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ESTIMATING STEM VOLUME USING BREAST HEIGHT AND STUMP DIAMETERS FOR *Tectona grandis* Lin F. IN AFE BABALOLA PLANTATION, ADO EKITI, NIGERIA

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ABSTRACT

Forest plantation has been identified as a quick fix to the attendant problems of deforestation. Information on appropriate volume models estimated with Diameter at Breast Height (dbh) and stump diameter of plantation grown species for sustainable management is inadequate. Therefore, this study was carried out to develop volume models using dbh and stump diameter for *Tectona grandis* in Afe Babalola plantation, Ado Ekiti, Nigeria. Four age series (22, 20, 14 and 11 years old) of *Tectona grandis* were purposively selected based on availability. A total of 40 temporary sample plots (20 x 20 m) were laid using stratified random sampling, considering each age series as a stratum, all trees with DBH ≥ 10cm in each plot were enumerated. Tree dbh, Diameter at Stump Height (DSH), Total Height (TH) and Merchantable Height (MH) were measured. Basal area (BA, m^2/ha) and Total Volume (TV, m^3/ha) were estimated. Five models were selected each for DBH and DSH to predict stem volume. The suitability of these models was evaluated and the best selected based on least Root Mean Square Error (RMSE), Akaike Information Criterion (AIC) and highest adjusted R^2 (R^2adj). Data were analyzed using descriptive statistics and regression at $\alpha_{0.05}$. The dbh observed ranges between 10.0 to 34.0 across all the age series while the mean height varied from 16.15±0.21m to 16.79±1.69m. The basal area ranged from 20.17m^2h^{-1} to 23.81m^2h^{-1}. The DSH ranges between 19.55±0.32cm and 19.43±0.26cm. The estimated merchantable volume range between 140.0±0.007m^3/ha and 167.32±0.005m^3/ha for the whole stand. The selected model for volume - DBH relationship was $V = 0.0000476D^{1.666} \times H^{1.296}$ (AIC = -2693.595, R^2adj = 0.8388, RSME = 0.0466) while for volume – DSH relationship, the best model was: $V = 0.2447 + 0.00591Dst + 0.0004Dst^2 + 0.0134H$ (AIC = -2642.177, R^2adj = 0.8285, RSME = 0.0480). Stand volumes can be estimated using the selected models.

Keywords: Stump diameter; volume models; *Tectona grandis*; Afe Babalola

INTRODUCTION

Tropical forests are exceptional in many admirations, structurally complex, rich genetically, diversified into several subtypes and highly productive in terms of biomass

(Turan, 2009). Forest comprises so many resources which is a very important renewable resource for timber, raw material for pulp and paper, charcoal, fuel wood and other forest genetic resources. In Nigeria the tropical rain forest comprises of three distinctive vegetation types, which includes freshwater swamp forest, mangrove as well as the lowland rainforest. While the mangrove forest is found entirely outside legally constituted forest reserves, others are found both within and outside forest reserves. This represent about 7% of the earth's land surface but are estimated to contain over 50% of its species (Richard and Rachael, 2013). It is ostensible that the tropical rainforest in Nigeria is under tremendous pressure and thus would require much effort for sustainable management.

Tectona grandis (Teak) is among the several exotic species planted widely in Nigeria. It has good anatomical and physical properties (Miranda *et al*., 2011). It is mostly used for several purposes; thus, it is incessantly demanded for (Miranda *et al*., 2011). Since the 1850s, Teak plantations have been broadly established throughout tropical region, because of its high timber quality, high market demand, valuation and cultivation. These unique properties and versatility of Teak timber and its famous suitability wide range of uses has been documented (Miranda *et al*., 2011). The Teak plantation in Afe Babalola University Ado Ekiti was established and managed by the Forest Management Department to meet timid population demand for timber and pole production in Nigeria.

However, Sustainable management of the forest requires enormous amount of relevant information most especially where management of a forest is done for production of valuable forest resources, raw materials and the assessment of present growth variables such as timber height, diameter and most importantly volume estimation of the future growth values are important. Illegal felling of trees had been a major challenge of tropical forests in the country. Where this act occurs, it is usually difficult to access the growth characteristics such as height and DBH because only the stump is left in the forest. In 2016, the Federal Ministry of Environment reported that the rate of depletion of Nigerian forest is 3.5% annually. Moreover, this rate of depletion was ascribed to illegal felling of timber species (Emeghara *et. al.*, 2012). As a result, evidence supported with related facts are needed for judicial reports.

