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SITE VARIABLES CONTROLLING TEAK (*TECTONA GRANDIS*) GROWTH IN THE HIGH FOREST ZONE OF GHANA

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SALIFU, K. F. 2001. Site variables controlling teak (*Tectona grandis*) growth in the High Forest Zone of Ghana. Investigations of site variables controlling teak (*Tectona grandis*) growth are necessary in order to recommend guidelines for the selection of suitable and highly productive sites for industrial scale teak plantation establishment. Regression techniques were used to relate teak dominant height (DH) growth with soil textural properties under teak plantations in the High Forest Zone of Ghana. Soil samples were collected from 28 (1 x 1m) soil pits, in both A-horizon (about 0–20 cm) and B-horizon (about 20–60 cm), at 14 plots. Data on plot means were pooled for regression analyses. Dominant height was negatively correlated with sand ($r = -0.9047$, $p < 0.001$), and was positively correlated with silt ($r = 0.6103$) and clay ($r = 0.5998$) both at ($p < 0.05$). Multiple regression relationships indicate that DH can be accurately predicted ($R^2 = 0.82$, $p < 0.001$) from sand, or ($R^2 = 0.81$, $p < 0.001$) from silt and clay. It is recommended that prior to establishment of teak plantations, site evaluation should consider these relationships. Developed models can also be extended to other exotic tree species both in the study location and other comparable sites.

Key words: Growth - *Tectona grandis* - total nutrients - rooting depth - regression analysis

SALIFU, K. F. 2001. Pemboleh ubah tapak yang mengawal pertumbuhan pokok jati (*Tectona grandis*) di Zon Hutan Tinggi di Ghana. Siasatan mengenai pemboleh ubah yang mengawal pertumbuhan pokok jati (*Tectona grandis*) adalah sesuai untuk mengesyorkan garis panduan bagi pemilihan tapak yang sesuai dan sangat produktif untuk skel penubuhan ladang jati. Teknik regresi digunakan untuk mengaitkan pertumbuhan ketinggian unggul pokok jati (DH) dengan ciri-ciri tekstur tanah di bawah peladangan jati di Zon Hutan Tinggi di Ghana. Sampel tanah dikutip dari 28 lubang tanah (1x1 m), di kedua-dua horizon A (kira-kira 0–20 cm) dan horizon B (kira-kira 20–60 cm) di 14 petak. Data di petak dikumpulkan untuk analisis regresi. Ketinggian unggul berkorelasi secara negatif dengan pasir ($r=-0.9047$, $p< 0.001$), dan berkorelasi secara positif dengan lodak ($r=0.6103$) dan lempung ($r=0.5998$), kedua-duanya pada ($p< 0.05$). Perhubungan regresi berganda menandakan bahawa DH boleh diramalkan dengan tepat ($R^2=0.82$, $p<0.001$) daripada pasir, atau ($R^2=0.81$, $p<0.001$) daripada lodak dan lempung. Disyorkan bahawa terdahulu daripada penubuhan ladang jati, penilaian tapak mestilah mengambil kira mengenai perkaitan ini. Model-model yang dibangunkan dapat juga diperluaskan kepada spesies pokok eksotika yang lain di lokasi yang dikaji dan tapak-tapak lain yang boleh dibandingkan.

Introduction

Large scale industrial teak (*Tectona grandis* Linn. F.) plantation establishment is increasing in Ghana because of the rapid economic returns from teak. These plantations are also used to augment the declining roundwood log supplies available from natural forests to meet domestic and export demands. But the success of these plantations will largely depend on careful site evaluation and selection (Zech & Drechsel 1991). If planted off site, teak yield may decline and dieback caused by mineral or water deficiency may occur, especially during the first year of establishment (Akinsanmi 1976, Zech & Drechsel 1991).

The optimum rainfall for teak is between 1500 and 2000 mm per annum. Teak will grow and survive in a wide range of edaphic conditions. It requires well-drained sandy loam soils that are mildly acidic to neutral in the topsoil (Hedegart 1976, Bhoumik & Totey 1990). Teak thrives on parent materials derived from gneiss, granite, schists, slates, porous sandstones and limestone (Seth & Yadav 1959, Singh *et al.* 1986, Borota 1991, Weaver 1993). Limiting soil factors for teak growth include shallowness, hardpans, waterlogged conditions, compaction and heavy clays with low contents of Ca and Mg (Streets 1962). Teak has also shown sensitivity to phosphate deficiency (Murray 1961). Similarly, dry hilltops and wet depressions are unproductive sites for teak (White 1991, Zech & Drechsel 1991). Teak grows in its natural habitat at altitudes ranging from 800 to 1300 m above mean sea-level (Hedegart 1976). Zech and Drechsel (1991) and Drechsel and Zech (1994) hypothesised that nitrogen (N) nutrition, root depth (RD) and precipitation are the most important variables influencing teak growth in West Africa. Besides N, pH, calcium (Ca) and phosphorus (P) were also found to be important for variations in teak growth. However, the conclusions of these authors were based on research data collected over a wide geographical area.

