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# Evaluation of growth and carbon storage as influenced by soil chemical properties and moisture on teak (*Tectona grandis*) in Ashanti region, Ghana

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## Abstract

This study was conducted to assess the growth and carbon storage of *Tectona grandis* (Verbenaceae) and to evaluate the influence of chemical properties and moisture of soil on teak (*Tectona grandis*) growth in Afrensu Brohuma Forest Reserve, Ghana. Teak growth was classified as good (1), medium (2) and poor growth (3) and aboveground biomass and carbon storage were estimated. The aboveground carbon storage and chemical properties of soils in the study sites and those of other teak plantations and different tree species were compared and the relationships between the volumetric water content of soils and growth class of teak were determined. Precipitation seemed to influence height and aboveground biomass of teak. The soil total N and exchangeable K in the study sites were lower than those in other teak plantations in the region. The volumetric water content in soils of most Class 1 sites was significantly higher than that in Class 2 sites. Consequently, teak growth was probably affected by some chemical properties and moisture status of soils in the present study sites. It is therefore necessary to preserve the teak plantation on long term to achieve efficient carbon storage in a plantation for carbon projects.

*Key words:* Teak, *Tectona grandis*, plantation, tree growth, growth class, soil chemical properties, soil moisture, biomass, N, K, carbon storage.

## Introduction

Large-scale industrial *Tectona grandis* (Verbenaceae) plantations are increasing in Ghana because of the quick economic returns [1]. Teak (*Tectona grandis*) is used for transmission and telephone poles, fence posts and for furniture in Ghana, and it is exported for foreign exchange. In addition to the traditional economic value of teak afforestation, under the Kyoto Protocol, the increase of carbon stock by afforestation has an additional economic value. The primary factors affecting the growth of teak 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.

Salifu [1] in the study of site variables controlling growth of teak 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 that silt and clay improve the nutrient and moisture storage of soils, which is important for teak growth. However, no relationships between nutrient and moisture of soils and teak growth were reported. Several authors reported that mineral nutrition of soil affects growth of teak in West Africa [3-6]. However, relationships between chemical properties of soil and teak growth have been poorly reported in Ghana. In addition to above factors, annual precipitation in teak plantations is between 1200 and 2200 mm [7] in Ghana, and is sometimes less than the optimum precipitation required by teak, 1500 to 2000 mm per year [8].

Many of the voluntary carbon sequestration initiatives are based in Latin America and Asia, but fewer forestry based carbon projects have been located in Africa than in other developing regions of the world [9]. Therefore, estimation and evaluation of carbon storage in forest could have important implication for management of carbon projects in Africa.

In this study, a teak plantation in a major forest region, Ashanti region, Ghana, was selected to evaluate the influence of soil chemical properties and moisture on growth and to estimate and evaluate carbon storage.

## Material and Methods

***Study area:*** The study was conducted in the Afrensu Brohuma Forest Reserve (Latitude 7°22'N, Longitude 1°54'W) in Ashanti region, Ghana (Fig. 1). The elevation ranged from approximately 350 to 450 m above the sea level and the relief ranged from gently to steep sloping. The mean annual precipitation was approximately 1350 mm from 2000 to 2006, with the main raining season from mid-March to July and the minor season from September to mid-November. The monthly mean temperature of this area ranged from a minimum of 21°C to a maximum of 34°C as recorded by the Meteorological Station, Kumasi Airport. The natural vegetation

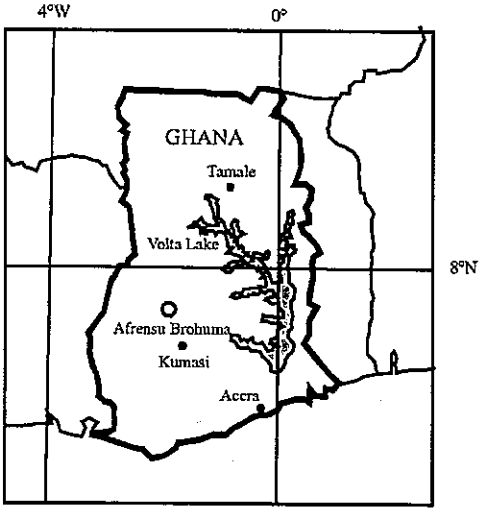

*Figure 1.* Location of study site of the Afrensu Brohuma Forest Reserve in Ashanti region, Ghana.

