DEVELOPMENT OF VOLUME MODELS FOR TEAK(*Tectona Grandis*)(LINN F.) STANDS IN OGWASHI-UKWU FOREST RESERVE, DELTA STATE, NIGERIA.

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Abstract

This study was carried out to develop tree volume (V) models for *Tectonagrandis* using diameter at breast height (Dbh) and stump diameter (Dst) as a predictor variable.The objective was to investigate the relationship between V, Dbh and Dstfor *Tectonagrandis* stands in Ogwashi - Ukwu Forest Reserve and to implement it for sustainable forest management. Systematic sampling technique (systemic line transect) was employed for laying of plots. Two transects with a distance of 500 m between them were laid and sample plots of size, 20m x 20m (0.04 ha) were laid in alternate direction along each transect at 250 m interval and thus summing up to 4 sample plots per transect and a total of 8 sample plots.Several regression equations were fitted to the empirical data and analyse dusing Microsoft Excel and SPSS software computer package. The regression equations were fitted for choosing the best model. The following equations were adjudged the best out of the several regression equations fitted. The equations were

$V = 0.02 + 7.36\,x10^{-5} Dbh^2 H_T$;

$lnV = -11.10 + 0.00 D_{st}{}^2 + 1.70\,x10^{-5} D_{st}{}^2 H_T + 1.082 lnD_{st} H_T$;

$V = 0.006 + 7.4\,x10^{-5} Dbh^2 H_m$

and $V = -0.63 + 6.36\,x10^{-5} Dst^2 H_m$.

This indicates model significant status for the purpose of prediction. Residual analysis showed that error is normally distributed and variance is constant along regression line. The result of data validation between predicted and observed values using paired t-test showed no significant difference (P>0.05). The study showed that stump diameter is suitable for tree volume estimation, especially when Dbh is unavailable and that linear regression equations may not be appropriate in fitting individual tree volume equations for the forest reserve under investigation, which made data transformation necessary and needed.

Keywords: *Tectonagrandis*, tree volume, stump diameter, diameter at breast height, modelling, Ogwashi - Ukwu.

Introduction

Tectonagrandis(Teak) is a genus of tropical hardwood trees in the family Vabenaceae, native of the South and South-East Asia, and commonly found as a component of monsoon forest vegetation (Robertson, 2002). They are large trees growing up to 30-40 m tall which is 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 hard wood is dark golden brown, sometimes with darker markings (Hart, 1973).

According toTurner(2001), the tropical ecosystem contains more plants and animal species than any other biome, making it the most diverse of all terrestrial ecosystems.The need to sustainably manage this rich ecosystem is imperative.However, Ogwashi – Ukwu Forest Reserve have not been sustainably managed due to inadequate management tools. With the rate Nigeria forests are being depleted at alarming rate under poor management techniques, there is need to adopt sound management programme to revive the dwindling forest resources. Global forest resources assessment revealed that Nigeria is one of the five countries in the world with the highest annual rate of deforestation for the period 2000 – 2010 (FRA, 2010). Between 1990 and 2000, Nigeria lost about 2.7% of its forests to deforestation which increased to about 18.56% (about 2.06 million ha) between 2000 and 2010 (FRA, 2010; FAO, 2011). Lack of modelling tools for sustainable and adequate estimates of growing stocks within the forest plantation is also a challenge. Such information guides forest managers in timber valuation and proper management prescriptions (Akinsanmi, 1999).Volume equations are used to appraise average value of standing tree of various species and sizes (Avery and Burkhart, 2002). Where unapproved logging activities occurs, the plantation supervisor is still concerned in assessing the volume of trees illegally felled and even when trees are legally taken away, the stump can still serves as reference where diameter at breast height (Dbh) and tree height measurement cannot be made(Aigbe *et al.*,2012). Thus, volume equation that has diameter at breast height (Dbh) as predictor variable only cannot be used directly (Aigbe *et al.*, 2012).

Therefore, this study was conducted to develop tree volume equations for *Tectonagrandis* stands in Ogwashi – UkwuForest Reserve, Delta State, Nigeria from diameter at breast height and stump diameter.