This study tests the applicability of the above hypotheses within a uniform geographical area in Ghana, and provides information with regard to site conditions influencing teak growth within this area. The objectives were to investigate site variables controlling teak growth, and to recommend guidelines for the selection of highly productive sites for this species in the study region. This was accomplished by investigating soil total nutrients under teak plantations and presenting various regression models for teak growth in Ghana.

Materials and methods

Study sites at Bosomoa, Tain II and Yaya forest reserves were purposely chosen on the basis of perceived similarities in geology, topography, drainage, stocking and management history. Ages of the plantations used for the study ranged from 15 to 29 y. Fourteen teak plantations were each represented by one randomly located 20 × 20 m temporary sample plot (Aborisade & Aweto 1990, Zech & Drechsel 1991). Data for model analysis were collected from two (1 × 1 m) soil pits within a plot to estimate plot means, which were then pooled for regression analysis.

Dominant heights (DH) of four trees were measured using a Suunto clinometer, on each plot. Dominant height, is defined as the average height of the tallest 100 trees per hectare (Friday 1987, Keogh 1982). For this study, plots were 0.04 ha, and DH was estimated from the average height of 4 trees in a plot. Dominant height is a good indicator of a site's potential for productivity, and is also reasonably independent of stocking density (Friday 1987).

The soils are Oxisols and divided into two great soil groups: Savanna and Forest Ochrosols. Savanna Ochrosols, referred to as Haplic Acrisol (FAO/UNESCO 1988), occurs in Bosomoa. These soils are inherently deficient in P and N; despite this, they are able to support excellent plant growth in the northern savanna zone (Boateng 1966). Forest Ochrosols, referred to as Haplic Ferralsols (FAO/UNESCO 1988), occurs in Tain II and Yaya. A complete description of study sites, survey procedures and laboratory analyses are given in Salifu and Meyer (1998).

Data analyses

Soil total nutrients under teak were computed for Bosomoa, Tain II and Yaya based on uniform soil depth, horizon surface, percentage coarse fragments and bulk density per hectare.

Total nutrient content is expressed mathematically as

$$\begin{aligned}&\text{Total nutreint content (kg ha}^{-1}) = \\ &\quad [\text{Nc (eq kg}^{-1}) \times \text{weight of soil (kg ha}^{-1})] \\ &\quad \times \text{ equivalent weight(kg eq}^{-1}) \qquad [1]\end{aligned}$$

$$\begin{aligned}&\text{Nc (eq kg}^{-1}) = \\ &\quad \text{Nc (eq / 100)} \times 10 \qquad [2]\end{aligned}$$

$$\begin{aligned}&\text{Nc (eq/100 g)} = \\ &\quad \text{Nc meq / 100} \times \text{eq / 1000 meq} \qquad [3]\end{aligned}$$

$$\begin{aligned}&\text{Weight of soil (kg ha}^{-1}) = \\ &\quad [h - (h \times CF / 100)] \times Db \times \text{kg / 1000g} \times [A \times 10^{8}]\ \text{ha}^{-1} \qquad [4]\end{aligned}$$

where

Nc = nutrient concentration
h = thickness of soil horizon (cm)
CF = coarse fragment (%)
Db = bulk density (g cm^{-3})
A = area (cm^2) = 1 ha

Total nutrients, expressed as kg ha^{-1} in this study, gives an indication of the amount of nutrients available to be exploited by plant roots, and a reflection of stand growth. Previous analysis of soil nutrients examined concentrations of elements (Salifu & Meyer 1998).

Regression analysis using the backward elimination procedure of variable selection was used to model DH as a function of sand, silt and clay at the 0.05 significance level. Soil chemical properties were also considered for regression analysis. Soil data from the three study locations were pooled to model DH according to the coefficient of determination of their corresponding regression equations (Manrique & Jones 1991). SPSS version 6.1 was used for the regression analyses.

