ISSN (Online): 2349-1183; ISSN (Print): 2349-9265
TROPICAL PLANT RESEARCH
The Journal of the Society for Tropical Plant Research
7(3): 678–683, 2020
DOI: 10.22271/tpr.2020.v7.i3.085

Research article

Nonlinear yield models for young *Tectona grandis* L. f. stands in Nnamdi Azikiwe University Awka, Southeastern Nigeria

Onyekachi Chukwu* and Anabel A. Emebo

Department of Forestry and Wildlife, Nnamdi Azikiwe University, Awka, Nigeria

*Corresponding Author: onye20042000@yahoo.com [Accepted: 13 December 2020]

Abstract: Yield models are very important to forest management, especially for site quality assessment, subsequent inventories, timber valuation and assessment of stand growth. This study developed yield models for the young *Tectona grandis* stands in Nnamdi Azikiwe University Awka, Southeastern Nigeria. These models were necessary to the guide forest managers in timber valuation as well as monitoring growth of the stand. Data for this study was collected through complete enumeration method, tree height and stem diameters of the 295 Teak stands were measured. Non-destructive method (Newton's formula) was used in computing individual tree volumes. The tree growth variables data were subjected to descriptive statistics and used for fitting five nonlinear regression functions. The mean stem height, diameter at breast height and volume were 10.6 m, 8.9 cm, 0.032 m^3, respectively. Out of the five yield equations fitted; the generalized combined variable model had the best predictive ability; with the lowest root mean square error (0.0084 m^3) and Akaike information criterion (-2809). Therefore, the generalized combined variable model was recommended for yield estimation of *Tectona grandis*.

Keywords: Forest plantation - Generalized combined variable - Regression models - Teak - Tree yield - UNZIK.

[Cite as: Chukwu O & Emebo AA (2020) Nonlinear yield models for young *Tectona grandis* L. f. stands in Nnamdi Azikiwe University Awka, Southeastern Nigeria. *Tropical Plant Research* 7(3): 678–683]

INTRODUCTION

Yield models are mathematical expressions, which relate tree volume to tree's measureable variables such as stem diameter and/or height; the models are used to estimate average content of standing trees of various sizes and species (Avery & Burkhart 2002). Tree stem volume is referred to quantity and used to measure the solid content of a tree. Studies have encouraged the non-destructive methods of tree yield estimation such as use of allometric equations and/or models (Paul *et al.* 2013, Adeyemi & Moshood 2019). Hence, the development of yield models for *Tectona grandis* L. f. stands in Nnamdi Azikiwe University Awka, Southeastern Nigeria.

Tectona grandis is a large deciduous tree of the family Lamiaceae with a rounded crown and a tall cylindrical bole of more than 25 m. The properties of Teak which makes it valuable are lightness with strength, stability, durability, ease of working without cracking and splitting, resistance to termites (Bhuyan *et al.* 2004). Teak is known to perform well in plantations under favorable conditions. According to Akpan-Ebe (2017), the rate of deforestation in Nigeria is high, hence, the need for afforestation. The Teak plantation in Nnamdi Azikiwe University Awka was raised to serve as shelterbelt to the School of Postgraduate Studies' building, to counteract soil degradation by restoring vegetation cover while decreasing the existing pressure on native forests and also increase soil carbon (C) and nitrogen (N) pools and to serve as a source of timber at maturity. It is also part of the afforestation or reforestation project of the University management. The demand of wood and wood products, continuous depletion of forest resources in Nigeria has increased leading to a situation where the resources can no longer meet current demands and the future needs of the population. This has led to a shift from tropical natural forest management to the management of plantation of mainly exotic species in Nigeria (Akpan-Ebe 2017). In plantation forest, yield estimations of the growing stock are often expressed in terms of volume, which can be estimated from easily measurable dimensions of the tree (Osho 1983, Husch *et al.* 2003).

Previous studies have developed several volume equations for tree species in the tropical region of Nigeria

Received: 22 June 2020 Published online: 31 December 2020
https://doi.org/10.22271/tpr.2020.v7.i3.085

(Osho 1983, Akindele & LeMay 2006, Dantani *et al.* 2019) none of these models exists for the young Teak plantation within the Awka campus of Nnamdi Azikiwe University. Such information is necessary to guide forest managers in site quality assessment, subsequent inventories, assessment of stand growth and yield, timber valuation as well as in the allocation of forest areas for harvest (Akindele & LeMay 2006). Therefore, it is of vital importance to develop a yield model for the plantation. The objective of this study was to develop models that will estimate the yield of the young *Tectona grandis* (Teak) stands in Nnamdi Azikiwe University, Awka, Nigeria for sustainable management.