Materials and Method

This study was conducted in Ogwashi-Ukwu Forest Reserve in Aniocha South Local Government Area of

Delta State, Nigeria. The geographic boundaries are set by latitude 6°00º - 6º 25ºN and longitude 6º 5º- 6º 25º E. It has a total area of 258 ha, with natural lowland rainforest occupying less than 27 ha (10.5%) while the logged areas have been regenerated with foreign tree species (FORMECU, 2000). The pattern of rainfall is bimodal, with maximum periods in July and September, and an annual average between 1600 – 2000mm. Average annual temperatures are between 25 – 29°C and a relative humidity of 75% (Meteorological Service Station, 2013). The entire region built up by the sedimentation of the Niger Delta and consists of the delta in various stages of development. According to Perekeme (2000), the geology of study area is covered by various degrees of gneis, isolated deposition of amphibolite, granites andshits. The vegetation is completely secondary forest that is made up of *Gmelinaarborea* and *Tectonagrandis* with intrusion of taungya farming practice at its peripheries. The vegetation is meaningfully of humid forest (NEST, 1991).

Methods of Data Collection

Sampling Technique

The sampling design employed was Systematic sampling technique (systemic line transect). Two transects with a distance of 500 m between them were laid at the centre of *Tectonagrandis* stands.20m x 20m (0.04 ha)sample plots were laid in alternate direction along each transect at 250 m interval and thus summing up to 4 sample plots per transect and a total of 8 sample plots. In each plot, the outside bark stump diameter (Dst) of the tree were measured at 10 cm above ground (since all timber exploitation done in the plantation shows that trees were cut at this point), Diameter at breast height (Dbh) (taken at 1.3m from ground), merchantable tree height (taken at point between ground level and point of the first surviving whorl of branch), total tree height, outside bark diameter at base, middle and top position were all measured. Individual tree volume was calculated using the Newton's formula (Husch,*et al*, 1982).

Data Analysis

Preliminary Data Analysis

The preliminary analysis of the plantation data enabled computation of individual tree volume and per-hectare estimates of stand variables from the raw data. The procedure used at this stage is the mean tree method used by Abayomi (1984) and Akindele (1989, 1992). The calculation also included the range of value (minimum and maximum). The procedures include the following steps:

(1) Estimation of minimum, maximum and mean basal areas per hectare from dbh using the formula:

$BA = \pi D^2/4$………… equation 1

Where:

BA = basal area (m^2)

π = 3.142 (a constant)

D = Dbh (m)

(2) Calculation of tree volume for each of the trees in each plot, using Newton's formula (Husch*et al*. 1982).

$$V = \frac{h}{6}\left(A_b + 4A_m + A_t\right) \text{.............. equation (2)}$$

Where:

V = tree volume (m^3)

h = tree height (m)

A_b = Cross –sectional area at the base (m^2)

A_t = Cross –sectional area at the top (m^2)

A_m = Cross –sectional area at the middle (m^2)

(3) Estimation of stand variables on a per-hectare basis

The variables estimated on per-hectare basis were basal area and volume. Total parameters per plot were obtained by adding the parameters of all individual trees within the plot. Mean plot parameters were then computed by summing the total parameters of all the sample plots and dividing by the number of sample plots selected in the stands. Parameters per hectare were obtained by multiplying the mean plot parameters by the number of sample plots per hectare.

Model Development

The preliminary data results were the basis for the statistical data analysis investigation of the relationships between the variables which were analyzed using Microsoft Excel and SPSS software computer package. Several regression equations were fitted to the data. The equations were evaluated and compared on the basis of overall standard error of estimate, variance ratio and coefficient of determination,. Some of the regression equations tried were:

$V = b_1D$……………… equation 3

$V = a + b_1 D$…….. … equation 4

$V = aD + b_1D^2$……... equation 5

$V = a + b_1D + b_2D^2$……. equation 6

$V = a + b_1D^2$………..... equation 7

$\text{In } V = a+b_1\text{In}D$……... equation 8

Where a is regression constant and b_1 and b_2 are regression coefficients

V = Volume of tree in m^3

D = stump diameter/Dbh in m

The relationships between variables were analyzed using correlation and graphs.