Results

Data used for regression analysis are presented in Table 1. The soil data from the three study locations were grouped using R^2 as the grouping criterion as follows: Group 1 ($R^2 > 0.50$) and Group 2 ($R^2 < 0.50$). Thus soil data were partitioned according to strong ($R^2 > 0.50$) and weak ($R^2 < 0.50$) predictor variables to reduce the variability in predicting DH for the three locations. Further analyses involved Group 1 ($R^2 > 0.50$). The results and discussion of this paper are focused on Group 1.

Table 1. Sample size (n), mean, range and coefficient of variation (CV%) for DH, sand, silt and clay

Variable[a]	n	Mean	Range		CV%
			Lower	Upper	
DH	14	26.09	21.35	30.76	10
Sand	14	62.52	31.76	87.20	27
Silt	14	23.66	10.68	39.78	45
Clay	14	13.98	8.71	29.26	52

[a] DH (m), sand, silt and clay (%).

Soil properties that met the significance criterion for inclusion into predictive models were sand, silt and clay (Table 1). The average age of the plantations for the study was 25 y (cf. Table 1 in Salifu & Meyer 1998). Dominant height at this age varied from 21.35 to 30.76 m (26.09 m) (Table 1). Other soil properties that did not meet the criterion for inclusion into predictive models are presented in Table 2. Phosphorus levels were low and ranged from 15 to 28 kg ha^{-1} (20.33 P kg ha^{-1}) at Yaya and from 22 to 118 kg ha^{-1} (68 P kg ha^{-1}) at Bosomoa. Calcium ranged from 1195.32 to 5643.29 kg ha^{-1} (3380.34 Ca kg ha^{-1}) at Yaya (Table 2).

Table 2. Pooled means of soil total nutrients by location and horizon thickness

		Mean nutrient content (kg ha^{-1}) (standard error of mean)					
		Available	Exchangeable cations				
Location	Horizon thickness (cm)	P	N	K	Mg	Ca	Na
Bosomoa	45.80	68.00 (19.11)	2993.60 (442.10)	285.28 (40.70)	397.85 (65.98)	2514.59 (452.33)	33.12 (10.11)
Tain II	45.00	27.00 (9.83)	5200.66 (923.05)	303.50 (49.46)	723.26 (123.75)	4192.36 (622.65)	34.08 (11.01)
Yaya	37.33	20.33 (4.48)	2808.33 (915.97)	218.29 (80.51)	268.57 (115.99)	3380.34 (1284.62)	11.24 (6.01)

Predicted models of DH for the three locations are summarised in Table 3. The assumptions of normality of residuals were met by model 1 as indicated by the normal probability plot of residuals (Figure 1). The assumptions of homoscedasticity were also met as shown by the null plot in the scatter plot (Figure 2). These assumptions were similarly met by model 2 (plots not presented). DH was predicted using sand (model 1) or silt plus clay (model 2) (Table 3). Model 1 and model 2 accounted for up to 82 and 81% of the variation in teak DH growth across the study locations respectively (Table 3). Dominant height was negatively and significantly correlated ($r = -0.9047$, $p < 0.001$) with sand fraction and was positively and significantly correlated with silt ($r = 0.6103$) and clay ($r = 0.5998$) fractions (both at $p < 0.05$).

Table 3. Regression coefficients and related statistics for models of DH at Bosomoa, Tain II and Yaya

		Regression coefficients			Goodness of fit statistics		
		Independent variables					
Model	Intercept	Sand	Silt	Clay	R^2	SE*	n
1	34.65[a]	-0.14[a]	-ϕ	-	0.82[a]	1.13	14
2	20.93[a]	-	0.12[c]	0.17[c]	0.81[a]	1.20	14

*SE = standard error of the estimate for the model.

[a] = p <0.001.

[c] = p < 0.05.

ϕ Blanks in the table represent variables not considered in the model.