Development of effective and accurate volume models is essential to predict the growth, valuation of timber loss, and proper decision making for forest managers. However, information on such models is so limited and also restricted to particular locations. In Nigeria, using stump diameter as the only independent variable to develop volume models for predicting tree volume has been limited (Onyekachi, 2020).

Stand models that provide accurate estimates of stand growth and yield have become essential tool for evaluating the numerous management and utilization decision. No single type of stand model can be expected to provide information efficiently for all levels of decision making (Adesoye, 2002 and Ige, 2017). Therefore, there is need for wide variety of models of varying degree of complexity for the management of natural and plantations forest.

Stand volume models are essential in order to estimate conveniently the standing volume and even when they have been harvested either legally or even illegally. This can also help in valuation and research purpose.

Where illegal logging occurs, the forest manager is still very much interested in defining or estimating the volumes of trees that were illegally removed and even when trees are legally removed, the remaining stump can serve as location or indicator for volume estimation where measurements of diameter at breast height (DBH) and tree height cannot be assessed. Hence, this study aimed at estimating stem volume using DBH and stump diameter as predictors with a view to predicting future yield of the forest for sustainable management of *Tectona grandis* plantation in Afe Babalola plantation, Ado Ekiti.

METHODOLOGY

The Study Area

The study was conducted in the *Tectona grandis* stands of Afe Babalola Plantation, Ado- Ekiti, Ekiti State which lies between Latitudes 7.5689^o and 7.5608^{o}N and Longitudes 5.2033^o and 5.2107^{o}E. (Fig 1). The vegetation of the study area is a moist semi-evergreen tropical rainforest. The plantation occupies a total land area of 33.1 hectares which has been divided into four compartments (Table 1) by the management. The focus of forest management is timber and pole productions.

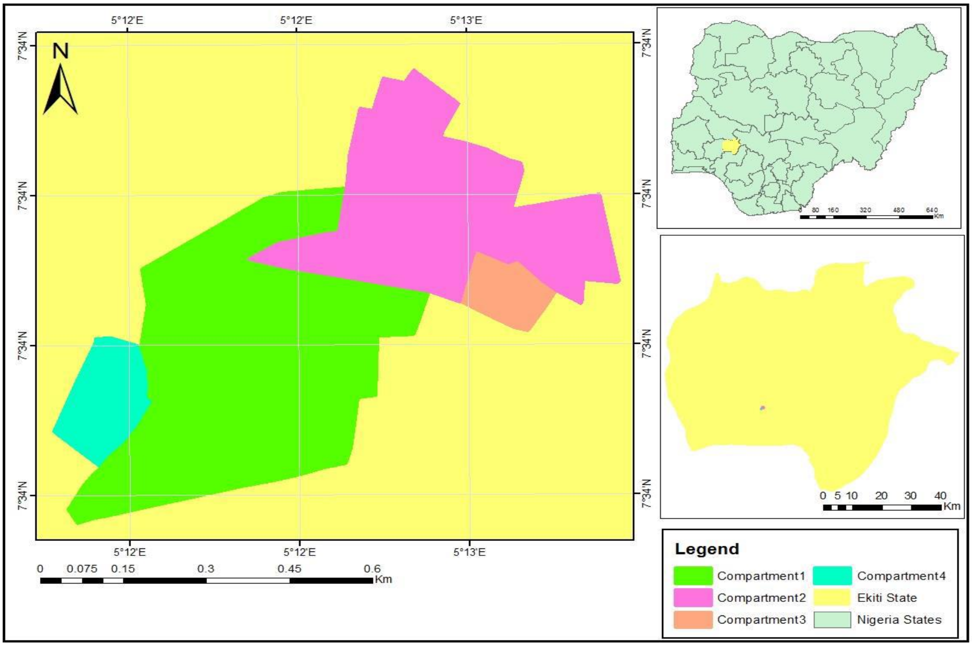

Figure 1: Map of Afe Babalola Forest Plantation, Ado Ekiti

Table 1: Compartments in Afe Babalola Teak Plantation

S/N	Compartment	Year Planted	Age (years)	Size (ha)
1	CA	2000	22	10.0
2	CB	2002	20	6.1
3	CC	2008	14	7.5
4	CD	2011	11	9.5

Data Collection

Stratified sampling technique was used for this study, whereby the plantation was divided into four compartments based on age differences. In each compartment (Table 1), 10 plots of 20 x 20 m were randomly laid, thereby making a total number of 40 sample plots. Within each plot, all trees with diameter at breast height (dbh) ≥ 10cm were measured for: Total tree height (Ht m), merchantable height (Mht m), dbh (cm), diameters at the base (Db cm), middle (Dm cm), top (Dt cm) and stump diameter (Dsm cm).