Model Validation

The validation data (i.e. the one tenth of the data observed value) set aside for model validation and not use for model calibration were used for this purpose. The validation was carried out by testing for significant difference between the actual (observed) value and the predicted value using paired t- test. If there is no significant difference ($P < 0.005$) between the observed and predicated values, then it means the model is acceptable. (Aigbe *et al*, 2013).

Results and Discussion

TREE GROWTH ATTRIBUTE

A total of 177individual trees were measured in eight temporary sample plots from the *Tectonagrandis* stands. The results as shown in Table 1 indicated that the mean Dbh and stump diameter were 34.38 cm and 40.00 cm respectively, while the mean total tree and merchantable height were 5.09 m and 12.42 m respectively. *Tectonagrandis* shows disparity in growth characteristic contrary to anticipation as shown in Table 1. The disparity could be due to inadequate attention given to the forest estate since the time of establishment. There were large gaps between some trees, signifying that there was no beating up at the early stage of plantation establishment.

The mean value for total tree volume per hectare and merchantable volume per hectare were674.74m^{3}ha^{-1}and 279.44 m^{3}ha^{-1}respectively. The mean volume per hectare recorded in this study are higher than the values reported for tropical rainforest ecosystems in Nigeria by previous researches (e.g. Adekunle*et al.*, 2004 who reported 181.36 m^3/ha in Shasa Forest Reserve; 227 m^3/ha in Ala Forest Reserve; 91.71 in Omo Forest Reserve; andAdekunle and Olagoke, 2008 who reported 262.36m^3/ha). The higher values obtained in this study is an indication that Ogwashi – Ukwu Forest Reserve is rich in timber resources.

The mean basalarea per hectare was47.23 m^{2}ha^{-1} (Table 1).The value of the mean basal areaper hectare (47.23 m^2) could be attributed to the density of trees in the Forest Reserve. The implication for the value of mean basal area per hectare is that the forest is well stocked when compared proportionally with report of Alder and Abayomi (1994), which stated that for a well-stocked rainforest in Nigeria, the mean basal area is 15m^2. The value of mean basal area per hectare obtained in the forest reserve was higher than what was reported by Adekunle *et al*, (2004) and Onyekwelu *et al.* (2008) for some tropical forests in southwestern Nigeria; Aigbe and Oyebade (2014) for *Terminalia ivorensis* in Sokponba Forest Reserve.

Table 1: Summary Statistics of *Tectonagrandis* in Ogwashi – Ukwu Forest Reserve

Variable	Minimum	Maximum	Mean ± SE
Diameter at breast height (cm)	17.80	72.10	34.38 ± 0.73
Stump diameter (cm)	24.00	78.50	40.00 ± 0.73
Merchantable height (m)	3.00	7.00	5.09 ± 0.065
Total height (m)	9.40	14.60	12.42 ± 0.075
Basal area per hectare (m^2/ha)	30.69	68.79	47.23 ± 5.33
Merchantable volume per hectare (m^3/ha)	170.65	403.49	279.44 ± 1.39
Total volume per hectare (m^3/ha)	403.40	1021.00	674.74 ± 39.07

DEVELOPMENT OF MODEL

The correlation coefficients between the various individual tree growth parameters are presented on Table 2. The Table shows that Dbh and stump diameter had strongest linear relationship (r = 0.986) follow by Dbh/BA (r = 0.983) and BA/total volume (r = 0.982) respectively. Merchantable height and basal area had the weakest linear relationship (r = 0.380) (Table 2).The high correlation coefficients between diameter at breast height stump diameter and stump diameter(r = 0.986) suggests that the stump diameter could serve as substitute to diameter at breast height inestimation of tree volume. This particular relationship between stump diameter and volume will be very useful to forest manager in quantifying the trees illegally removed from the forest, thereby increasing surveillance activities against illegal activities. By implication, tree stump diameter – volume model will be a good management tool for the forest reserves under study since it can be used to estimate the volume of trees removed from the forests if the stump diameter is known. Comparable results have been reported for pines and oaks (Bylin, 1982), teak (Osho, 1983), Bald cypress (Parresol, 1998) and Gmelina (Akindele, 2003).