MATERIALS AND METHODS

Study area

This study was carried out in the 5 years old Teak plantation located at the School of Postgraduate Studies (SPGS), Nnamdi Azikiwe University (NAU), Awka Campus. The University is located in Awka Metropolis, Southeastern Nigeria. NAU lies from latitude 6.2465 N to 6.2469 N and longitudes 7.1156 E to7.1167 E (Fig. 1). The climate of NAU is tropical wet and dry type with rugged relief topography. The average annual temperature is 27°C to 30°C between June and December but rises to 32–34°C between January and April and the last few months of the dry season marked by the intense heat. The rainfall average is 1828 mm. It lies below 300 m above sea level in a valley on the pains of the Mamu River (Ezenwaji *et al*. 2013, Chukwu *et al.* 2020).

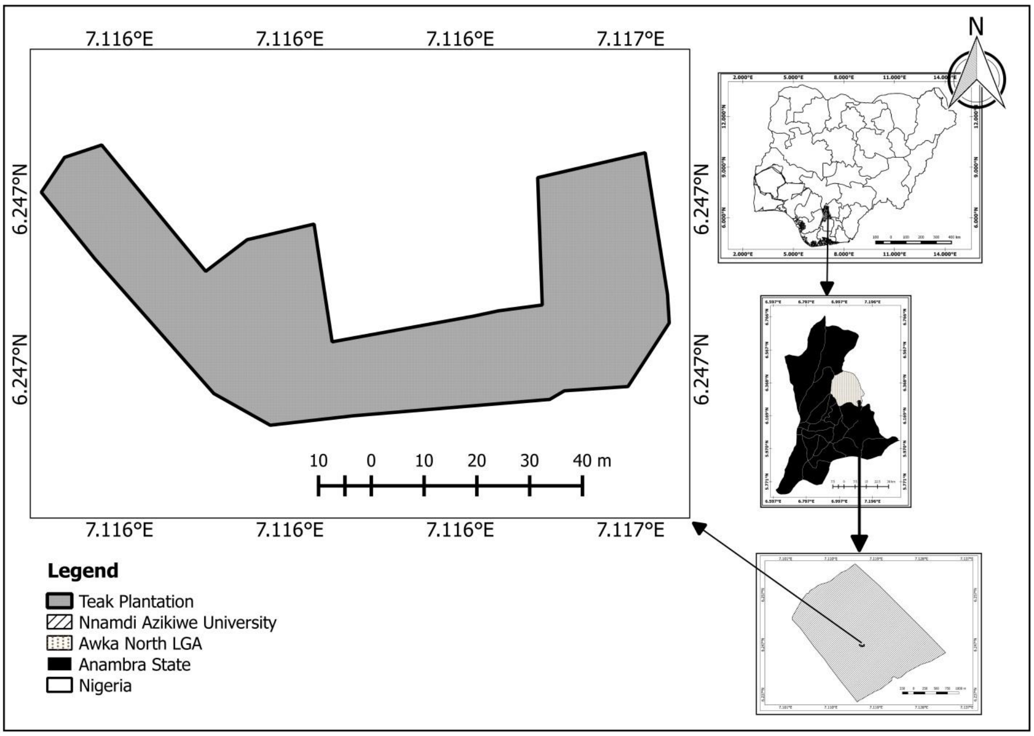

Figure 1. Map of the Study area. [Source: Field Survey (2019)]

Data collection and computation

Data used for this study was collected through total enumeration of the 5 years old Teak plantation. This involved taking measurement on all the living *Tectona grandis* stands in the plantation. The following tree growth variables were measured total height (m), diameter at the top (cm), and diameter at the middle (cm) using a Spiegel Relaskop. Diameter at the base and Diameter at breast height (1.3 m above the ground) were measured using diameter tape calibrated in centimeters. The measured tree variables were used as input variables to compute stem volume using Newton-Simpson's formula, expressed as:

$$V = \pi\frac{H}{24}(D_b^2 + 4D_m^2 + D_t^2) \tag{1}$$

Where; V = stem volume (m^3), H = stem height (m), π = Pi is constant (3.143), D_b = Diameter at the base (m), D_m = Diameter at mid-point (m) and D_t = Diameter at the top (m).

