DEVELOPMENT OF VOLUME EQUATIONS FOR TEAK PLANTATION IN NIMBIA FOREST RESERVE IN NIGERIA USING Dbh AND HEIGHT

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DEVELOPMENT OF VOLUME EQUATIONS FOR TEAK PLANTATION IN NIMBIA FOREST RESERVE IN NIGERIA USING Dbh AND HEIGHT

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ABSTRACT

Volume equations were developed for teak (*Tectona grandis* (Linn. f.)) plantation in Nimbia Forest Reserve using diameter at breast height (Dbh) and merchantable height as independent variables. Data were collected from 10 sampled plots of 20m x 20m each. The number of trees per plot ranged from 21 to 43 with a total of 364 trees. The mean Dbh and height were 13.58cm and 5.50m, respectively. Three different models were obtained through regression analyses (multiple linear, simple linear and double log form) which were ranked 1st, 2nd and 3rd. Adjusted coefficient of determination (Adjusted R^2) and root mean square error (RMSE) were used to rank the developed models.Log-transformed values yielded better results compared with the untransformed values. The resulting equations were tested for validation with processed data obtained from independent additional plots and were found to be desirable for estimating the merchantable volume for teak in Nimbia Forest Reserve, Nigeria.

Keywords: Volume equations; *Tectona grandis*; Nimbia; Dbh and Height

INTRODUCTION

Sustainable forest management requires estimates of growing stock. Such information guides Forest Managers in timber valuation as well as in allocation of forest areas for harvest. For timber production, an estimate of growing stock is often expressed in terms of timber volume, which can be estimated from easily measurable tree dimensions. The most common procedure is to use volume equations based on relationships between volume and other variables such as diameter and height (Akindele and LeMay, 2005). According to Avery and Burkhart (2002), volume equations are used to estimate average content of standing trees of various sizes and species. The reliability of volume estimates depends on the range and extent of the available data, and how well volume equations fit the data.

Teak is one of the most important tropical hardwood species of high quality timber in the international market. Its high durability, good dimensional stability and aesthetic qualities make it a very valuable timber species for industrial plantations. Its impressive rates of growth (when optimal sites are chosen) and the high demand for this hardwood for yatching, building and furniture production make it a very profitable option for both public and private forestry schemes (Tewari, 1992). Teak, though native to India, Myanmar (Burma), Thailand and Laos, grows nowadays in the whole intertropical region (excluding desert areas of Africa) (Bermejo *et al.,* 2004).

Efficient management of timber resources depends on accurate volume assessments of forest stands. The goal of timber management is to provide the mix of timber quality, quantity and size that will maximize owner satisfaction while resolving imposed constraints (Newberry, 1984). Consequently, accurate and flexible methods are required to estimate stand and tree growth and yield for evaluating the numerous management and utilization alternatives for timber resources (Sharma *et al.,* 2000).

As a sustainable supply of timber from natural forests shrinks and the demand continues to increase, the general trend in the future of teak growing will be towards increasing production and utilizing more plantation-grown teak (Pandey and Brown, 2000). This suggests a need for enhanced knowledge ranging from diverse aspects of teak plantation establishment as well as silviculture, management, utilization and the ecological aspects of both plantations and natural stands (Krishnapillay, 2000).

MATERIALS AND METHODS

Study Area

The study was conducted at the Nimbia Forest Reserve, Kaduna State, Nigeria. It covers an area of approximately 22 square kilometers (217 ha). The plantation consists of mostly *Tectona grandis* plots with very few *Gmelina arborea* plots. Nimbia forest reserve is located in the Southern Guinea Savanna zone of Nigeria in the Eastern part of Jema'a Local Government Area of Kaduna State, 70km South-east of Jos, along Jos-Kafanchan road. It lies between latitudes $8^0$20' and $9^0$32'N and longitudes $8^0$27' and $8^0$36'E with an elevation of about 600m above sea level. The position of Nimbia with respect to altitude (600m above sea level) induces orographic (topographic) rain and has an annual rainfall of between 1650 and 1700mm spread over a period of seven months (April - October) and five months (November - March) of dry period. Minimum temperatures range between 17 and 22^0C (December - March) and the maximum ranges from 28 and 35^0C (August - March). Relative humidity is between 30 and 36% in the dry season and 95% in the rainy season (Adegbehin, 2002).

Data Collection

Data for this study were obtained from the total number of 10 plots (20m x 20m) sampled randomly by stratification within the two age series of teak plantation in Nimbia forest reserve. The data consisted of the Dbh (1.3m above ground) and merchantable height. Within each randomly selected sample plot, preference was given to the enumeration of healthy trees with more typical growth forms; dead trees and trees with abnormal form were avoided. This was because the volume equations developed in this study are for the growing stock defined as living trees of commercial value classified as sawn-timber or poles, and which must meet grade, soundness and size requirements for commercial logs or poles. While this sampling guideline appeared to introduce a bias in favour of better-formed trees, it was justified because only healthy trees with good form are of commercial value and require volume computation.

Data Analysis

In this study, tree volume was computed using Newton's formula. The formula requires the use of tree height as well as the diameter at base, middle and top along the stem. Measuring tree diameter at these points ensures that tree form is taken into consideration, and this makes the Newton's formula more accurate than other common formulas such as Huber's and Smalian's formulas (Avery and Burkhart, 2002). According to Husch *et al.* (2003), Newton's formula is expressed as:

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

Where:
V = Tree Volume (m^3);
H = Tree height (m); and
D_b, D_m, and D_t are tree diameters at base (45cm above ground level), middle and top positions (7cm upper limit diameter), respectively.

