Volume estimation models from stump diameter for teak (*Tectona grandis* Linn f.) plantation in Nimbia forest reserve, Nigeria

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Five different equations were developed for teak (*Tectona grandis* (Linn. f.)) plantation in Nimbia forest reserve using stump diameter (Dst) as independent variable. The volume equations developed were linear, logarithmic and quadratic in nature. Stratified random sampling technique was employed to select 10 sampling plots for data collection. The number of trees per plot ranged from 21 to 43 with the total of 362 trees. The mean Dst and volume was 17.83 and 0.076607 respectively. Adjusted coefficient of determination (Adjusted $R^2$) and root mean square error (RMSE) were used to rank the developed models. The resulting equations were tested for validation with independent data set obtained from additional plots and were found to be desirable for estimating the merchantable volume for teak in Nimbia forest reserve, Nigeria.

**Key words:** Volume equations, teak, stump diameter and volume, Nimbia.

**INTRODUCTION**

Teak (*Tectona grandis*) is a genus of tropical hardwood trees in the family Verbenaceae, native to the South and South East Asia, and is commonly found as a component of monsoon forest vegetation. They are large trees, growing to 30 – 40m tall, deciduous in the dry season (Robertson, 2002). Teak is one of the most valuable timbers in the world on account of its outstanding properties. The sapwood is white to pale yellow-brown, narrow to moderately wide. The hardwood is a dark golden-yellow when fresh, turning to a dark golden-brown, sometimes with darker markings. On prolonged exposure to the weather, the colour becomes lighter. The grain is generally straight, but may occasionally be figured. Density is 670kg/m$^3$ at 12% moisture content. Plantation material may be lower in density. The timber has a distinct oily feel and this, with other properties, make the wood highly resistant to acids and fire (Hart, 1973). Teak possesses excellent properties and as such it has a very wide range uses, including flooring, decking, framing, cladding and barge boards.

Volume equations are mathematical expressions which relate tree volume to tree’s measurable attributes such as diameter at breast height and/or height. They are used to estimate the average content for standing trees of various sizes and species (Avery and Burkhart, 2002). In other words they give average volume of single trees of given dimensions (Van Laar and Acka, 1997). Clutter et al. (1983) and Husch et al. (2003), described that the volume of the stem of a tree is considered a function of the independent variable, diameter, height, and form which is expressed as follows:

$$V = f(D, H, F) \quad \text{………………….. (1)}$$

Where;
- $V$ = volume,
- $D$ = dbh,
- $H$ = total, merchantable, or height to some specific limit and
- $F$ = measure of form such as the Girrard form class or absolute form quotient.

Developing volume equations will guide the forester on the estimation of volume of timber per unit area as well as in forest resource management. In this study, stump diameter was used as independent variable in the volume equations. The establishment of volume equations from stump diameter is to enable the forester to convert stumps counted in the forest into harvested volumes, and thereby know the amount of wood that has been exploited from the forest. Efficient management of timber resources depends on accurate volume assessments of
forest stands and trees. The goal of timber management is to provide the mix of timber quality, quantity and size that will maximize owner satisfaction while meeting 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).

METHODOLOGY

The study area

The study was conducted at the Nimbia Plantation, 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°20’ and 9°32’N and longitudes 8°27’ and 8°36’E with an elevation of about 600m above mean 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 1650mm – 1700mm spread over a period of seven months (April - October) while the dry months are five months (November - March). Minimum temperatures range between 17°C to 22°C (December - March) and the maximum ranges from 28°C to 35°C (August - March). Relative humidity is between 30 – 36% in the dry season and 95% in the rainy season.

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 (15 and 20 years old) of teak plantation in Nimbia Forest Reserve. The data consisted of the stump diameter and merchantable volume. All tree stands within each randomly selected sample plot were enumerated. Preference was also 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 saw timber or poles, and which must meet grade, soundness and size requirements for commercial logs or poles.

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 form at these points ensures that tree form was 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:

\[
V = \frac{\pi H}{24} \left( D_b^2 + 4D_m^2 + D_i^2 \right) \quad \text{............... (1)}
\]

Where;

\[ V = \text{Tree Volume (m}^3\text{) measured over bark;} \]
\[ H = \text{Tree height (m);} \]
\[ D_b = \text{Stump diameter (45cm above ground)} \]
\[ D_m = \text{Diameter at middle position of tree} \]
\[ D_i = \text{Diameter at top (up to 7cm top diameter limit)} \]

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 stump diameter (as independent variable). Linear and logarithmic functions were adopted, and the parameters of the functions were estimated using relevant software such as Microsoft Excel and Statistical Package for 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 \( (R^2) \) 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

Summary of the field data was presented in table 1. The distribution of Dst ranged from 15.23cm to 20.81cm, Dbh ranged from 11.51cm to 16.24cm, and merchantable volume ranged from 0.050567 m\(^3\) to 0.118436m\(^3\) in all the sampled plots. It is evident that all the selected trees in the data set 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). There was a close relationship in terms of Dst, Dbh, and volume distribution across the selected plots.

Correlation analysis was carried out to establish relationship between the merchantable volume, Dst and Dbh. The results of correlation analysis indicate a strong positive correlation between the volume, Dst and dbh (table 2). The correlation coefficient of Dst vs dbh was 0.918 which is the highest value compared with other
Table 1. Data summary (n=362).