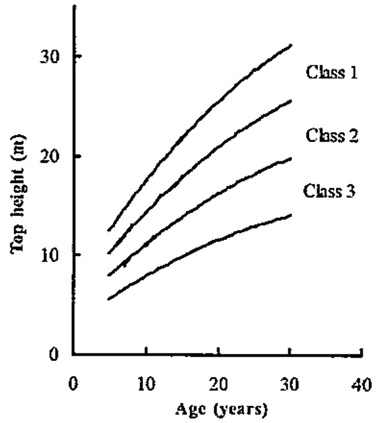

*Figure 2.* Regional site index curves and classes of teak in Ghana [12].

was classified as the moist semi-deciduous forest [10]. The major primary soil material is sandstone. Soils at the study sites are mainly classified as Alfisols and Entisols using the USDA [11] soil taxonomic system.

The teak plantation was established in 1992. Before planting, the ground was cleared using slash and burn method. Teak was planted by stumps as planting material and under Taungya system. The planting distance adopted was 3 m by 3m. Weeding had been done during 3 years from establishment. Thinning had not been conducted at the time of this study. The teak trees in the study sites are almost closing canopy. Different sites with different soil types within the plantation were selected for this study.

***Field survey***: Field survey was conducted from July to August and November to December 2006. Ten study sites were selected within the teak plantation. In each site, 25 m × 25 m quadrate plot was demarcated. All plantation trees in the quadrate plot were measured for height and diameter at breast height (DBH). Some old teak trees, grown before ground clearance remaining in some sites, were omitted from measurement. The teak plantation sites have naturally regenerated, and trees with the DBH less than 10 cm from the measurement as the natural regeneration tree were omitted.

A site classification was used to evaluate the growth status of teak in Ghana [12]. It consists of three classes depicted as good (1), medium (2) and poor growth (3), respectively (Fig. 2). Top height is an indicator of growth in the growth class of teak. Five trees with the wise diameter were selected at each site and their height measured. The mean height of the five trees was considered the top height, following a modified method of Friday [13] and categorized the top height into 3 classes. The growth class of teak was used as an indicator of the teak growth in respective sites.

Soil samples were collected from the depths of 0-20, 20-30 and 30-40 cm at 5 points of the 25 m × 25 m quadrate plot of the respective sites and combined at each layer for the chemical analysis. A soil profile at the depth of 100 cm was prepared for the soil observation and the deep soil sampling in each study site. Soil samples were collected from the depths of 0-5, 10-15 and 50-55 cm in the soil profile for physical analysis and 50-55 cm depth for chemical analysis. Soil volumetric water content in the depths of 0-5 and 10-15 cm was recorded in one central point and four corner points of each plot using a frequency domain reflectometer (DIK-310A, Daiki Rika Kogyo Co., Ltd., Shiga). It was recorded 6 times throughout 20 days in raining season.

***Laboratory analysis***: Soil bulk density was determined by establishing the weight of core samples oven-dried for 24 h at 105°C. 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 soil to solvent ratio of 1:2.5. Total carbon and nitrogen contents were determined using a CN corder (MT-700, J-Science, Co., Kyoto). Available P was resolved using the Bray-1 method [14] and the content determined by colorimetry using an UV/VIS spectrophotometer (Jasco V-530, Tokyo, Japan). Exchangeable cations (exch. Ca, Mg, K and Na) were extracted from the soil in the 1 mol $L^{-1}$ ammonium acetate [15] and exch. Ca and Mg were determined by an inductive coupled plasma emission photometer (ICPS-2000, Shimadzu, Co., Kyoto) and exch. K and Na by an atomic absorption spectrophotometer (Shimazu, AS 680).