Data analysis

The inventory data collected for this study was arranged and fitted to five (5) nonlinear yield functions proposed by Akindele & LeMay (2006) for tropical timber species in Nigeria (Table 1). Least squares method was used to fit the models in SPSS Statistics 20.0 software.

Table 1. Candidate yield functions.

S.N.	Function name	Function form	Equation No.
1	Constant form factor	$V_i = b_1 D_i^2 H_i + \varepsilon_i$	(2)
2	Combined variable	$V_i = b_0 + b_1 D_i^2 H_i + \varepsilon_i$	(3)
3	Logarithmic	$V_i = e^{b_1} D_i^{b_2} H_i^{b_3} e^{\varepsilon_i}$	(4)
4	Generalised combined variable	$V_i = b_0 + b_1 D_i^2 + b_2 H_i + b_3 D_i^2 H_i + \varepsilon_i$	(5)
5	Generalised logarithmic	$V_i = b_0 + b_1 D_i^{b_2} H_i^{b_3} e^{\varepsilon_i}$	(6)

Note: V_i- Individual tree stem volume, D_i- Individual tree diameter at breast height, H_i- Individual tree total height, b_0, b_1, b_2 and b_3- Regression parameters, e- Exponential function, ε_i- Error term.

Model evaluation

Models were evaluated based on graphical and numerical analysis of the residuals which are: model with the lowest value of root mean square error (RMSE) in m^3 and Akaike information criterion (AIC) was selected as the best model. The model evaluation indices are mathematically expressed as:

$$RMSE = \sqrt{\frac{\sum(Y_i - \hat{Y}_i)^2}{n}} \quad (7)$$

$$AIC = 2p + n\ln\left(\frac{RSS}{n}\right) \quad (8)$$

Where; Y_i = observed value of Y for observation *I*, $\hat{Y}_i$ = predicted value *i*, n= the total number of observations Y_i (trees) used to fit the model, *p* = the number of model fixed parameter, *ln* = natural logarithm and RSS = residual sum of squares.

RESULTS

A total number of two hundred and ninety-five (295) Teak stands were measured in the plantation. The distribution of diameter at breast height (DBH) ranged from 3.0 cm to 18.0 cm with a mean of 8.9, total height ranged from 1.8 cm to 17.3 cm with a mean of 10.6 and the stem volume ranged from 0.002 m^3 to 0.195 m^3 with a mean of 0.031 (Table 2). Pearson's product-moment correlation analysis (square matrix) was carried out to establish the association between the tree growth variables (Table 2). It reveals a positive correlation between DBH, H and V. All the variables were significant at 95% probability level. The graphical relations of V versus DBH and V versus H showed that DBH and H had curvilinear relations to V (Figs. 2 & 3).

Table 2. Summary statistics of tree growth variables.

Growth variables	Descriptive statistics				Correlation coefficient (r)		
	Min.	Max.	Mean	Std. Dev.	DBH	H	V
DBH	3.0	18.0	8.9	0.188	1		
H	1.8	17.3	10.6	3.931	0.62*	1	
V	0.002	0.195	0.032	0.031	0.85*	0.67*	1

Note: *- Correlation is significant at the 0.05 level (2-tailed), DBH- Diameter at breast height (cm), H- Total height (m), V- stem volume (m^3), Number of tree = 295.

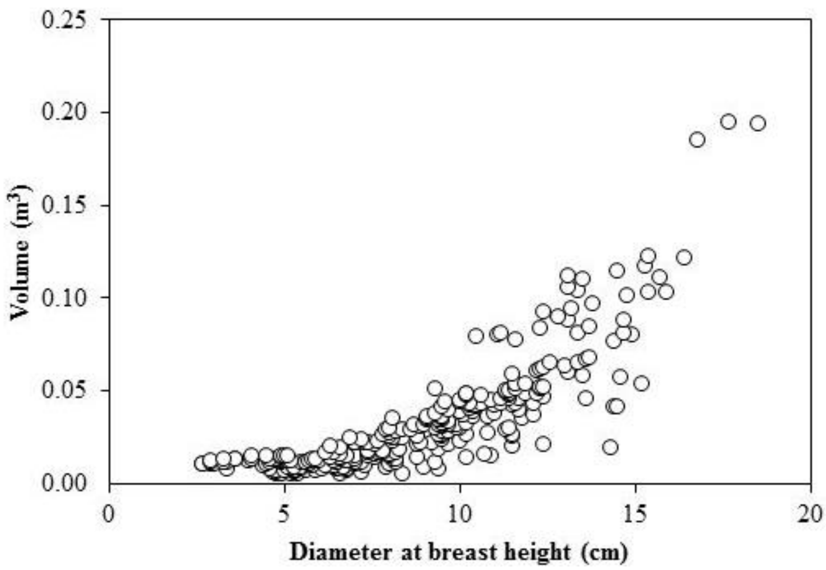

Figure 2. Relationship of tree volume and diameter at breast height.

