1 ± 1.3	19.0
3. Opro River Forest Reserve				
Or1	9	26.4 ± 3.4	19.5 ± 1.2	28.2
Or2	9	18.9 ± 3.1	18.8 ± 1.6	26.7
Or3	9	18.6 ± 2.7	19.0 ± 1.6	27.2
4. Afrensu Brohuma Forest Reserve				
Ab1	30	33.1 ± 6.6	24.5 ± 2.6	18.5
Ab2	30	27.9 ± 11.6	19.7 ± 2.6	14.5
Ab3	27	35.7 ± 8.4	22.9 ± 1.7	18.4
Ab4	27	43.2 ± 9.5	26.6 ± 5.3	21.1
Ab5	27	43.9 ± 13.5	26.7 ± 3.0	22.8
Ab6	27	38.6 ± 9.2	26.4 ± 3.0	20.3
Ab7	27	39.3 ± 13.7	28.2 ± 2.0	23.4
Ab8	3	9.5 ± 1.2	7.8 ± 0.7	19.6
Ab9	31	36.3 ± 6.2	27.5 ± 4.1	21.4
5. South Fomangsu Forest Reserve				
Sf1	8	21.5 ± 4.1	18.6 ± 2.0	28.3
Sf2	5	13.4 ± 2.6	14.1 ± 1.1	27.5
6. Private Plantation				
Dp1	8	16.0 ± 3.6	15.9 ± 2.3	24.2
Dp2	8	13.2 ± 2.2	14.5 ± 1.3	22.1
Dp3	8	19.1 ± 2.9	19.1 ± 1.9	29.1
Dp4	8	12.7 ± 2.7	12.3 ± 1.4	18.7
Dp5	8	14.6 ± 3.0	13.5 ± 1.4	20.6
Dp6	8	14.0 ± 2.4	13.9 ± 1.3	21.3
Dp7	8	11.2 ± 3.0	8.4 ± 1.6	13.5
Dp8	8	14.4 ± 3.3	14.1 ± 1.4	21.6
Dp9	7	13.4 ± 2.5	13.2 ± 1.3	21.7
Dp10	10	17.7 ± 4.5	16.9 ± 2.2	23.2
Dp11	8	20.5 ± 3.6	15.9 ± 1.6	23.1
Dp12	8	15.7 ± 2.3	12.6 ± 0.9	19.0
Dp13	8	18.1 ± 4.0	16.7 ± 1.5	25.5
7. Awura Forest Reserve				
Af1	13.5	19.8 ± 4.0	18.4 ± 1.4	21.4
Af2	13.5	23.3 ± 4.1	18.1 ± 1.6	21.1
Af3	13.5	20.6 ± 3.5	15.8 ± 1.3	18.4
Af4	13.5	27.7 ± 6.9	19.5 ± 1.8	22.6
8. Aboma Forest Reserve				
As1	5	15.1 ± 2.1	11.9 ± 0.9	23.4
As2	4	13.7 ± 2.7	10.7 ± 1.1	22.7
As3	4	13.3 ± 2.6	11.8 ± 1.1	25.9
9. Asubima Forest Reserve				
Am1	6	20.3 ± 4.8	15.3 ± 1.4	27.2
Am2	6	22.7 ± 3.4	18.3 ± 1.3	32.5
Am3	6	21.6 ± 3.6	19.0 ± 1.2	33.7
Am4	6	19.6 ± 3.7	15.4 ± 0.9	27.4
Am5	6	15.4 ± 3.3	14.2 ± 1.0	25.3
Am6	6	21.7 ± 4.4	16.0 ± 1.2	28.4
10. Anum su Forest Reserve				
An1	32	27.6 ± 7.1	21.6 ± 1.7	15.8
An2	32	23.6 ± 6.7	17.3 ± 1.5	12.7

DBH, diameter at breast height.
Data in columns the mean ± standard deviation (n = 20).

Table 3. Comparison of teak site index values by site factors.