Data Processing

Basal Area Computation

Individual tree basal area within each sample plot was computed as follows:

$$BA = \pi(\frac{Dbh^2}{4}) \ldots\ldots 1$$

Where BA = basal area (m^2), Dbh = diameter at breast height.

Tree Volume Estimation

The individual tree volume was computed using Newton's formula as follows:

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

Where V = stem volume, H = total height, Db = tree diameter at base, Dm = diameter at middle, Dt = diameter at top

Models Development

Five candidate models were selected for model calibration to estimate stem volume from stump diameter:

1. $V = a \times Dst^b + £$ …………………………...……...... 3
2. $V = a + b \times Dst^2 + £$ …………………………….... 4
3. $V = a + b \times Dst + c + Dst^2 + £$ ………………… ...5
4. $V = b_0 + b_1(Dst) + b_2 + b_3(H)$ …………………..... 6
5. $V = b_0 + b_1(Dst) + b_2(H)$ ……………………… 7

Where V = volume, Dst = diameter at stump, £ = error term, H = total height, a, b, b_0, b_1, b_2 are equation parameters to be estimated.

Five models were also selected as candidate models for estimating stem volumes using dbh:

1. $V = a + b_1D + b_2D^2$ ………………………………………………… 8
2. $\ln V = a + b_1 \ln D$ ………………………………………………… 9

3. $V = aD^2 + bD + c$ ... 10
4. $V = b_0 + b_1 D^2 H + \varepsilon_i$ ... 11
5. $V = a \times d^b \times ht^c$ ... 12

Where V= volume, b_0, b_1= are equation parameters D =diameter at breast height, H = height and ε_i=error term, lnV and lnD is natural log of volume and dbh respectively; a, b, c are equation parameters.

Model Verification and Validation

a. The Mean Square Error (MSE). This is a measure of the spread of the data and therefore, an indication of the precision of the predicted response. The suited and best model must have least MSE value. This is expressed as:

$$MSE = RSS/_{n - p} \quad \ldots 13$$

b. The Adjusted Square Multiple Correlation Coefficients (R_a^2). The model with highest value is considered the best. This is given as:

$$R_a^2 = 1 - \text{MSE}\left[n - 1/_{n - p}\right]$$
$$R_a^2 = 1 - \text{MSE}\left[n - 1/_{TSS}\right] \quad \ldots 14$$

Where:
p = number of parameters in the model
n = number of observations
RSS = Residual sum of square
TSS = Correlated total sum of squares

c. Akaike information criterion (AIC). Model with least AIC is always selected as the best. The AIC is of the form:

$$AIC = 2k - 2*\ln(\text{L}) \quad \ldots 15$$

Where:
K = number of estimated parameters in the model
ln = Natural logarithm
L = the maximized value of the likelihood function for the model

d. The significance of each regression coefficient in the models were tested using the Student's t-test (eq 16) for paired observations. The t-values were compared with the critical value of t at α = 0.05 level. Where t-calculated for the regression coefficient exceeded the critical value of t, the independent variable was considered significant and vice-versa. The paired sample student T-test used is as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_{X_1X_2} \cdot \sqrt{\frac{2}{n}}} \quad \ldots 16$$

Where:

$$S_{X_1X_2} = \sqrt{\frac{1}{2}(S^2_{X_1} + S^2_{X_2})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 17$$

$\overline{X}$ = Means for prediction model and real data respectively
$S_{X1\&X2}$ = Pooled standard deviation

RESULTS

Summary of Growth Characteristics

As shown in Table 2, the growth variables were statistically summarized for all the age series. Across the four-age series (22, 20, 14 and 11 years old), the respective mean dbh of individual trees includes 16.42±0.28cm, 15.56±0.20cm, 16.36±0.21cm and 16.66±0.24cm.