In applying the formula, each diameter value was divided by 100 in order to convert it from centimetre to metre. This ensures that the volume was computed correctly in cubic metres. Microsoft Excel was used for the computation.

Regression analysis was conducted to generate equations relating tree volume (as dependent variable) to diameter at breast height and merchantable height (as independent variables). Linear ($V = a + bD^2H$) and logarithmic ($LnV = a + bLnD^2H$) functions were adopted.

Where:
V = Tree volume (m^3)
D^2H = Dbh square and height
Ln = Natural log
a and *b* are the parameters of the function.

The parameters of the functions were estimated using Statistical Package for the Social Scientists (SPSS) version 13. Some of the statistics generated from the regression analysis were used to evaluate the equations. These statistics include adjusted coefficient of determination (Adjusted R^2) and overall standard error of estimate (also called Root Mean Square Error). In addition, residual analysis was also performed to examine any violation of statistical assumptions regarding residuals.

RESULTS AND DISCUSSION

Table 1 shows that mean DBH ranged from 11.51 to 16.24cm, mean height ranged from 4.62 to 6.48m and mean merchantable volume ranged from 0.050567 to 0.118436m^3 in the sampled plots. It is evident that all the selected trees in the data set (Table 1) tend to follow similar trend of tapering from bottom to the top, which confirms the biological validity of the data set as indicated by Husch *et al.* (2003).

Table 1: Distribution of Dbh, height and volume across the plots

Stratum	Plot No.	No. of trees per plot	Mean Dbh (cm)	Mean Height (m)	Mean Volume (m^3)
A	04	21	15.80	5.60	0.09253
A	05	37	13.22	5.35	0.072941
A	16	35	15.71	6.24	0.118436
A	02	39	16.24	5.86	0.110099
A	11	36	12.96	4.99	0.062284
B	22	42	12.28	5.40	0.065517
B	09	43	13.65	6.48	0.080985
B	10	31	14.00	5.34	0.076355
B	03	41	11.51	4.62	0.050567
B	14	43	11.87	5.12	0.054804

Comparisons of the correlation coefficients between Dbh, height and volume (Table 2) showed significant positive relationships, thus the two independent variables (Dbh and height) can be used together to develop models for estimating volume. Akindele and LeMay (2005) found the relationship between height and volume as weak and positive and did not show any meaningful trend, which were attributed to the variability of the Crown Point for measuring upper limit merchantable height between and within species.

Using height in the volume equation generally provides a better estimate as it helps account for soil, climate and some cultural variations (thinning, weeding and pruning at regular intervals). In this case, standard volume equations were adopted using Dbh and height as independent variables to estimate merchantable volume as adopted by Pillsbury *et al.* (1998) and Bermejo *et al.* (2004).

Table 2: Coefficients of correlation between the variables

Variables	Correlation coefficient
Dbh vs height	0.588
Dbh vs volume	0.889
Height vs volume	0.683

Different equations were developed from regression analysis carried out, which were linear, log-transformed and quadratic in form. Three best models were selected and presented in Table 3 based on the Adjusted R^2, RMSE and F values. The equation ranked 1st was the double log equation with the highest adjusted R^2 and F values. This could be attributed to the assumption that Dbh and height are two different independent variables and combining them together in an equation may need some transformation of the original data as confirmed by Akindele and LeMay (2005). According to Husch *et al*. (2003), logarithmic transformation of Dbh and height is used to equalize the variation about the regression line and linearize a non-linear function. This is the normal procedure when fitting non-linear tree volume equations, because the logarithmic forms tend to reduce variance in homogenous samples. The two other equations ranked 2nd and 3rd were the simple linear and multiple linear equations, respectively.

Table 3: Volume equations using Dbh and height

Equation	Adjusted R^2	RMSE	F Value	Rank
$V = -0.158 + 0.012Dbh + 0.014H$	0.83	0.0247	879.68*	3rd
$V = 0.001 + 0.000065D^2H$	0.93	0.0160	4636.11*	2nd
$LnV = -9.413 + 0.968LnD^2H$	0.94	0.1649	5594.69*	1st

*denotes significant effect ($P<0.05$)

In order to confirm the validity of using these equations, residual analysis was conducted as pointed out by Huang *et al*. (2003), and it was discovered that all the three selected equations did not violate the statistical assumptions regarding the residuals. Therefore, the efficiency of using the selected equations was significant. Apart from the residual analysis, additional data were also collected from independent plots and used for computing volume using both Newton's formula and developed volume equations. The volumes were tested for significance using t-Test, and the result showed no significant differences (Table 4). This is an indication that the developed models are valid for use. The same procedure was adopted by Akindele and LeMay (2005) and Osho (1983).

Table 4: Results of paired t-Test of selected equations

Equation	t-Stat	t-Tab
$LnV = -9.413 + 0.968LnD^2H$	-0.412^{ns}	0.681
$V = 0.001 + 0.000065D^2H$	-0.704^{ns}	0.483

^{ns} denotes not significant ($P>0.05$)

CONCLUSION

Findings of this study confirmed positive correlation between the merchantable volume as dependent variable and Dbh as independent variable, while merchantable height showed weak correlation with volume. Therefore, using height alone can not give a better estimate of volume. For multiple regression modeling, the Dbh and merchantable height are the most suitable independent variables. Logarithmic transformation gives better results compared with other untransformed values. This is so because of high variability within and among species in terms of their size and height. It is not practicable to use the developed equations (Table 3) for other species in the same region and outside, therefore, similar studies should be conducted for other species available in the Nimbia Forest Reserve.

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