	Category	n	Site index Mean	Site index SD[3]	
Parent Material	Granite	13	23.74	4.25	ns[4]
	Sandstone	24	22.45	5.11	ns
	Tarkwaian[1]	15	22.63	4.06	ns
Position	Crest	6	25.36	5.44	ns
	Upper slope	15	20.95	5.02	ns
	Middle slope	10	23.63	3.48	ns
	Lower slope	15	22.87	3.68	ns
	Bottom	6	23.52	5.69	ns
Gradient	Level	6	20.71	4.50	ns
	Gently sloping	9	22.87	5.60	ns
	Sloping	18	23.53	4.12	ns
	Strongly sloping	10	24.22	4.03	ns
	Steep	9	21.21	4.96	ns
Aspect of slope	E	10	21.67	4.90	ns
	SE	11	24.46	3.90	ns
	S	7	23.37	5.55	ns
	W	3	20.19	1.33	ns
	NW	5	25.73	1.89	ns
	N	9	23.33	5.82	ns
	NE	7	19.76	2.72	ns
Drainage	Well	33	22.88	4.76	ns
	Moderately well	8	23.02	3.78	ns
	Imperfectly	11	22.50	4.87	ns
Groundwater[2]	Not observed	46	22.75	4.66	ns
	Moderately deep	2	25.00	2.54	ns
	Deep	4	22.55	4.75	ns
Erosion	Sheet	40	22.77	4.44	ns
	Rill/Gully	12	23.00	5.23	ns
Soil classification FAO/Unesco	Acrisols	6	23.70	3.92	ns
	Arenosols	6	20.35	2.71	ns
	Fluvisols	5	21.98	5.61	ns
	Gleysols	3	26.91	0.27	ns
	Leptosols	2	21.47	3.91	ns
	Lixisols	17	23.37	5.57	ns
	Nitisols	13	22.43	4.15	ns

[1] Consist of quartzite, phyllite, grits, conglomerates, schist and gray to black shady sandstone.
[2] The depth of ground classes for water in the soil are M deep 50-100 cm, Deep: 100-150 cm and Not observed: >150 cm.
[3] Values of standard division of mean of site index.
[4] Not significant (P>0.05).

correlation at 5 and 1% level, respectively. Exchangeable Ca (depth of 0-5 cm), Mg (depth of 0-5 and 30-35 cm) and eCEC (depth 0-5 cm) showed a positive significant correlation at 5 and 1% level, respectively.

Discussion

Effect of soil moisture: The VWC in the soil has positive significant correlation with site index at 5 and 1% level, respectively (Table 6). The VWC is affected climate condition. However, the MWHC has positive significant correlation with the site index ($P<0.05$) (Table 6). In the study area, the amount of annual rainfall was 1246.6 ± 217.6 mm, which was less than the optimum rainfall for teak, i.e. 1500 - 2000 mm per year [19]. This result agrees with the findings of Salifu [1] who reported positive and significant correlation between dominant height of teak and silt and clay contents in Brong Ahafo region in Ghana, and considered that clay and silt improve the water holding capacity of the soil. Watanabe *et al.* [20] reported that the growth of *Pinus caribaea* was positively correlated with the VWC at Nigeria. Consequently, soil moisture is important to control the growth of teak, thus the water holding capacity in soil is important factor for teak growth.

Total carbon showed positive significant correlation ($P<0.05$) with the site index (Table 6). This can be because soil organic matter improves soil water holding capacity and reduces evaporative water losses in soil [21]. Similarly, total carbon showed positive significant correlation with the VWC and MWHC ($P<0.01$) and negative significant correlation with the bulk density ($P<0.01$) (Table 7). These results indicate that soil organic matter contributes to increase in water holding capacity and water contents in the soil. Therefore, soils rich in organic matter support good growth of teak. Consequently, soil organic matter is important factor for teak growth.

Wet depressions and poor drainages were observed to cause dieback or chlorosis of teak plantation in Thailand and Liberia [4, 6], thus, teak developed best on deep and well drainage soils, while limiting soil factors were waterlogged condition in India and Myanmar [22]. Although the sites used in this study included imperfect drainage at soil depth of 1.5 m, there were no significant differences among well and imperfect drainage and groundwater sites (Table 3). In our observation, more than half of the water logged or imperfect drainage sites had sandy loam texture. Mean value for the saturation hydraulic conductivity was 0.00814±0.01162 m s^{-1}, therefore these imperfectly drained sites might give significant advance effect on teak growth.