Table 2: Correlation Matrix for the Tree Growth of*Tectonagrandis* in Ogwashi – Ukwu Forest Reserve

	Dbh(cm)	***THT(m)***	***MHT(m)***	***D_s(cm)***	***BA/m2***	***Mvol/m3***	***Tvol/m3***
Dbh(cm)	1						
THT(m)	0.657	1					
MHT(m)	0.422	0.625	1				
D_s(cm)	0.986	0.677	0.454	1			
BA/m2	0.983	0.590	0.380	0.971	1		
Mvol/m3	0.937	0.625	0.554	0.957	0.957	1	
Tvol/m3	0.962	0.638	0.420	0.977	0.982	0.977	1

Dbh-Diameter at breast height; THT- Total tree height; MHT- Merchantable height; D_s-Stump diameter; BA-basal area; Mvol- Merchantable volume; Tvol- Total volume

The scatter diagram of the dependent and predictor variables are shown in figures 1a –d. It is evident from the scatter plots of the relationships between tree variables (Figures 1a – d) that none of the predictor variableshad perfectly linear relationship with tree volume. This shows that linear regression equations may not be appropriate in fitting individual tree volume equations for the forest reserve under investigation, which made some data transformations necessary

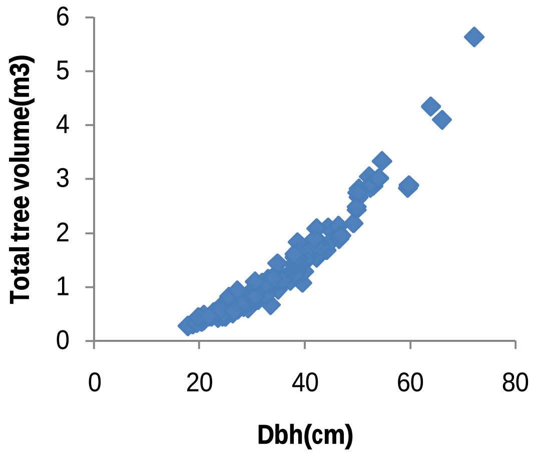

Figure 1a: Relationship between total tree volume and Dbh

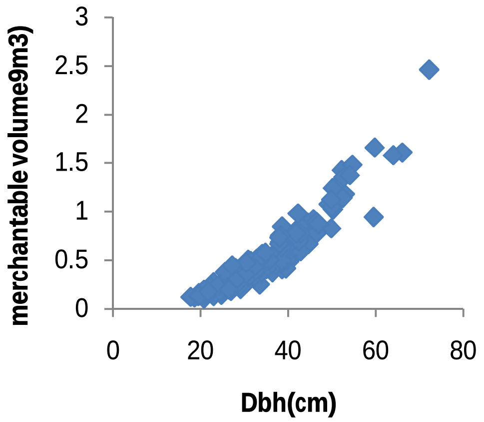

Figure 1b: Relationship between Merchantable volume and Dbh

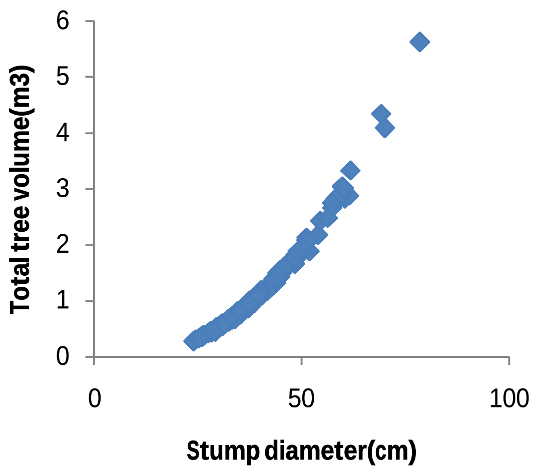

Figure 1c: Relationship between Total tree volume and Stump diameter

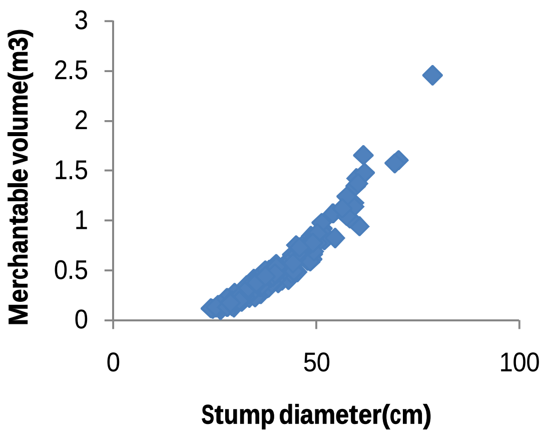

Figure 1d: Relationship between Total tree volume and Stump diameter

The parameters of tree growth models developed in this study are presented on Tables 3 – 6. The tree model is based on the relationship between total volume, merchantable volume and other tree growth variable predictors.Several volume equations were fitted to the predictor variables(Tables 3 – 6) and the best volume equations were selected. The equations adjudged the best were based on highest adjusted coefficient of determination, lowest standard error and highest F ratio. Equations code 6 and 12 wereadjudged the best for total volume based on Dbhand stump diameter respectively (Tables 3 and 4) while equations code 6 and 6 were adjudged the best for merchantable volume based on Dbh and stump diameter respectively (Tables 5 and 6). This suggests that data transformation is effective in stabilizing errorvariance, and the use of the