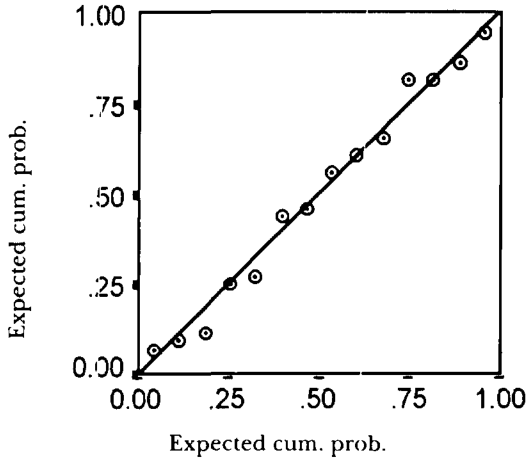

Figure 1. Normal probability plot of residuals for the relationship between dominant height growth of teak and sand at Bosomoa, Tain II and Yaya forest reserves in Ghana

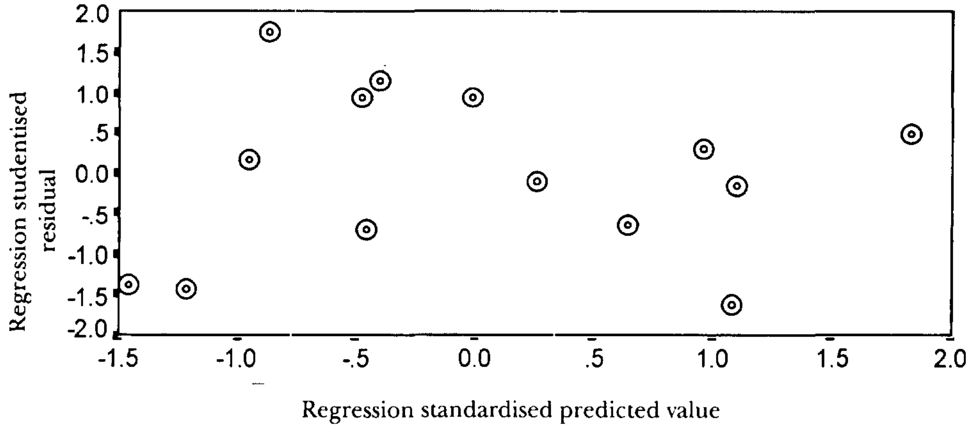

Figure 2. Scatter plot of studentised residuals vs. standardised predicted values for the relationship between dominant height growth of teak and sand at Bosomoa, Tain II and Yaya forests reserves in Ghana

Discussion

The most favourable growth conditions for teak exist in tropical climates that have 1250 to 1800 mm of annual precipitation, and a more or less uniform temperature with a minimum of 12 °C and a maximum of 38 °C (Hedegart 1976, Borota 1991). Teak has been found to grow in areas with rainfall ranging from as low as 600 mm (e.g. Togo) to as high as 4000 mm (e.g. Bangladesh) (Hedegart 1976). However, the recommended optimum rainfall for teak is between 1500 and 2000 mm per annum (Troup 1921, Kadambi 1972). The minimum rooting depth suggested for teak in Ivory Coast and Nigeria is 50–60 cm (FAO 1957, Streets 1962). Drechsel and Zech (1994) suggested 65 cm for site class II teak in West Africa. Estimated modal rooting depth for teak in the High Forest Zone of Ghana ranges from 40 to 50 cm.