***Estimation of carbon storage in teak forests***: Kraenzel *et al.* [16] measured aboveground biomass (leaves, flowers, twigs, branches and trunks) and each tissue carbon content of 20-year-old teak in Panama and calculated simple linear regressions of log DBH versus log dry aboveground biomass and log DBH versus log aboveground carbon storage. Aboveground biomass and carbon storage in the respective sites were estimated using following linear regressions [16]: log aboveground biomass (kg) = 2.575 × log DBH (cm) – 1.042 and log aboveground carbon storage (kg) = 2.574 × log DBH (cm) – 1.345.

***Statistical analysis***: Statistical differences of soil chemical properties were subjected to a multiple comparison test and for soil volumetric water content nonparametric test was used.

## Results and Discussion

***Tree growth and carbon storage in teak forest in Ashanti region:*** Growth size and class and biomass and carbon storage in the respective sites are indicated in Table 1. The mean and top height of 14-year-old teak in the respective sites ranged from 13.3 to 18.6 m and 15.0 to 20.4 m, respectively. In the estimation of aboveground biomass and carbon storage, the mean aboveground biomass ranged from 91.0 to 239.0 kg tree$^{-1}$, while total aboveground biomass ranged from 30.6 to 145.1 Mg ha$^{-1}$ and total aboveground carbon storage is between 15.2 and 72.0 Mg C ha$^{-1}$.

These findings on height and aboveground biomass of teak compared favourably with those in other regions of Ghana and other countries (Table 2)[17-20]. Mean height observed in the present study sites was lower than that in Costa Rica [17, 18] but was higher than those in India [19] and Northern Ghana [20]. Aboveground biomass observed in the study sites was lower than that in Costa Rica [17] but was higher than that in India [19]. Annual precipitation was less in the present study sites than in Costa Rica [17, 18] and more than in India [19] and Northern Ghana [20]. Also mean height and aboveground biomass of teak in the present study sites were lower than those in Costa Rica [17, 18] and higher than those in India [19] and Northern Ghana [20]. From these data, the annual precipitation appears to be a limiting factor for the tree growth and aboveground biomass of teak.

A comparison of aboveground carbon storage among other plantations of teak and different tree species (Table 2)[16,21,22] shows that aboveground carbon storage of teak in the study sites was lower than that of radiata pine (*Pinus radiata*) in Australia [21] and higher than that of white pine (*Pinus strobus*) in Canada [22]. A 20-year-old teak plantation in Panama [16] showed higher aboveground carbon storage than the study sites, which may be due to not only the age of the plantation but also the annual precipitation.

***Soil chemical properties:*** Soil chemical properties at the different soil depth are shown in Table 3. Total C and N, available P and exch. Ca at 0-20 cm soil depth were significantly higher than that of 30-40 and 50-55 cm soil depth ($P < 0.05$). However, the mean pH ($H_2O$), pH (KCl), exch. Mg, exch. K and exch. Na were not significantly different in soil depths. Drechsel and Zech [3] mentioned that the most deficient nutrients in teak plantation are N, Ca and P in West Africa. Ezenwa [6] reported that pH, total N and exch. Ca and K in soils positively correlated with teak height and basal areas in Nigeria. However, no relationship between nutritional status and teak growth was found in this study. The comparison of soil chemical properties in the surface soil of this study sites and in other plantation regions (Table 4)[4,23-25] shows that the soil pH of the study sites was higher than that in other plantation regions [4,23-25] and was in the range of 6.5 to 7.5 [25] which is suitable for teak. Therefore, soil pH was not the limiting factor in teak growth in the study sites.

The soil total N of the study sites was lower than that in other plantation regions [4,23-25]. The soil available P of the study sites was similar to that in Tanzania [24] and was higher than that in Liberia [4] and another plantation in Ashanti region, Ghana [23]. The soil exch. Ca of the study sites was lower than that in another plantation in Ashanti region, Ghana [23] and Eastern Java [25] and was higher than that in Liberia [4], Tanzania [24] and Southern Sumatra [25]. The soil exch. K of the study sites was lower than that in another plantation in Ashanti region of Ghana [23], Tanzania [24], Eastern Java [25] and Southern Sumatra [25] and higher than that in Liberia [4]. In terms of teak growth, some withered teaks showed N, P and Ca deficiency in Liberia [4] and the environmental condition in Southern Sumatra was not suitable for teak growth [25]. The soil total N and exch. K of the present study sites were comparable or even lower than that in Liberia [4] and Southern Sumatra [25].

