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VOLUME MODELS FOR *Tectona grandis* (Linn F.) IN MBAVAA FOREST RESERVE, BENUE STATE, NIGERIA

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ABSTRACT

Tectona grandis (Teak) is a fast-growing exotic tree species utilised for numerous purpose such as pole and furniture making and it is one of the most preferred species for investment opportunities, due to its high wood quality and excellent growth performance. Effective management of Teak plantation requires information on volume of the growing stock of the plantation. In spite of the importance of volume models, accurate and site-specific models is not available for the study area. The objective of the study was to develop equations which best predict individual-tree volume that will evaluate and estimate the yield of Tectona grandis trees in Mbavaa Forest Reserve, Konshisha Local Government Area of Benue State. Simple random sampling was used in selecting sample plots. Temporary sample plots of size 20m x 20m resulting in Ten (10) plots was laid. Thirteen volume models which consisted of the simple linear regression models, multiple linear regression models and logarithmic transformed models were used for tree volume estimation. Diameter at breast height values ranged from between 25cm to 32cm. The logarithmic combined variable equation of diameter and height (equation 11) had more precision in the estimate, as displayed by the values of coefficient of determination, standard error of estimate and root mean square error) it was therefore selected as the best model for volume estimation for the study area. Precaution should be taking when applying the equation in other locations with similar site condition.

Keywords: *Tectona grandis*, volume models, linear models, model evaluation

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INTRODUCTION

The potential for growing and managing teak in various ecological zones and under diverse objectives is being increasingly recognized, this has led to intensive domestication and cultivation of the tree in countries beyond its natural habitat. Tree volume models are mathematical expressions that shows the relationship of tree volume to tree's measurable parameters like height and/or diameter. Volume models are applied to predict the mean content of standing trees of different sizes and species (Avery and Burkhart, 2002). Volume models have an important role in forest management. The significance of volume models is displayed through the various models and the never-ending search for their advancement.

Sustainable forest management needs predictions of growing stock, flexible and accurate equations which could estimate the volume of trees, individual log and the whole stands. This data guides forest managers in timber valuation and also in allocating the forest areas for timber harvest (Akindele and LeMay, 2006).

Growth rates, management and production objectives are unique to each country, the same volume models should not be used for different countries assuming the trees have same bole shapes (Vindhya and Bilas, 2018).

The establishment of teak plantation is an investment that involves a huge investment with a long gestation period. Private sectors, Communities and NGOs are uneager in investing their resources in establishing plantation due to dearth of information that will inform them about the growth rate and yield increment of these species. Unfortunately, such information is lacking for *Tectonia grandis* in Mbavaa Forest Reserve of Konshisha Local Government Area of Benue State.

There has been a decline in the supply of teak wood which has led to an increase in the creation of Teak plantations and community woodlots in Nigeria (Amusa and Adedapo, 2020). In Africa Nigeria has the largest teak plantation of about 70,000 hectares, this is an estimate of 52.7% of the total area which teak plantation covers in Africa (Dantani *et al*., 2019). Literature review on *Tectonia grandis* in which volume equations are reported from various countries such as Malaysia, Ghana and Costa Rica (Nunifu and Murchinson, 1999; Perez and Kanninen, 2003; Tewari *et al*., 2013). It cannot be used on teak stands in Mbavaa Forest Reserve due to the fact that data from this reserve was not used in these researches.

Tectona grandis. is an important wood plant that is cultivated in various tropical countries (Vindhya and Bilas, 2018). Teak is a fast-growing exotic tree species utilised for numerous purpose such as pole and furniture making and it is one of the most preferred species for investment opportunities, due to its high wood quality and excellent growth performance. Effective management of Teak plantation requires information on volume of the growing stock. Therefore, the need to increase the supply of Teak timber for socio-economic development through enough measurement of its stands to determine the volume and improve the quality and quantity of the stands is crucial.