Although, N and P are among the most crucial nutrients for teak growth in the tropics, N is usually deficient and its availability has been found to vary with season (Ahn 1962, Young 1976). Soil N increased with increasing rainfall at the beginning of the rainy season after which quantities present were again reduced by leaching and plant absorption in Ghana (Ahn 1962) and in Liberia (Zech & Drechsel 1991). Soil available P is often in short supply in the tropics (Table 2) (Ahn 1962, Young 1976), probably due to high P fixation under strong acid conditions in soils rich in iron and aluminum oxides (Young 1976). In such cases, P fixation lowers available P thereby restricting root and plant growth. The minimum nutrient requirements for a 15-y-old teak plantation in Nigeria was estimated as being 328, 76, 556, 357 and 62 kg ha^{-1} for N, P, K, Ca and Mg respectively (Nwoboshi 1984). Comparing these values to Table 2 shows that the study location has good potential for future teak plantation establishment. Zech and Drechsel (1991) found pH ($CaCl_2$) values to be less than 4.3 in declining teak stands and above 4.7 in healthy ones in Liberia. The pH ($CaCl_2$) values of the studied plantations range from 5.4 to 6.7 (cf. Salifu & Meyer 1998) and meet the requirements of mildly acidic to neutral pH conditions for healthy teak growth (Hedegart 1976, Bhoumik & Totey 1990). Large amounts of Ca were stored in the bark (400-427 kg ha^{-1}) of teak, compared to the smaller amounts stored in the bark free bole (about 166 kg ha^{-1}) (Nwoboshi 1984, Zech & Drechsel 1991). Therefore, tree harvesting had the potential for site nutrient depletion. Hase and Foelster (1983) found that the removal of teakwood resulted in losses of 220–3070 Ca kg ha^{-1} in 50-y rotations and decreased soil pH and biological activity. This means that total Ca reserves in the soils of the Bosomoa teak plantation (2515 kg ha^{-1}), the Tain II teak plantation (4192 kg ha^{-1}), and the Yaya teak plantation (3380 kg ha^{-1}) could sustain teak growth for the first 50 y (Table 2). However, teak harvesting could potentially deplete soil Ca reserves in the second rotation of teak with a consequent reduction in site productivity, and in teak growth. Teak harvest in Venezuela resulted in considerable loss of soil Ca through biomass removal (Hase & Foelster 1983), and loss of N, S, and K through leaching and erosion (McColl & Powers 1984, Balagopalan 1987). According to Drechsel and Zech (1994), between 70 and 90% of the variation in teak growth in West Africa could be explained by N, RD (root depth) and precipitation. They found N deficiency to be significant ($r = 0.80 - 0.90$, $p < 0.01$) on all soils except Vertisols, on areas of low site index. Nwoboshi (1984), Marquez *et al.* (1993) and Drechsel and Zech (1994), also found that P and Ca were positively correlated with teak growth. The results of this study support the hypotheses of Zech and Drechsel (1991) and Drechsel and Zech (1994) when the weak predictor variables ($R^2 < 0.05$) were considered (results not presented). However, textural properties were more important predictors of DH when the high predictor variables were considered ($R^2 > 0.05$) (Table 3). This study has demonstrated that, apart from soil chemistry, sand, silt and clay are important for the variations in teak growth in the study region. Multiple linear regression relationships showed that sand alone accounted for 82% of the variation in DH, and clay plus silt accounted for 81% of DH across the study locations. Also, Akinsanmi (1985) has used sand fraction, and clay plus silt fractions to explain volume production of teak in southwestern Nigeria. The negative and significant correlation ($r = -0.9047$, $p < 0.001$) between DH and sand fraction indicates that nutrient and moisture storage is more important than growth-limiting stagnic properties. Aeration was adequate, because the soils studied are well drained (cf. Table 1 in Salifu and Meyer 1998). The positive and significant correlation between DH and silt and clay fractions ($p < 0.05$) further supports the contention that nutrient and moisture storage is more important for teak growth at this location. Clay and silt improve the nutrient storage and water holding capacity of the soil, and the finer the soil texture, the greater will be the amount of water and nutrients stored for plant use (Medin 1960). Akinsanmi (1985) has also found that mean tree total height was significantly negatively correlated with sand, and positively correlated with clay.

In another study (Medin 1960), a positive and significant correlation was found between soil depth and annual production of true mountain mahogany (*Cercocarpus montanus*) in Colorado. Similar results were found for scarlet and black oak in the Southern Appalachian (Doolittle 1957) and for teak in West Africa (Zech & Drechsel 1991). Increasing root depth (RD) implies greater nutrient reserves and may result in a positive response in plant growth. However, there is need for caution with this interpretation, since most available plant nutrients are found in the top soil horizon (Ahn 1962, Young 1976). Furthermore, Choompol-Ngampongsai (1973), Singh and Srivastava (1985) and Yadav and Sharma (1968) found that teak roots were confined to the upper 30 cm of the soil and could meet its water and nutrient requirements from smaller soil masses. Also, Brady (1974) and Kimmins (1987) observed that most fine feeding roots may be concentrated in the upper few centimeters of the soil even though depth of maximum rooting may be as great as 2 m.

The high R^2 values of the regression equations suggest that DH can be accurately predicted using sand (model 1) or clay plus silt (model 2). These results are similar to reported relationships between DH and the predictor variables (Akinsanmi 1985, Zech & Drechsel 1991). The unexplained variations in the models could be associated with either the management history of the plantations, precipitation, soil pH and organic matter content (Akinsanmi 1985, Zech & Drechsel 1991), or base saturation and potassium (Chijioke 1988) which were not considered in the multiple regression analysis.

Conclusion

In this study, sand or silt plus clay significantly contributed to explaining over 81% of the variations in DH growth of teak. To sustain productivity of plantations, these relationships should be considered during site evaluation and selection for teak plantation establishment. The models can also be applied to other exotic tree species in the study location, and other comparable sites. The developed models constitute an important first hand information for the study region, and locations with similar site conditions. If the models are validated through further sampling, they could predict DH in these and other similar locations.

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