In addition, the total N and exch. K contents of the surface soil among the growth classes were compared (Fig. 3). Although there were not significant differences among the growth classes, the mean soil total N at the 0-20 and 20-30 cm depth and exchangeable K at the 0-20 cm depth tended to be higher in Class 1 sites than in Class 2 sites. From these results, total N and exch. K levels of the surface soil in the study sites might be related to the growth.

***Soil moisture:*** Daily changes in volumetric water content in the soils of 0-5 and 10-15 cm depth of the different growth class sites are shown in Fig. 4. The volumetric water content in soils of 0-5 cm depth ranged from 0.05 to 0.33 m$^3$ m$^{-3}$ and that of 10-15 cm depth ranged from 0.07 to 0.30 m$^3$ m$^{-3}$. Although, measured in raining season, the soils of the sites were felt dry. Results of the nonparametric test indicated the volumetric water content in Class 2 sites was significantly lower than those in Class 1 sites in both depths during the measurement period (Fig. 4).

In the study sites, the amount of annual precipitation was approximately 1350 mm, which was less than the optimum precipitation for teak that is between 1500 and 2000 mm per year [8]. If the annual precipitation was 1846 mm, Koppad and Rao [26] reported that moisture conservation methods significantly increased plant survival, plant height and collar diameter of teak in South India. We speculated that precipitation amount was not sufficient for ideal teak growth and soil moisture possibly had influenced on teak growth in the present study sites.

## Conclusions

The data obtained in this study indicated that precipitation seemed to influence size and biomass of teak, and some nutrients and volumetric water content in soils seemed to influence teak growth. Salifu [1] speculated that silt and clay improve the nutrient and moisture storage of soils, which are important for teak growth in Brong Ahafo region, Ghana. The result of this study was congruent with speculation of Salifu [1]. Consequently, it is suggested that afforestation methods, nutrients and moisture in the soil should be considered during site evaluation and selection for teak plantation. In terms of carbon storage in the forest, the 14-year-old teak forest was able to accumulate more carbon in the study sites. It is therefore necessary to preserve the teak plantation on long term to achieve efficient carbon storage in a plantation for carbon projects.

## Acknowledgements

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**Table 1.** Growth size, class, biomass and carbon storage of teak in each study site (14-year-old).

| Site | DBH Mean (cm) | Height Mean (m) | Height Top (m) | Growth class | Mean aboveground biomass ($kg\ tree^{-1}$) | Total aboveground biomass ($Mg\ ha^{-1}$) | Total aboveground carbon storage ($MgC\ ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| T1 | 19.5 (4.6) | 18.4 (1.8) | 20.4 (0.8) | 1 | 213.1 (137.9) | 133.0 | 66.0 |
| T2 | 14.7 (2.7) | 16.7 (1.7) | 17.4 (1.3) | 1 | 98.9 (45.2) | 98.1 | 48.7 |
| T3 | 20.2 (5.3) | 18.6 (3.0) | 19.6 (3.8) | 1 | 237.1 (139.1) | 102.4 | 50.8 |
| T4 | 16.2 (5.4) | 16.1 (3.9) | 19.4 (2.3) | 1 | 145.4 (121.7) | 46.5 | 23.1 |
| T5 | 14.3 (3.3) | 15.2 (1.5) | 16.5 (1.6) | 2 | 95.3 (54.7) | 54.9 | 27.2 |
| T6 | 14.2 (2.9) | 14.5 (1.1) | 15.5 (0.5) | 2 | 91.0 (48.6) | 30.6 | 15.2 |
| T7 | 16.5 (3.7) | 14.8 (1.0) | 15.4 (1.1) | 2 | 135.7 (79.1) | 91.2 | 45.3 |
| T8 | 16.1 (3.3) | 13.3 (1.6) | 15.0 (1.2) | 2 | 125.6 (66.2) | 74.3 | 36.9 |
| T9 | 17.9 (3.8) | 15.6 (2.1) | 16.2 (1.9) | 2 | 168.0 (91.9) | 145.1 | 72.0 |
| T10 | 20.7 (4.2) | 18.6 (1.8) | 19.5 (1.2) | 1 | 239.0 (121.8) | 76.5 | 38.0 |

Tree biomass and carbon storage for each site was calculated by allometric equations of Kraenzel *et al.*[16].
Number in parentheses shows standard deviation.