Predicting the total volume of trees and stands, as well as the merchantable volume of standing trees and eventually harvested logs, is vital for the biological assessment valuation of Teak plantations. It is important to have precise estimate of the wood volume to be harvested and its actual commercial value prior to each thinning and the terminal harvest. To accomplish this, accurate volume models and sampling procedures have to be properly developed and enforced in the analysis. In Addition, accurate growth and yield projections and the resultant return-on-investment projections has to be made, and scientifically-based tools to know asset value (such as total and merchantable volume models) must be enforced to ascertain the financial credibility and attractiveness of a tree plantation project.

The objective of the study was to develop equations which best predict individual-tree volume for Teak in Mbavaa Forest Reserve, Konshisha Local Government Area of Benue State. The Volume equations for *Tectona grandis* is focused on Mbavaa Forest Reserve, Konshisha local government area of Benue state in Nigeria.

MATERIALS AND METHODS

The Study Area

This study was carried out in Teak plantation in Mbavaa Forest Reserve situated at Konshisha Local Government Area of Benue State, Nigeria as shown in Figure 1. The plantation is one thousand seven hundred and sixty-six (1766) hectares. Konshisha local government is named after River Konshisha which has its origin in Gboko local government. Konshisha local government area is located on a leveled land in the North-East of Benue state, situated in the middle belt of Nigeria. The plantation was established from 1985 till 1991 on grazed land. At present, the area is a mosaic of Teak plantations of different ages, cultivated under various management practices, surrounded by small grazed patches, small villages and secondary forests close to streams. The actual young plantations (1–5 years) were established in harvested areas after the first rotation. They were established following different methods depending on the site: (1) clones were planted in the most productive sites and were managed intensively using herbicide for weed control and

(2) the coppice method was used in less productive sites where weed control was done manually and only around trees that would remain until the final cut (low intense management).