Effect of soil nutrition: Soil pH was not correlated with site index (Table 6). Teak occurred predominantly on soils with pH values ranging from 6.5 to 7.5 [3]. The pH values ranges of the study sites were 4.67 - 8.37 (depth 0-5 cm), 4.85 - 8.31(depth 30-35 cm) and 4.74 - 8.94 (depth 75-80 cm). pH values showed positive significant correlation with exch. Ca, Mg and K ($P<0.01$) (Table 7). It can be speculated that the rate of N mineralization becomes lowered in lower pH even in N rich soil, while the Ca, Mg and K contents are high in alkaline soils.

Total N has positive significant correlation with site index at 5 or 1% level (Table 6). Total N content of the study sites was lower than in other countries except Liberia. Drechsel and Zech [5] reported that relationship between site index and soil N nutrition was most clearly established in Togo, Benin, Cote d'Ivoire, Liberia and Nigeria. The result of Drechsel and Zech [5] was congruent with this study. Consequently, soil nitrogen is important factor of teak growth in Ghana.

Exchangeable Ca and Mg showed positive significant correlation with site index at 5 and 1% level, respectively (Table 6). Teak is a "calcicolous" tree species and requires a relatively large amount of calcium for its growth development [23, 24]. Mg is the component of chlorophyll and consequently, soil Ca and Mg are important factors of teak growth. Solla-Gullon *et al.* [25] reported that ash improved the nutrient status of *Pinus radiata* plantation, mainly in terms of Ca and Mg, these elements were limiting factor of forest production. Limiting factors for teak growth include low contents of Ca and Mg [19].

Table 4. The mean soil physicochemical properties at different soil depth (n = 52).

Depth (cm)	Bulk density ($Mg\ m^{-3}$)	VWC ($m^3\ m^{-3}$)	MWHC ($m^3\ m^{-3}$)	pH H_2O	pH KCl	TC ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)
0-5	1.25 (0.11)	0.16 (0.08)	0.47 (0.07)	6.47 (0.78)	5.43 (0.86)	14.3 (5.2)	1.3 (0.5)
30-35	1.51 (0.12)	0.17 (0.06)	0.39 (0.08)	6.26 (0.93)	4.88 (0.87)	4.5 (1.6)	0.4 (0.2)
75-80	1.56 (0.10)	0.24 (0.08)		5.80 (0.95)	4.43 (0.78)	3.2 (1.3)	0.3 (0.1)

Depth	Excangeable ($cmol_c\ kg^{-1}$)					eCEC	Bray-1 P
(cm)	Ca	Mg	K	Na	acidity	($cmol_c\ kg^{-1}$)	($mg\ P_2O_5\ kg^{-1}$)
0-5	6.17 (4.61)	1.23 (0.81)	0.15 (0.07)	0.06 (0.02)	0.16 (0.22)	7.76 (5.33)	8.45 (4.27)
30-35	2.03 (1.68)	0.62 (0.78)	0.08 (0.07)	0.06 (0.07)	0.44 (0.57)	3.23 (2.20)	2.93 (1.13)
75-80	1.48 (2.26)	0.95 (1.69)	0.12 (0.25)	0.09 (0.18)	0.90 (0.97)	3.54 (3.84)	2.45 (1.75)

VWC, volumetric water content; MWHC, maximum water holding capacity; TC, total carbon; TN, total nitrogen.
Number in parentheses shows standard deviation.

Table 5. Chemical properties of the soil in the topsoil derived from other teak studies.