D^2H as a weightingfactor in this study appeared to be appropriate for reducingheteroscedasticity. Theresidual plots for the model generallyindicate an even spread of residuals above and below the zeroline, with no systematic trend (Figures 2a–d).The Figures indicated a homogenous distribution of residuals, which implies independence of experimental errorand suggests thatthe assumption of linear regression do not appear to have been violated by the equations. The results of the t-test carried out to validate each of the equation at 95% probability level, shows that there was no significant difference ($p > 0.05$) between predicted and observed values for all the models (Table 7).The coefficientof determination (R^2) for the models, ranged between 0.981 and 0.999. This suggests that a substantial proportion of the variation in treevolumeis explained by Dbh, stump diameter, merchantable height and totaltree height.

Table 3: Total Tree Volume Models for *Tectonagrandis* in Ogwashi – Ukwu Forest Reserves Based on Diameter at Breast Height

Code	Model Form	α_0	β_1	β_2	β_3	R^2_{adj}	SEE	F ratio
1.	$V = \alpha + \beta(lnDbh) + \varepsilon_i$	-3.343	1.103	-	-	0.195	0.718	43.28
2.	$V = \alpha + \beta(lnDbh^2) + \varepsilon_i$	-3.342	0.650	-	-	0.195	0.713	43.28
3.	$V = \alpha + \beta Dbh^2 + \varepsilon_i$	0.590	0.000	-	-	0.221	0.702	39.25
4.	$lnV = \alpha + \beta(lnDbh^2) + \varepsilon_i$	-7.328	1.050	-	-	0.964	0.111	4665
5.	$V^{-1} = \alpha + \beta(lnDbh^2) + \varepsilon_i$	8.952	-1.115	-	-	0.854	0.248	1055
6.	$V = \alpha + \beta Dbh^2 H_T + \varepsilon_i$	0.020	7.36 x 10^{-5}	-	-	0.981	0.111	8999
7.	$V = \alpha + \beta(lnDbh^2 H_T) + \varepsilon_i$	-10.17	1.197	-	-	0.814	0.346	772
8.	$lnV = \alpha + \beta(lnDbh^2 H_T) + \varepsilon_i$	-9.001	0.948	-	-	0.972	0.097	6170
9.	$lnV = \alpha + \beta_1 Dbh + \beta_2 Dbh^2 + \varepsilon_i$	-2.928	0.111	0.000	-	0.963	0.111	2314
10.	$lnV = \alpha + \beta_1 Dbh^2 H_T + \beta_2 \ln Dbh^2 H_T + \varepsilon_i$	-8.256	5.337 x 10^{-5}	0.872	-	0.974	0.095	3253
11.	$V = \alpha + \beta_1 {D_{bh}}^2 + \beta_2 {D_{bh}}^2 H_T + \beta_3 lnD_{bh} H_T + \varepsilon_i$	-0.305	0.004	0.000	0.067	0.307	0.605	27
12.	$lnV = \alpha + \beta_1 {D_{bh}}^2 + \beta_2 {D_{bh}}^2 H_T + \beta_3 lnD_{bh} H_T + \varepsilon_i$	-8.273	0.000	1.294 x 10^{-5}	0.864	0.974	0.094	2174