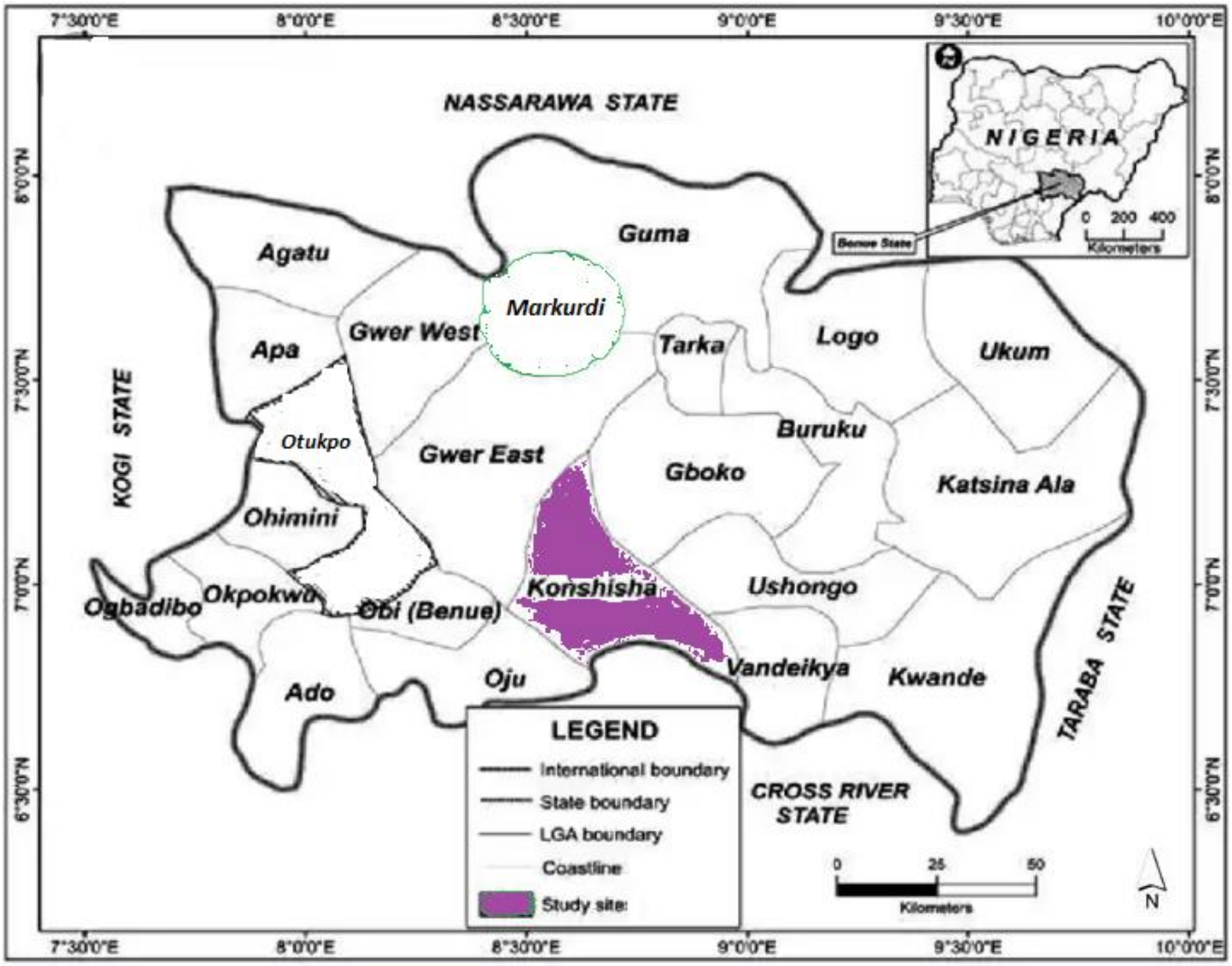

Figure 1: Map of the study area

Sample Plot

Simple random sampling was used in selecting sample plots. Temporary sample plots of size 20m x 20m resulting in Ten (10) plots was laid. A complete enumeration of trees larger than 10cm was carried out in the selected ten plots of *Tectona grandis* plantation.

Data Collection

Data were collected using diameter tape and Spiegel Relaskop to measure the diameter and height of Teak. Trees with no deformities were selected. Trees with deformities were not selected due to the fact that the volume models used in this study are for living trees of commercial importance classified as timber that need to meet the requirements for commercial logs. Measurements were limited to *Tectona grandis* plantation established at Mbavaa Forest plantation site.The following growth variables were measured.

i. Diameter at breast height: Diameter at breast height is the stem diameter at a position of 1.3m above the ground level.
ii. Diameter at the base.
iii. Total height.

Volume Computation

Volume of each tree in the plantation was computed as described in (Osho and Ajonina, 1999):

$V(M^3) = BA \times MH \times FF$ ….. (1)

Where

BA = Basal area, MH = Merchantable height and FF = Form factor

Form factor Determination

The form factor determination of the plantation was determined using Hohenald's formula (Osho and Ajonina, 1999). The formula is given below as

$$FF = 0.2\left[1+\left(\frac{d0.3}{d0.1}\right)^2+\left(\frac{do.5}{do.1}\right)^2+\left(\frac{do.7}{do.1}\right)^2\left(\frac{do.9}{do.1}\right)^2\right] \quad \ldots (2)$$

Where

Do.1 = diameter of the trees at 10% of length
Do.3 = diameter of the trees at 30% of length
Do.5 = diameter of the trees at 50% of length
Do.7 = diameter of the trees at 70% of length
Do.9 = diameter of the trees at 90% of length

Basal Area Computation

The basal area of each tree was computed as described in (Akinsanmi and Akindele, 2002):

$$BA(M^2) = \frac{\pi d^2}{4} \quad \ldots (3)$$

Where

BA = basal area, D = diameter at breast height, π = 3.142 and 4 = constant

Volume Models Generated

Thirteen (13) volume models which consisted of the simple linear regression models, multiple linear regression models and logarithmic transformed models were used for tree volume estimation. Tree volume was the dependent variable while the independent variables are diameter at the base, diameter at breast height and total height, which is expressed as follows:

$$V = b_o Db^{b1} \quad D^{b2}H^{b3} \quad \ldots (4)$$

Where V = volume, Db = diameter at the base, D = diameter at breast height, and H = total height. The simple linear model uses one variable (D), (Db), and combined variable (D^2H), and (DH) to estimate tree volume Simple and multiple regression analysis were used to develop the volume prediction equations (Husch *et al.*, 2003; Akindele and LeMay, 2006).