<table>
<thead>
<tr>
<th>Strata</th>
<th>Plot Number</th>
<th>Number of Trees</th>
<th>Mean Dst(cm)</th>
<th>Mean DBH(cm)</th>
<th>Mean Volume(m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>21</td>
<td>20.70</td>
<td>15.80</td>
<td>0.09253</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>37</td>
<td>16.90</td>
<td>13.22</td>
<td>0.072941</td>
</tr>
<tr>
<td>A</td>
<td>16</td>
<td>35</td>
<td>20.29</td>
<td>15.71</td>
<td>0.118436</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>39</td>
<td>20.81</td>
<td>16.24</td>
<td>0.110099</td>
</tr>
<tr>
<td>A</td>
<td>11</td>
<td>36</td>
<td>17.46</td>
<td>12.96</td>
<td>0.062284</td>
</tr>
<tr>
<td>B</td>
<td>22</td>
<td>42</td>
<td>16.87</td>
<td>12.28</td>
<td>0.065517</td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>43</td>
<td>17.40</td>
<td>13.65</td>
<td>0.080985</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>31</td>
<td>18.38</td>
<td>14.00</td>
<td>0.076355</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>41</td>
<td>15.23</td>
<td>11.51</td>
<td>0.050567</td>
</tr>
<tr>
<td>B</td>
<td>14</td>
<td>43</td>
<td>16.05</td>
<td>11.87</td>
<td>0.054804</td>
</tr>
</tbody>
</table>

Dst = Stump diameter (45cm above ground); DBH = Diameter at Breast Height (1.3m above ground); Stratum A = 20 years old; Stratum B = 15 years old

Table 2. Correlation analysis.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dst vs dbh</td>
<td>0.918</td>
</tr>
<tr>
<td>Dst vs volume</td>
<td>0.889</td>
</tr>
<tr>
<td>Dbh vs volume</td>
<td>0.889</td>
</tr>
</tbody>
</table>

Figure 1. Relationship between merchantable volume and stump diameter.

values in table 2, therefore the two independent variables (Dst and dbh) can be used interchangeably. In order to come up with the best relationship, the relationship was depicted in a scatter diagram (figure 1) and it reveals that
Figure 2. Residual plot for log Dst and log Volume regression.

Figure 3. Residual plot for volume log Dst regression.

Dst and Dbh had a strong positive curvilinear relationship with volume.

In order to avoid problem of co-linearity among the two independent variables (Dst and dbh) as indicated by Huang et al. (2003), only one independent variable was selected for developing volume estimation models. The essence of using stump diameter alone was because of illegal activities within the plantation and the only way of
estimating volume after exploitation is through the stumps. Similar relationships were obtained by Akindele (1985) and Akinnifesi (1988), therefore it will not be appropriate to combine these two independent variables in a single equation.

The developed models (table 3) are in simple linear, log and quadratic functions with a double log equation ranked 1st. The criteria adopted for ranking the models was through comparison of adjusted $R^2$ and RMSE which is one of the standard ways of ranking and validating models as pointed out by Huang et al. (2003). In spite that log-transformed models appeared to have higher adjusted coefficient of determination (Adjusted $R^2$), they also have relatively higher root mean square error (RMSE) which is not good predictor of best models. Therefore, the two factors (adjusted $R^2$ and RMSE) were considered in ranking and subsequent selection of the models.

The higher the adjusted $R^2$ values the better and the lower the RMSE the better. Akindele (1985) and Odunlami (1992) confirmed the efficiency of this procedure. The index of fit, which is the adjusted coefficient of determination ($R^2$), ranged between 0.72 and 0.85. This indicates that the variation in tree volume can be explained by the variation in stump diameter. The equations were not conditioned to pass through the origin since the dependent variable was merchantable, rather than total tree volume.

As noted by Avery and Burkhart (2002), for merchantable volume prediction, negative intercepts are expected. In this study, however, all the intercepts are negative. Once a model is fitted, an assessment of its validity using independent data set is needed to see if the quality of the fit reflects the quality of predictions. The basic idea behind model validation is to see if a fitted model provides acceptable performance when it is used for prediction.

At the end of the regression analysis where equations were developed, additional data sets from independent plots were used to validate the equations. Two volumes were computed, the first one using the Newton's formula and the second using the selected volume equations. Paired T-test was used to test for significance between the two volumes and the result showed a non-significant difference. This indicates that the developed volume equations are valid for volume estimation of teak plantation in Nambia forest reserve. In addition, residual plots were also plotted to see if there is any violation in the statistical assumptions regarding residuals and confirms the validity of these equations (figure 2 and 3).

**Conclusion**

Findings of this study confirmed that there was a strong positive correlation between the merchantable volume as dependent variable and Dst and dbh as independent variables. Therefore, using Dst and dbh alone can give good estimates of volume. Stump diameter alone could be a good estimator of volume in an event of illegal felling where it is not possible to obtain dbh and height measurements. The strong positive relationship between the Dst and dbh also makes it appropriate to use them interchangeably as 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 these equations for other species in the same region and outside, therefore, similar studies should be conducted for other species available in Nambia forest reserve. In the case of illegal activities within the plantation where trees are cut down and left only the stumps in the area, these equations are recommended for volume estimation i.e. to measure only the stump diameter to estimate the quantity of wood taken out of the plantation. Finally, the management of the plantation is advised to be conducting an inventory of the plantation from time to time so as to have reliable estimates of the plantation’s growth and yield performance.

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