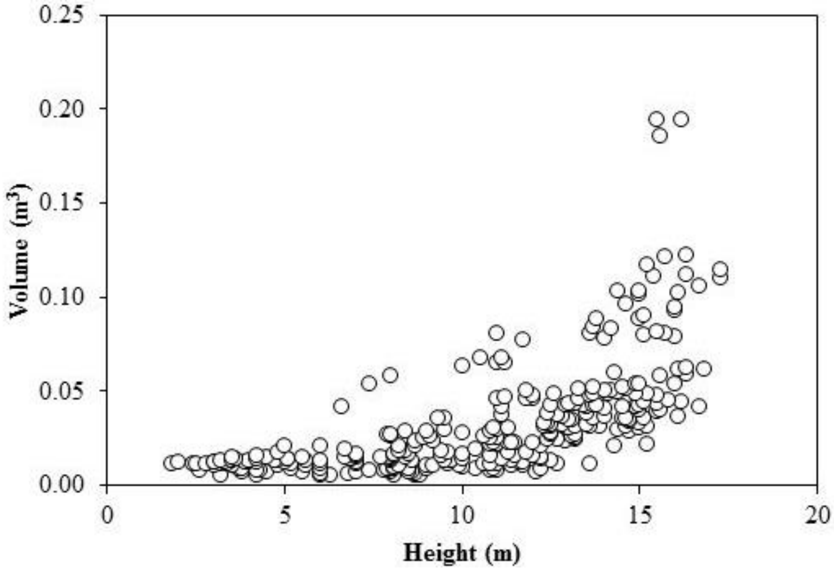

Figure 3. Relationship of tree volume and height.

The results of the individual tree level models developed for predicting yield from diameter at breast height (DBH) and stem height (H) was shown in table 3. The result revealed that Generalised combined variable (equation 5) had the lowest values of RMSE (0.0084 m^3) and AIC (-2809) and followed by Combined variable (RMSE= 0.0086 m^3 and AIC= -2800), Constant form factor (RMSE= 0.0087 m^3 and AIC= -2802), Logarithmic model (RMSE= 0.0099 m^3 and AIC= -2716), and Generalized logarithmic had the lowest performance with highest values of RMSE= 0.0195 m^3 and AIC= -2315 (Table 3). The result of the scattered plot of residual from the generalized logarithmic model (equation 9) showed that the error in the model was within ±0.4 (Fig. 4).

$$V_i = 0.007 - 0.0001D_i^2 - 0.001H_i + 0.0001D_i^2H_i \quad (9)$$

Where, V= Total volume (m^3), D= diameter at breast height (cm) and H= total height (m).

Table 3. Candidate models' parameter estimates and fit statistics.

S.N.	**Functions**	**Parameters**				**Fit indices**	
		b_0	**b_1**	**b_2**	**b_3**	**RMSE**	**AIC**
1	Constant form factor		0.00003			0.0087	-2802
2	Combined variable	-0.002	0.00003			0.0086	-2800
3	Logarithmic	-52.330	-0.7960	-0.366		0.0099	-2716
4	Generalized combined variable	0.007	-0.0001	-0.001	0.0001	0.0084	-2809
5	Generalized logarithmic	40.054	-40.159	-0.001	0.000	0.0195	-2315

Note: b_0, b_1, b_2 and b_3- Regression parameters, AIC- Akaike information criterion, RMSE- Root mean square error (m^3).