Not all tree inventories include height, the simple linear models using diameter are:

$V = ß_0 + ß_1(D)$ ….. (5)

$V = ß_0 + ß_1(Db)$ ….. (6)

When height is included in the equation it gives good estimate because it takes into account of climate and soil variations.

$V = ß_0 + ß_1(D^2H)$ ….. (7)

$V = ß_0 + ß_1(DH)$ ….. (8)

Logarithmic transformation of the independent variables in equation (5, 6, 7 and 8) was also used to estimate volume:

$\ln V = ß_0 + ß_1 \ln(D)$ ….. (9)
$\ln V = ß_0 + ß_1 \ln(Db)$ ….. (10)
$\ln V = ß_0 + ß_1 \ln(D^2H)$ ….(11)
$\ln V = ß_0 + ß_1 \ln(DH)$ ….. (12)

Multiple linear models are:

$V = ß_0 + ß_1(D) + ß_2(H)$ ….. (13)

$V = ß_0 + ß_1(D) + ß_2(D^2)$ ….. (14)

$V = ß_0 + ß_1(D) + ß_2(D^2H)$ ….. (15)

$V = ß_0 + ß_1(D) + B_2(H) + B_3(D^2H)$ ….. (16)

$V = ß_0 + ß_1 \ln(D) + ß_2 \ln(H)$ ….. (17)

Model Evaluation

The significance of model evaluation in knowing the predictive ability of an equation before its use (Tewari *et al.*, 2013). The statistical criteria used are:

Multiple Correlation Co-efficient

The (R) measures the degree of association between two variables (Z-Dependent variable and X Independent variable. The R- value should be high (> 0.50) for the model to be selected for estimation (Mead *et al.*, 1994).

$$R_{Z,xy} = \sqrt{\frac{r_{xz}^2 + r_{yz}^2 - 2r_{xz}\, r_{yz}\, r_{xy}}{1-r_{yz}^2}} \quad \ldots (18)$$

Where Z = dependent variable, x and y = independent variables, R = multiple correlation coefficient

Coefficient of Determination (R^2): It measures the proportion of variation in the dependent variable that is explained by the behavior of the independent variable. For the model to be selected for estimation of tree volume the R^2 value should be >50% (Thomas, 1977).

$$\boldsymbol{R^2} = 1 - \frac{SSE}{SST} \; ..... (19)$$

Where R^2 = Coefficient of determination, SSE (error/residual sum of squares), SST (Total sum of squares) and 1= regression line

Furnival Index

This is a good factor in comparing the precision of regression equations whose dependent variables are variously defined (Furnival, 1961). It gives the opportunity of comparing the precision of models with either untransformed or transformed dependent variable. The value should be small for the model to be selected. The formula is

$$\text{F1} = \frac{1}{[f'(Y)]}\sqrt{\text{MSE}} \; ..... (20)$$

Where $f'(Y)$ is the derivative of the dependent variable with respect to volume, MSE is the mean square error of the fitted equation, and the square bracket [()] is the geometric mean.

Regression Standard Error of Estimate: The value has to be quite small for the model to be chosen for estimation.

$$\sigma\text{est} = \sqrt{\frac{\sum(Y-\hat{Y})^2}{N}} \; ..... (21)$$

Where $(Y-\hat{Y}')^2$ = the squared errors of prediction, N = observation and σest = Regression Standard Error of Estimate

Significance of Regression

It was applied in testing the overall significance of the regression equation. The critical value of F (F-tabulated) at $p < 0.05$ level of significance was compared with the F-ratio (F-calculated). Where the variance ratio (F-calculated) is greater than the critical values (F-tabulated) the equation is significant and can is accepted for estimation.

Models Validation

It is important to validate volume equations used in order to be certain of their suitability and know if it can be applied in forest resource management (Aghimien *et al*., 2016).