Table 4: Total Tree Volume Models for *Tectonagrandis* in Ogwashi – UkwuForest Reserves Based on Stump Diameter

Code	Model Form	α_0	β_1	β_2	β_3	R^2_{adj}	SEE	F ratio
1.	$V = \alpha + \beta \ln(Dst) + \varepsilon_i$	-4.192	0.738	-	-	0.179	0.720	39
2.	$V = \alpha + \beta ln(Dst^2) + \varepsilon_i$	-4.192	0.738	-	-	0.179	0.720	39
3.	$V = \alpha + \beta Dst^2 + \varepsilon_i$	0.539	0.000	-	-	0.189	0.716	42
4.	$lnV = \alpha + \beta \ln(Dst^2) + \varepsilon_i$	-9.197	1.259	-	-	0.996	0.037	42716
5.	$V^{-1} = \alpha + \beta \ln(Dst^2) + \varepsilon_i$	10.80	-1.318	-	-	0.861	0.224	1093
6.	$V = \alpha + \beta Dst^2 H_T + \varepsilon_i$	-0.163	6.41 x 10^{-5}	-	-	0.996	0.046	54138
7.	$V = \alpha + \beta ln(Dst^2 H_T) + \varepsilon_i$	-12.68	1.413	-	-	0.850	0.310	1001
8.	$lnV = \alpha + \beta ln(Dst^2 H_T) + \varepsilon_i$	-10.90	1.110	-	-	0.997	0.030	6575
9.	$lnV = \alpha + \beta_1 Dst + \beta_2 Dst^2 + \varepsilon_i$	-3.738	0.126	0.000	-	0.995	0.043	16172
10.	$lnV = \alpha + \beta_1 Dst^2 H_T + \beta_2 \ln Dst^2 H_T + \varepsilon_i$	-10.73	8.515 x 10^{-7}	1.091	-	0.997	0.030	33194
11.	$V = \alpha + {D_{st}}^2 + \beta_2 {D_{st}}^2 H_T + \beta_3 lnD_{st} H_T + \varepsilon_i$	-1.984	0.003	0.000	0.233	0.273	0.677	22
12.	$lnV = \alpha + \beta_1 {D_{st}}^2 + \beta_2 {D_{st}}^2 H_T + \beta_3 lnD_{st} H_T + \varepsilon_i$	-11.10	0.000	1.700 x 10^{-5}	1.082	0.999	0.018	59410

Table 5: Merchantable Volume Models for *Tectonagrandis* in Ogwashi – Ukwu Forest Reserves Based on Diameter at Breast

Code	Model Form	α_0	β_1	β_2	β_3	R^2_{adj}	SEE	F ratio
1.	$V = \alpha + \beta(lnDbh) + \varepsilon_i$	-1.322	0.521	-	-	0.161	0.320	32
2.	$V = \alpha + \beta(lnDbh^2) + \varepsilon_i$	-1.322	0.261	-	-	0.161	0.320	35
3.	$V = \alpha + \beta Dbh^2 + \varepsilon_i$	0.259	0.000	-	-	0.176	0.317	38
4.	$lnV = \alpha + \beta(lnDbh^2) + \varepsilon_i$	-8.515	1.091	-	-	0.906	0.191	1693
5.	$V^{-1} = \alpha + \beta(lnDbh^2) + \varepsilon_i$	23.49	-2.941	-	-	0.777	0.857	614
6.	$V = \alpha + \beta Dbh^2 H_m + \varepsilon_i$	0.0066	7.4 x 10^{-5}	-	-	0.982	0.047	9596
7.	$V = \alpha + \beta(lnDbh^2 H_m) + \varepsilon_i$	-3.705	0.489	-	-	0.805	0.155	729
8.	$lnV = \alpha + \beta(lnDbh^2 H_m) + \varepsilon_i$	25.61	-2.637	-	-	0894	0.645	1216
9.	$lnV = \alpha + \beta_1 Dbh + \beta_2 Dbh^2 + \varepsilon_i$	-3.994	0.118	0.000	-	0.905	0.192	838
10.	$lnV = \alpha + \beta_1 Dbh^2 H_m + \beta_2 \ln Dbh^2 H_m + \varepsilon_i$	-8.591	1.055 x 10^{-5}	0.887	-	0.976	0.096	3611
11.	$V = \alpha + \beta_1 {D_{bh}}^2 + \beta_2 {D_{bh}}^2 H_m + \beta_3 lnD_{bh} H_m + \varepsilon_i$	-0.078	-4.459 x 10^{-6}	2.730 x 10^{-5}	0.047	0.178	0.317	14
12.	$lnV = \alpha + \beta_1 {D_{bh}}^2 + \beta_2 {D_{bh}}^2 H_T + \beta_3 lnD_{bh} H_T + \varepsilon_i$	38.62	0.000	0.000	-4.359	0.949	0.408	1102