**Table 2.** Tree height, aboveground biomass and carbon storage, and climatic conditions derived from other plantations of teak and different tree species.

| Study site | Precipitation (mm) | Land use type | Age (year) | Mean height (m) | Aboveground biomass ($kg\ tree^{-1}$) | Aboveground biomass ($Mg\ ha^{-1}$) | Aboveground carbon storage ($MgC\ ha^{-1}$) | References |
|---|---|---|---|---|---|---|---|---|
| Present study site | 1350 | Teak plantation | 14 | 16.2 | 154.9 | 85.3 | 42.3 | |
| India | 762 | Teak plantation | 14 | 12.6 | | 39.9 | | (Karmacharya & Singh 1992) [19] |
| Northern Ghana | 960-1200 | Teak plantation | 16 | 6.4-13.4 | | | | (Nunifu & Murchison 1999) [20] |
| Costa Rica | 1901 | Teak plantation | 14 | 20.3-21.1 | 291.0-372.9 | | | (Cordero & Kanninen 2003) [17] |
| Costa Rica | 1659-4107 | Teak plantation | 14-15 | 19.4-25.2 | | | | (Pérez & Kanninen 2005) [18] |
| Australia | 623 | Radiata pine plantation | 16 | | | | 77.7 | (Guo *et al.* 2008) [21] |
| Canada | 832 | White pine plantation | 15 | | | | 32.4 | (Peichl & Arain 2006) [22] |
| Panama | 2300-3000 | Teak plantation | 20 | 20.4 | | | 104.5 | (Kraenzel *et al.* 2003) [16] |

**Table 3.** The mean soil chemical properties at different soil depth (n = 10).

| Depth (cm) | pH ($H_2O$) | pH (KCl) | Total C ($g\ kg^{-1}$) | Total N ($g\ kg^{-1}$) | Available P ($mg\ kg^{-1}$) | Exchangeable cations Ca ($cmol_c\ kg^{-1}$) | Exchangeable cations Mg ($cmol_c\ kg^{-1}$) | Exchangeable cations K ($cmol_c\ kg^{-1}$) | Exchangeable cations Na ($cmol_c\ kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 0-20 | 7.14 a<br>(0.35) | 6.15 a<br>(0.48) | 11.35 a<br>(2.49) | 1.03 a<br>(0.22) | 7.46 a<br>(2.46) | 7.16 a<br>(2.80) | 0.95 a<br>(0.40) | 0.24 a<br>(0.06) | 0.05 a<br>(0.02) |
| 20-30 | 7.21 a<br>(0.47) | 6.12 a<br>(0.69) | 6.08 b<br>(1.62) | 0.58 b<br>(0.16) | 4.46 b<br>(1.64) | 4.55 ab<br>(1.43) | 0.64 a<br>(0.23) | 0.15 b<br>(0.04) | 0.05 a<br>(0.01) |
| 30-40 | 7.15 a<br>(0.48) | 5.77 a<br>(0.47) | 4.41 bc<br>(1.47) | 0.43 bc<br>(0.12) | 3.46 b<br>(1.16) | 3.31 b<br>(0.65) | 0.61 a<br>(0.27) | 0.15 ab<br>(0.08) | 0.05 a<br>(0.01) |
| 50-55$^{\dagger}$ | 7.06 a<br>(0.77) | 5.47 a<br>(0.79) | 2.93 c<br>(1.74) | 0.32 c<br>(0.16) | 2.71 b<br>(0.97) | 2.94 b<br>(1.73) | 0.69 a<br>(0.50) | 0.19 ab<br>(0.18) | 0.06 a<br>(0.01) |

Number in parentheses shows standard deviation.
$^{\dagger}$50-55 cm depth samples were corrected in the pit. Other depth samples were corrected from 5 points in each site.
Different letters indicate significant difference at $P < 0.05$ using Dunnett's C test.