The calibrating set had 190 (70%) of tree variables that was used to estimate total volume. The validating set had 82 (30%) tree variables.

Marshal and Northway, 1993 noted that for equations with good fit, there is no significant difference (p>0.05 or t-statistic < t-tabulated/critical) between the mean of the observed and predicted values with the result of the student t-test. Volume equations outputs was individually compared with observed volume using the Student t-test for paired means (Neter *et al*., 1996) and the simple linear regression equation (Amaro *et al*., 1998). The observed volume was the dependent variable while the predicted volume was the independent variable.

Alo, *et al*. (2011); Adekunle *et al*. (2013) and Aghimien *et al*. (2016), noted that for simple and multiple regression equation, the equation has to be significant ($p < 0.05$) have a very high F-ratio value, the observed and the predicted values should have high correlation, the coefficient of determination values should be very high (close to 100%) and the standard error of estimate must be small.

The following statistics were used to assess the goodness of fit for the models: Absolute Bias, Absolute percentage Bias, Root Mean Square Error (RMSE), t test and Furnival Index.

Root Mean Square Error (RMSE)

The Root Mean Square Error (RMSE) must be relatively small for the model to be acceptable for volume estimation and for management purposes (Adekunle *et al*., 2013). The formulas are below;

$$RMSE = \sqrt{\frac{\sum(y_i-\hat{y}_i)^2}{n-1}} \; ..... (22)$$

Where $y_i = actual\ value\ /observation,\ \ \hat{y}_i = predicted\ values\ of\ y_i$ and n = number of observations

The student t-test

This was used to test for any significant difference between the actual values or field values and the predicted values (model output) of the various models generated according to Goulding, (1979).

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_{X_1X_2} \cdot \sqrt{\frac{2}{n}}} \quad \text{….. (23)}$$

and,

$$S_{X_1X_2} = \sqrt{\frac{1}{2}\left(S_{X_1}^2 + S_{X_2}^2\right)} \quad \text{….. (24)}$$

Where:
$\bar{X}$ = Means for predicted and observed data respectively
$S_{X_1X_2}$ = Pooled standard deviation
This is also expected to show no significant difference in any of the species-size class at 5% level of significance.

Absolute Bias
The Absolute Bias should be small for the model to be considered good fit.

$$bias = \frac{\sum(y_i - \hat{y}_i)^2}{n-1} \quad \text{….. (25)}$$

Where $y_i = actual\ value\ /observation$, $\hat{y}_i = predicted\ values\ of\ y_i$ and n = number of observations

Percentage Bias Estimation
The absolute percentage difference (% bias) was determined by dividing the difference between volumes obtained with formula (observed volume) and models output by the same observed volume and multiplied by 100.
% bias = (V_o/V_p) 100 ….. (26)

Where
V_o =The observe volume
V_p =The predicted volume (models output)
The value must be relatively small for the model to be acceptable for management purpose.

RESULTS
Growth Estimate
The result of the tree variables measured are given in table 1. Diameter at breast height values are distributed between 25cm - 32cm, tree total height values are distributed between 9.2m - 18.6m and a standard deviation of 1.54.

Table 1: Summary of Tree Variables Measured for Model Generation

Tree variables	Number	Minimum	Maximum	Mean	SD	Range
Total height (m)	190	9.2	18.6	11.1	1.54	10.69
DBH (m)	190	0.25	0.32	0.27	0.03	0.23
Volume (m^3)	190	0.46	1.27	0.89	0.188	0.97
Form factor	190	0.63	0.84	0.72	0.02	0.59