Table 2: summary of growth characteristics

Variables	Statistic	Age Series (Years)			
		22	20	14	11
DBH (cm)	Mean	16.42±0.2777	15.57±0.1976	16.36±0.2102	16.66±0.2449
	Minimum	10.00	10.00	10.00	10.00
	Maximum	34.00	24.30	26.50	28.50
Total Height (m)	Mean	16.15±0.2129	16.28±0.1745	16.40±0.1711	16.79±0.1607
	Minimum	6.00	5.50	7.90	8.90
	Maximum	34.80	27.1000	25.0000	25.30
Merch. height (m)	Mean	12.18±0.1882	13.67±0.1734	13.66±0.1745	13.22±0.1602
	Minimum	2.20	2.80	5.00	3.50
	Maximum	28.80	24.00	24.00	24.00
Basal Area (m2)	Mean	0.0230±0.0008	0.0201±0.0005	0.0221±0.0006	0.0230±0.0007
	Minimum	0.0079	0.0079	0.0079	0.0079
	Maximum	0.0908	0.0464	0.0552	0.0638
	Total	6.4530	6.6370	6.6656	5.8422
Total Volume (m3)	Mean	0.2077±0.0084	0.1744±0.0055	0.2159±0.0071	0.2304±0.0343
	Minimum	0.0287	0.0322	0.0361	0.0475
	Maximum	0.7109	0.5578	0.7714	8.7825
	Total	58.581	57.7418	65.2153	58.5282
Merchantable Volume (m3)	Mean	0.1589±0.0067	0.1468±0.0047	0.0287±0.0009	0.1844±0.0296
	Minimum	0.0077	0.0188	0.0047	0.0345
	Maximum	0.5882	0.4407	0.1009	7.5627
	Total	44.81	48.62	8.54	46.85
No of stands/ha	Mean	781	904	1120	899
	Minimum	550	700	1000	775
	Maximum	1100	1300	1275	1125
	Total	7810	5514	8400	8541

Moreover, the mean Diameter at Stump Height (DSH) recorded are 19.55±0.32cm, 17.91±0.23cm, 18.89±0.24cm and 19.43±0.26cm, respectively for 22, 20, 14 and 11 years old. Furthermore, the mean values for height for all age series (22, 20, 14 and 11 years old) are 16.15±0.21m, 16.28±0.17m, 16.40±0.17m and 16.79±0.1607m, respectively. For the merchantable volume, the mean values for each age series (22, 20, 14 and 11 years old) are 0.16±0.0067m3, 0.15±0.0047m3, 0.0287±0.0009m3 and 0.1844±0.0296m3 respectively.

While the merchantable volume estimated were 140.0±0.007m3/ha, 151.92±0.005m3/ha, 194.97±0.006m3/ha and 167.32±0.005m3/ha for 22, 20, 14 and 11 years old stands, respectively. The number of trees per hectare for each age series (22, 20, 14 and 11 years old) ranges from 550 – 1100 stems/ha, 700 – 1300 stems/ha, 1000 – 1275 stems/ha and 775 – 1125 stems/ha, respectively. Hence, 22 years old stand had the least number of trees while 14 years old stand had the highest.

Fitted Model Functions and Validation for the Whole Stand

Parameter estimates and model performance criteria for volume-DSH and volume-dbh models are presented in Table 3. For volume-DSH, model V4 performed better in terms of R2 (0.8285), RMSE (0.0480), and smaller AIC (-2642.177) than other fitted models while for volume-dbh model V10 performed better with R2 (0.8388), RMSE (0.0466), and smaller AIC (-2693.595) than other fitted models. The mean predicted volume (models' outputs) obtained by substituting the validating set into the equations is shown in Table 4. It was observed that there was no significant difference between the observed and predicted volume using the selected models. Hence it could be deduced that the models V4 and V5 have good fit.

Table 3: Model function for the whole stand

Model Name	Model function for pool data	b_0	b_1	b_2	b_3	RSME	AIC	R^2adj
				Diameter at stump height				
V1	$V = ADSH^b$	0.0009120	1.8397808			0.06302	-2199.619	0.7049
V2	$V = a+bDSH^2$	0.001130	0.0005256			0.0609	-2255.692	0.7244
V3	$V = a+bDSH+c(DSH^2)$	-0.09721	0.01035	0.00028		0.0595	-2293.47	0.7372
V4	$V = a+b(DSH)+c(DSH^2)+d(Ht)$	-0.2447	0.0059	0.0004	0.0134	0.0480	-2642.177	0.8285
V5	$V = a+b(DSH)+c(H)$	-0.3468	0.0181	0.0131		0.0516	-2526.98	0.8024
				Diameter at breast height				
V6	$V = a+bD+cD^2$	-0.2190	0.02679	$-6.164e^{-05}$		0.0601	-2277.216	0.7319
V7	$\ln V = a+b\ln D$	-7.8868	2.2096			0.3016	364.5673	0.7564
V8	$V = aD^2+bD$	-0.2190	-6.164e-05	0.0268		0.0601	-2277.216	0.7319
V9	$V = a+bD^2H$	0.01673	$3.857e^{-05}$			0.0479	-2649.053	0.8295
V10	$V = aD^bH^c$	4.760e-05	1.666	1.296		0.0466	-2693.595	0.8388