Site	Depth (cm)	pH(H_2O)	Total N ($g\ kg^{-1}$)	Bray-1 P ($mg\ kg^{-1}$)	Exch. Ca ($cmol_c\ kg^{-1}$)	Exch. Mg ($cmol_c\ kg^{-1}$)	Exch. K ($cmol_c\ kg^{-1}$)	Reference
Present study sites	0-5	6.47±0.78	1.3±0.5	3.69±1.86	6.17±4.61	1.23±0.81	0.15±0.07	
Tanzania	0-10	6.50-6.65[1]	1.80-2.01[2]	8-12	3.52-3.72	1.28-1.58	3.71-4.14	Chamshama *et al.* [18]
Eastern Java	0-9	6.9	2.6		82.4	1.4	0.7	Tanaka *et al.* [4]
Southern Sumatra	0-5	4.9	1.9		3.6	1.2	0.4	Tanaka *et al.* [4]
Liberia	Top layer	3.75-6.91[3]	0.89-1.93[2]	1.8-8.5	0.65-3.60[4]	0.17-0.80[4]	0.06-0.19[4]	Zech and Drechsel [6]

[1]Ratio 1:2; [2]Kjeldahl; [3]$CaCl_2$; [4]$MgCl_2$, other pH (H_2O) and total N methods were not described in the paper; other exchangeable cations were extracted with NH_4Oac.

Table 6. Correlation between soil physicochemical properties and site index of teak (n=52).

Depth	Bulk density	VWC	MWHC	pH H_2O	pH KCl	TC	TN
0-5 cm	-0.0 0	0.305 *	0.311 *	0.180	0.205	0.244	0.277 *
30-35 cm	0.002	0.220	0.107	-0.080	-0.027	0.324 *	0.373 **
75-80 cm	-0.173	0.37 **		-0.15	-0.083	0.321 *	0.361 **

Depth	Log Excangeable					Log eCEC	Log Bray-1P
	Ca	Mg	K	Na	acidity		
0-5 cm	0.315 *	0.405 **	0.13	0.0 2	-0.232	0.331 *	-0.170
30-35 cm	0.1 6	0.308 *	-0.144	-0.211	0.003	0.1 8	-0.21
75-80 cm	0.212	0.252	0.026	-0.034	-0.03	0.148	-0.242

*P<0.05; **P<0.01. BD, bulk density; VWC, volumetric water content.
MWHC, maximum water holding capacity; TC, total carbon; TN, total nitrogen.

Table 7. Correlation matrix of the average values of soil physicochemical properties among the depth 0-5, 30-35 and 75-80 cm (n=52).

	BD	VWC	MWHC	pH H_2O	pH KCl	TC	TN	Exch.Ca	Exch.Mg	Exch.K	Exch.Na	Acidity	eCEC	Bray-1 P
BD	1.00													
VWC	-0.01	1.00												
MWHC	-0.48 **	-0.05	1.00											
pH H_2O	0.28 *	0.02	0.00	1.00										
pH KCl	0.19	0.03	0.09	0.96 **	1.00									
TC	-0.33 **	0.40 **	0.43 **	0.07	0.11	1.00								
TN	-0.25	0.43 **	0.39 **	0.06	0.08	0.97 **	1.00							
Exch.Ca	-0.09	0.48 **	0.27	0.59 **	0.66 **	0.52 **	0.51 **	1.00						
Exch.Mg	-0.05	0.56 **	0.09	0.46 **	0.45 **	0.44 **	0.46 **	0.89 **	1.00					
Exch.K	0.01	0.19	0.22	0.52 **	0.58 **	0.21	0.15	0.52 **	0.35 **	1.00				
Exch.Na	0.27	0.13	-0.18	0.25	0.10	0.11	0.18	0.06	0.28 *	0.06	1.00			
Acidity	-0.37 **	0.08	0.12	-0.73 **	-0.71 **	0.08	0.05	-0.38 **	-0.31 *	-0.18	-0.12	1.00		
eCEC	-0.13	0.55 **	0.25	0.49 **	0.55 **	0.55 **	0.54 **	0.98 **	0.94 **	0.50 **	0.14	-0.23	1.00	
Bray-1 P	-0.25	-0.13	0.10	-0.15	-0.20	-0.02	-0.09	-0.30 **	-0.25	0.21	0.16	0.22	-0.26	1.00

*P<0.05; **P<0.01. BD, bulk density; VWC, volumetric water content; MWHC, maximum water holding capacity; TC, total carbon; TN, total nitrogen.

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