SD = Standard Deviation

Volume Models
The Thirteen volume models used for total volume and their evaluation criteria is presented in Table 2. The results of the evaluation criteria show that four (4) models (models 11, 7, 15, and 17) out of the Thirteen (13) models performed excellently for estimation of total volume of teak. The results of combined linear models (Table 2), with model V = $ß_0 + ß_1(D^2H)$ had a coefficient determination (R^2) of 93% and model lnV = $ß_0 + ß_1 \ln(D^2H)$ had a R^2 of 97% with small standard error of estimate (SEE) of 0.04 and 0.07 respectively, a small RMSE of 0.05 and 0.004 with very high F-value of 1110 and 1156 respectively. The F-ratio was significant ($p<0.05$) for both models. V= $ß_0 + ß_1(D) + ß_2(D^2H)$ had a R^2 of 93% with a standard error of estimate (SEE) of 0.04, RMSE of 0.05 and high F-value of 595 while V = $ß_0 + ß_1 \ln(D) + ß_2\ln(H)$ had a R^2 of 96%, small standard error of estimate (SEE) of 0.01, RMSE of 0.001 and high F-value of 420.

Table 2: Volume models for *Tectona grandis* in Mbavaa Forest Reserve, Konshisha Local Government Area of Benue State, Nigeria

No.	Volume models	R^2 (%)	SEE	RMSE	F-Ratio	Furnival Index
5.	V=0.53-3.23(D)	69	0.01	0.04	927	0.04
6.	V=0.1-1.22(Db)	42	0.02	0.04	51	0.03
7.	$V=0.07+0.59D^2H)$	93	0.04	0.05	1110	0.01
8.	V=0.46-0.31(DH)	65	0.2	0.05	290	0.05
9.	lnV=1.51+1.24ln(D)	62	0.1	0.03	120	0.19
10.	lnV=0.29-1.091n(Db)	31	0.1	0.02	76	0.18
11.	$lnV=0.7+0.64ln(D^2H)$	97	0.07	0.004	1156	0.07
12.	lnV=3.65-2.97ln(DH)	74	0.2	0.05	287	0.15
13.	V=0.21-2.76(D)+0.02(H)	92	0.3	0.007	351	0.06
14.	$V=0.4-1.22(D)+2.88(D^2)$	63	0.4	0.006	42	0.13
15.	$V=0.48-0.62(D)+0.41(D^2H)$	93	0.04	0.05	595	0.08
16.	$V=0.29-2.59(D)+0.1(H)+0.32(D^2H)$	91	0.03	0.005	342	0.05
17.	lnV=-0.47+1.56ln(D)+1.24ln(H)	96	0.01	0.001	420	0.01

H = Total height (m), Db = Diameter at the base (m), D = Diameter at breast height (m), V = Volume (m^3) R^2 = Coefficient of Determination, SEE = Standard Error of Estimate and RMSE = Root Mean Square Error

Models V = $ß_0$ + $ß_1$(Db) and lnV = $ß_0$ + $ß_1$ln (Db) had coefficient of determination that was less than 50%.

Fit Statistics

The Root Mean Square Error (RMSE), Absolute Bias (BIAS), absolute percentage difference (%BIAS) and F-value for the models are presented in Table 3. These statistical indices served as a criterion in ranking the models in terms of accuracy of the volume models. The first ranked volume model is model 11, the second ranked volume model is model 17 and the third ranked volume model is model 7.

Table 3: Statistical Indices for the Models

No.	Models	RMSE	BIAS	%BIAS	F-value	Rank
5.	V= $ß_0$ + $ß_1$(D)	0.09	0.005	0.08	160	8
6.	V= $ß_0$ + $ß_1$(Db)	0.06	0.005	0.23	42	12
7.	V= $ß_0$ + $ß_1$(D^2H)	0.05	0.0005	0.06	372	3
8.	V= $ß_0$ + $ß_1$(DH)	0.03	0.007	-0.03	145	9
9.	lnV= $ß_0$ + $ß_1$ln(D)	0.09	0.002	0.16	91	11
10.	lnV= $ß_0$ + $ß_1$ln(Db)	0.09	0.007	0.25	19	13
11.	Lnv= $ß_0$ + $ß_1$ln(D^2H)	0.01	0.00001	0.01	520	1
12.	lnV= $ß_0$ + $ß_1$ln(DH)	0.09	0.002	0.08	170	7
13.	V= $ß_0$ + $ß_1$((D)+B_2(H)	0.06	0.0009	0.04	214	5
14.	V= $ß_0$ + $ß_1$((D)+B2(D^2)	0.07	0.007	0.14	131	10
15.	V= $ß_0$ + $ß_1$(D)+B_2(D^2H)	0.05	0.0006	0.04	364	4
16.	V=$ß_0$ + $ß_1$(D)+B_2(H)+B_3(D^2H)	0.07	0.0008	0.05	211	6
17.	lnV= $ß_0$ + $ß_1$ln(D)+B_2ln(H)	0.02	0.00002	0.03	410	2