Table 4: model validation

Model Name	Model form	Model validation for pooled data form DST				
		Mean of Observed value	Mean of predicted value	Validation T-Value	P-Value	Shapiro wilk
V4	$V = a+b(Dst)+c(Dst^2)+d(H)$ $V = 0.2447+0.00591Dst+0.0004Dst^2+0.0134H$	0.1961	0.1927	0.3923	0.695	$2.2e^{-16}$
V5	$V = a+b(Dst)+c(H)$ $V = -0.3468+0.0181Dst+0.0131H$	0.1961	0.1954	0.0861	0.9314	$2.2e^{-16}$
			Model for pooled data Form for DBH			
V9	$V = a+bD^2H$	0.1961	0.1957	0.0518	0.9587	
V10	$V = aD^b \times H^c$ $V = 0.0000476D^{1.666} \times H^{1.296}$	0.1961	0.1961	0.0038	0.997	

DISCUSSION

High proportion of trees with small diameter values observed in this study could be due to lack of proper maintenance of the plantation since establishment and their geographical distribution could be affected by environmental factors such as soil moisture, organic matter, and elevation among others. Similar remark was made by Ige (2017) on influence of environmental factors on species composition and distribution in a community forest in Nothern Thailand. While variability in growth and number of trees in each age series may be ascribed to the observed removal of trees in some part of the plantation. The same was reported by Aigbe *et. al.* (2014) who also observed variability in stand growth in Afi River forest reserve. Furthermore, as observed in this study, the plantation entails trees with good heights as compared with the diameter of the trees. This may also connote that trees in this plantation can much more be used for pole production rather than timber production considering the current stand age.

Out of the selected five linear and nonlinear volume – dbh relationship models, the best developed volume - dbh model is: $V = 0.0000476D^{1.666} \times H^{1.296}$ (AIC = 2693.60; R^2adj = 0.838, RSME 0.047). This is very much suitable for volume estimation of the plantation. However, for volume – stump relationship, five linear and nonlinear models were also selected in which out of these, the best equation was the linear equation suitable for volume-stump relationship estimation and this is given as: $V = 0.2447+0.00591Dst+0.0004Dst^2+0.0134H$ (AIC = 2642.18, R^2 adj = 0.8285 and RSME 0.048). Hence, this shows that DBH is a good variable for predicting tree volume because it has the highest R^2adj, lowest AIC and RSME values and can be easily measured as compared to DSH. This contradicts what was reported by Humphrey *et. al.* (2014); and Shamaki and Akindele (2013) who reported that DSH as a good predictor of tree volume. Although both can be used depending on individual's choice, the DSH can be used especially where the tree has been felled.

These results indicated that for both volume- dbh as well as volume-DSH, models which entails the variable 'Height' (Ht) combined performed as the best models and this includes models V4 and V10. This is similar with what was reported by Akindele (1990) and Aibge *et al.* (2013) who also reported that volume models with heights performed very well in volume estimation using DSH and dbh. However, for dbh, the nonlinear model (model V10) was observed as the best which is nonlinear curve that provides better estimate of the volume of trees with large diameter (dbh $\geq$ 20) followed by model V4. While the single-entry models without heights did not perform very well. The same was reported by Salis *et al.* (2006).

CONCLUSION

It can be concluded that, tree volume of Afe Babalola plantation can be predicted from stump diameter and therefore considered as an important tree characteristic that can estimate tree volume with relative accuracy even in the case timber trespass, and this will ensure proper and effective management of the plantation. Furthermore for DBH, a nonlinear model which entails stem height (V $=0.0000476D^{1.666} \times H^{1.296}$) was observed as the best model and was used to develop the DBH-volume model for the whole stand which can be used to predict volume for the plantation while for stump a linear model with stem height included also (V$=0.2447+0.00591Dst+0.0004Dst^2+0.0134H$) was observed as the best model and was used to develop volume-DSH model for the whole stand. The developed models should be useful in all incidents or cases of pre- and post-harvest of *Tectonia grandis* in the study area.

According to the result obtained from this research work, it is recommended that application of volume-DBH as well as volume-DSH models developed during this study can be used for proper and effective management of the plantation as it will help the forest manager to know the extent of the forest area and even estimate the loss and worth of the timber in case of illegal felling. Each age series should have their own specific management plans as growth characteristics differs according to age series.

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