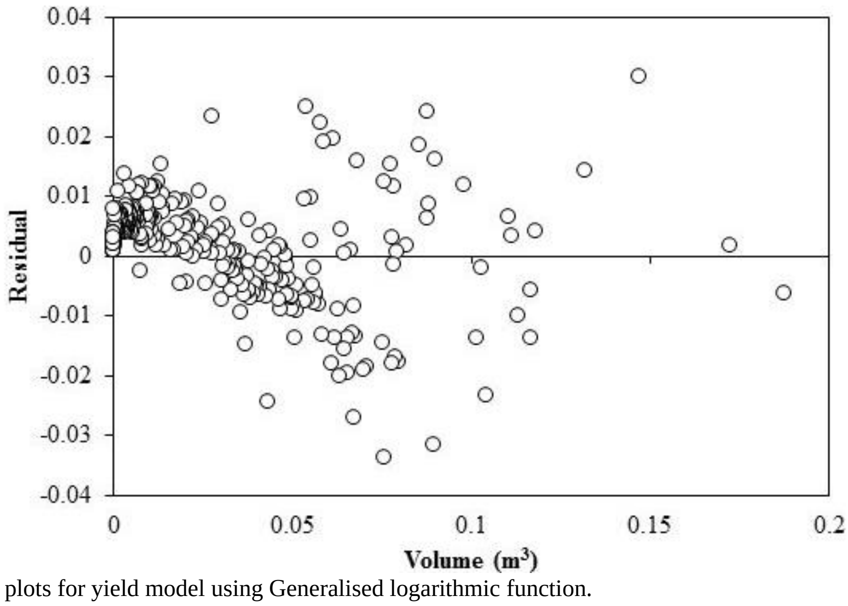

Figure 4. Residual plots for yield model using Generalised logarithmic function.

DISCUSSION

Pearson correlation analysis between the tree growth variables used for this study revealed that, there was high association between tree characteristics such as diameter at the breast height, height as well as volume. This is similar to the findings of Adekunle (2007) and Adeyemi (2016) that showed that tree height-DBH, height-volume, and DBH-volume displayed a positive correlation. Summary statistics of the 295 teak trees were also presented depicting low DBH, height and volume values considering the age of the plantation. The mean volume obtained in this study is lower than what was obtained by Dantani *et al.* (2019). This may be as a result of differences in stand ages, silvicultural practices, location, as well as soil factors in the study area.

The criteria adopted for selecting the best model for this study was through comparison of the following fit indices: root mean square error (RMSE) and Akaike information criterion (AIC), which are standard ways of verifying models predictive ability as pointed out by Shamaki & Akindele (2013) and Chukwu & Osho (2018). The generalized combined variable model (equation 5) was found to be the best, more precise and consistent in predicting yield of stands of the young Teak plantation in Nnamdi Azikiwe University, Awka; with the lowest values of RMSE and AIC values. Thus, the combined variable model (equation 3) also had similar performance. This result was comparable with Tewari & Singh (2018) that recommended combined variable equation for prediction of yield of *Tectona grandis* stands in Gujarat, India. However, this result was in disagreement with Akindele & LeMay (2006) and Aigbe & Ekpa (2015) that reported in separate studies, that the generalized logarithmic volume function (also termed Schumacher's volume function) performed better than other functions used in the development of tree volume equations for common timber species in the tropical rainforest area of Nigeria. This disagreement might be due to the stand age as the trees in the study area were still in their development stage. This disagreement might likewise be on the grounds that both of the earlier studies were conducted in natural forest stands.

The result of the graphical analysis of residual for the best models indicated an even spread of residuals about the zero line, with no systematic trend. This is an indication that the assumption of homoscedasticity in the distribution of error was not violated. This was similar to the report of Tewari & Singh (2018) for *Tectona grandis* stands in Gujarat, India.

CONCLUSION

Nonlinear models were developed in this study to estimate the yield of *Tectona grandis* stands in Nnamdi Azikiwe University Awka, Southeastern Nigeria. Findings from this study revealed that all the nonlinear models performed well; hence, the generalized combined variable model was found to be the most suitable for yield prediction in the plantation. The study therefore, recommended generalized combined variable model as a tool for subsequent volume data collection and management of the Teak plantation at the School of Postgraduate Studies of Nnamdi Azikiwe University, Awka, Nigeria. Furthermore, the study also recommended a recalibration before using this model outside the study area.

ACKNOWLEDGEMENTS

The authors specially acknowledge Prof. Harris I. Odimegwu [former Dean, School of Postgraduate Studies (SPGS), Nnamdi Azikiwe University (NAU) Awka, Nigeria] who established the Teak plantation as well as inspired this study. We also appreciate Prof. Philomena K. Igbokwe (Dean, SPGS NAU) who authorized the use of the Teak plantation for this study. In the same vein, the authors appreciate Dr. Caleb I. Ezeano (former Head, Forestry and Wildlife Department, Nnamdi Azikiwe University, Awka, Nigeria) for technical and material support.

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