H = Total height (m), Db = Diameter at the base (m), D = Diameter at breast height (m), V = Volume (m^3) R^2 = Coefficient of Determination, SEE = Standard Error of Estimate and RMSE = Root Mean Square Error

Validation of Volume Models

Thirteen (13) volume models were validated with data from eighty-two (82) trees which represents data for 30% trees that was used for model validation using simple and multiple linear regression equation. The result is presented in Table 5. Table 4 shows tree volume (m^3) ranged from 0.57 to 1.47 m^3.

Table 4: Descriptive statistics of Tree Variables Used for Validation

Tree variables	Number	Minimum	Maximum	Mean	SD	Range
Total height (m)	82	13.54	27.2	13.83	2.17	9.02
DBH (m)	82	0.30	0.36	0.29	0.03	0.15
Volume (m^3)	82	0.57	1.47	0.89	0.28	0.93
Form factor	82	0.70	0.99	0.85	0.05	0.26

SD = Standard Deviation

Table 5: Validation Results for the Volume Models

No.	Volume models	R^2 (%)	SEE	RMSE	F-Ratio
5.	V=0.48-2.73(D)	55	0.01	0.04	630
6.	V=0.2+1.51(Db)	42	0.02	0.03	38
7.	V=0.12+0.53D^2H)	92	0.03	0.05	651
8.	V=0.31-0.40(DH)	60	0.2	0.03	115
9.	lnV=1.83+1.21ln(D)	62	0.1	0.04	62
10.	lnV=0.15-1.011n(Db)	30	0.1	0.06	22
11.	lnV=0.4-0.49ln(D^2H)	95	0.09	0.006	614
12.	lnV=3.22-2.01ln(DH)	70	0.2	0.02	70
13.	V=0.15-1.53(D)+0.10(H)	91	0.2	0.009	214
14.	V=-0.3-1.01(D)+2.51(D^2)	61	0.5	0.005	78
15.	V=0.53-0.427D)+0.37(D^2H)	90	0.04	0.05	247
16.	V=0.23-2.21(D)+0.24(H)+0.43(D^2H)	91	0.02	0.001	317
17.	lnV=-0.47+1.56ln(D)+1.24ln(H)	94	0.01	0.001	342

H = Total height (m), D = Diameter at the base (m), D = Diameter at breast height (m), V = Volume (m^3) R^2 = Coefficient of Determination, SEE = Standard Error of Estimate and RMSE = Root Mean Square Error

Observed Validated Volume versus Predicted Validated Volume

All volume predicted were compared to observed volume using simple linear regression equation. The observed tree volumes were used as the dependent variable while the predicted tree volumes were used as independent variables. As shown in Table 6 there was high and very high Multiple Correlation Co-efficient (R) and coefficient of determination (R^2) for all the models, except model number 6 and 10 that has low R values (0.49 and 0.35 respectively). The t-test results shows that the t-statistics is less than the t-critical (tstatistic < t-tabulated/critical), which means there was no significant difference between the mean of the observed and predicted values with the result of the student t-test which implies that the models have a good fit (Table 6).