**Table 4.** Chemical properties of the soil in the top layer derived from other teak studies.

| Study site | Depth (cm) | pH ($H_2O$) | Total N ($g\ kg^{-1}$) | Available P (Bray 1) ($mg\ kg^{-1}$) | Exchangeable Ca ($cmol_c\ kg^{-1}$) | Exchangeable K ($cmol_c\ kg^{-1}$) | Reference |
|---|---|---|---|---|---|---|---|
| Present study sites | 0-20 | 7.14 | 1.03 | 7.46 | 7.16 | 0.24 | |
| Ashanti region of Ghana | 0-20 | | 2$^{*}$ | 1.2 | 12.4 | 0.3 | (Amponsah & Meyer 2000) [23] |
| Liberia | Top layer | 3.75-6.91$^{\dagger}$ | 0.89-1.93$^{*}$ | 1.8-8.5 | 0.65-3.60$^{**}$ | 0.06-0.19$^{**}$ | (Zech & Drechsel 1991) [4] |
| Tanzania | 0-10 | 6.50-6.65$^{\ddagger}$ | 1.80-2.01$^{*}$ | 8-12 | 3.52-3.72 | 3.71-4.14 | (Chamshama *et al.* 2000) [24] |
| Eastern Java | 0-9 | 6.9 | 2.6 | | 82.4 | 0.7 | (Tanaka *et al.* 1998) [25] |
| Southern Sumatra | 0-5 | 4.9 | 1.9 | | 3.6 | 0.4 | (Tanaka *et al.* 1998) [25] |

$^{\dagger}CaCl_2$ extraction. $^{\ddagger}$Ratio 1:0. $^{*}$Kjeldahl. $^{**}MgCl_2$ extraction.

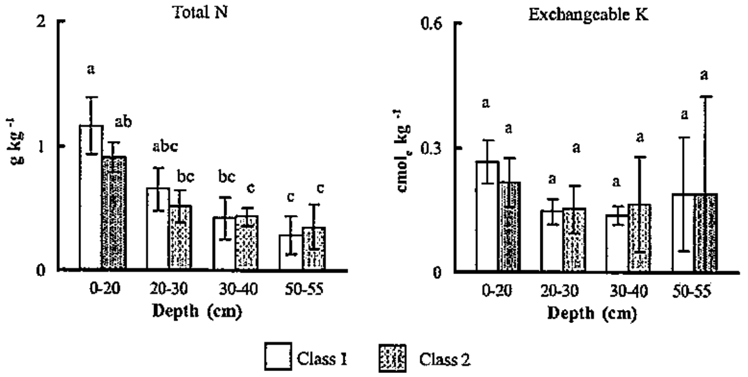

*Figure 3.* Comparisons of mean soil chemical properties among the growth classes and soil depths (n = 10). Different letters indicate significant difference at P < 0.05 using Dunnett's *C* test.

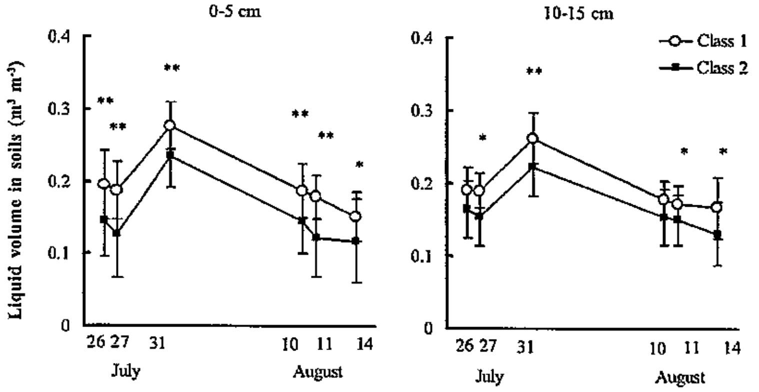

*Figure 4.* Daily change of volumetric water content in soils in depth of 0-5 cm and 10-15 cm at the different growth class sites (n = 10). (Bars indicate standard deviation. Significant at P < 0.05:*, P < 0.01:**).

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