Table 6: Observed versus Predicted Tree Volume

S/No.	R	R^2 %	SEE	RMSE	F-val.	P val.	t- stat	t-critical
5.	0.69	64	0.03	0.003	45.71	0.98	0.12	11.23
6.	0.49	42	0.003	0.03	23.56	0.87	0.54	15.6
7.	0.94	93	0.002	0.02	435	0.92	-0.56	12.46
8.	0.67	62	0.001	0.01	56.38	0.95	0.35	8.76
9.	0.69	61	0.04	0.004	30	0.79	0.005	6.25
10.	0.35	32	0.03	0.03	31	0.88	0.02	7.28
11.	0.99	97	0.002	0.002	468	0.63	0.5	9.34
12.	0.75	73	0.005	0.05	34.13	0.97	0.03	10.68
13.	0.93	92	0.03	0.02	112	0.98	-0.56	8.72
14.	0.63	61	0.02	0.002	27.5	0.74	0.63	19.22
15.	0.96	93	0.1	0.001	387	0.69	-0.26	25.02
16.	0.96	91	0.02	0.002	442	0.75	0.37	24
17.	0.98	96	0.04	0.004	543	0.92	0.13	27.20

R = Multiple Correlation Co-efficient, R^2 = Coefficient of Determination, SEE = Standard Error of Estimate and RMSE = Root Mean Square Error

DISCUSSIONS

Thirteen (13) trees volume models were used and tested for teak stands volume estimation. The simple linear model with stump diameter as the only variable performed poorly with the data set compared with diameter and height combined and their logarithmic transformed models performed excellently with the data set. The combined variable equation of diameter and height has been used in volume estimation of various tree species with R^2 that is above 95% (Avery and Burkhart, 1994).

The statistical indices that was used to determine the accuracy of the volume models are root mean square error, absolute bias, percentage bias estimation and F-value the values were very negligible (Table 3). The figures were very low and this showed that the volume equations have accurate predictions with an error that is manageable (Adekunle *et al*., 2013). The logarithm transformed model $\ln v=b_0+b_1\ln D+b_2\ln H$ had a good fit and is good for tree volume prediction, the root mean square error, absolute bias, percentage bias estimation and F-value were very low. This is in line with the study of Aghimien *et al*. (2016), in developing growth and yield models for uneven-aged secondary forest in IITA, Ibadan, Nigeria he stated that the logarithmic transformed model performed excellently.

The validation set consisted of eighty-two (82) trees different from the ones that was applied to the volume models. The level of multicollinearity of the models was checked in terms of the fitting and validation data to ascertain that no possible error of multicollinearity appears. Model (8) had the lowest standard error of estimate figures in the validation data. The logarithmic combined variable equation of diameter and height (equation 11) had more precision in the estimate, as displayed by the values of coefficient of determination, standard error of estimate and root mean square error (Table 5) it was therefore selected as the best model for volume estimation. Equation 11 showed little error between observed and predicted volume (Table 6). (Vindhya and Bilas, 2018). Diameter at Breast Height and total height as independent variables are more accurate, easy to measure, has a high correlation with volume, less biased compared to single volume models and more reliable in estimating the volumes of diverse stems. The volume equation; $v=b_0 +b_1D^2H$ has a R^2 value of 93, this is good so as to reduce heteroscedasticity. Similar observations were made by other authors such as Aghimien *et al*. (2016), Akindele and LeMay (2006) and Cunia (1964). Bi and Hamilton (1998) stated that this variable represents the volume of a cylinder of diameter D and height H.

CONCLUSION

Logarithmic transformation gave good outputs compared with other untransformed equations. The combined variable equation of diameter and height was the only untransformed equation that performed best among the untransformed equations. The validation results indicated that the logarithmic transformed combined variable equation of diameter and height was the best equation for *Tectona grandis* in Mbavaa Forest Reserve.

Recommendations

It is recommended that:

i. Benue State Forest Department should maintain the database, introduce new technologies of management and continue updating the baseline information to increase its relevance to the national policy processes and the international reporting.

ii. Inventory should be carried out on a continuous basis to enable maintenance and development of competence. The cycle for re-measurement should be around 5 years. A short cycle is not cost efficient and a longer cycle cannot meet the needs of updated information.

iii. Permanent sample plots are recommended in the study area and maintenance of the network of the permanent sample plots through safeguarding the records and undertaking periodic visits to the permanent sample plot location.

iv. The equations can be used in similar site condition precaution should be taking when applying the equations in other locations.

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