Table 6: Merchantable Volume Models for *Tectonagrandis* in Ogwashi – Ukwu Forest Reserves Based on Stump Diameter

Code	Model Form	α_0	β_1	β_2	β_3	R^2_{adj}	SEE	F ratio
1.	$V = \alpha + \beta \ln(Dst) + \varepsilon_i$	-1.681	0.597	-	-	0.151	0.322	32
2.	$V = \alpha + \beta ln(Dst^2) + \varepsilon_i$	-1.681	0.269	-	-	0.151	0.322	39
3.	$V = \alpha + \beta Dst^2 + \varepsilon_i$	0.238	0.000	-	-	.151	0.322	32
4.	$lnV = \alpha + \beta \ln(Dst^2) + \varepsilon_i$	-10.51	1.312	-	-	0.947	0.144	3128
5.	$V^{-1} = \alpha + \beta \ln(Dst^2) + \varepsilon_i$	28.49	-3.494	-	-	0.788	0.834	657
6.	$V = \alpha + \beta Dst^2 H_m + \varepsilon_i$	-0.063	6.36×10^{-5}	-	-	0.996	0.021	44823
7.	$V = \alpha + \beta ln(Dst^2 H_m) + \varepsilon_i$	-4.54	0.564	-	-	0.834	0.143	884
8.	$lnV = \alpha + \beta ln(Dst^2 H_m) + \varepsilon_i$	-29.69	1.110	-	-	0.878	0.634	1263
9.	$lnV = \alpha + \beta_1 Dst + \beta_2 Dst^2 + \varepsilon_i$	-4.897	0.135	0.000	-	0.946	0.145	1540
10.	$lnV = \alpha + \beta_1 Dst^2 H_m + \beta_2 \ln Dst^2 H_m + \varepsilon_i$	-10.48	2.905×10^{-6}	1.072	-	0.997	0.033	30642
11.	$V = \alpha + {D_{st}}^2 + \beta_2 {D_{st}}^2 H_m + \beta_3 lnD_{st} H_m + \varepsilon_i$	-0.508	1.397×10^{-5}	1.429×10^{-5}	0.096	0.153	0.322	12
12.	$lnV = \alpha + \beta_1 {D_{st}}^2 + \beta_2 {D_{st}}^2 H_m + \beta_3 lnD_{st} H_m + \varepsilon_i$	49.26	0.000	0.000	-5.452	0.969	0.321	1913

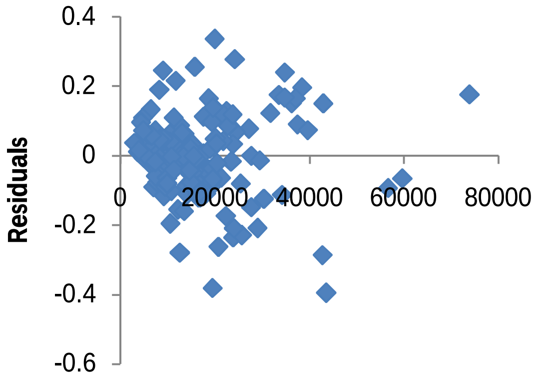

Figure 2a: Residual plot using Total tree volume function based on Dbh^{2}THT

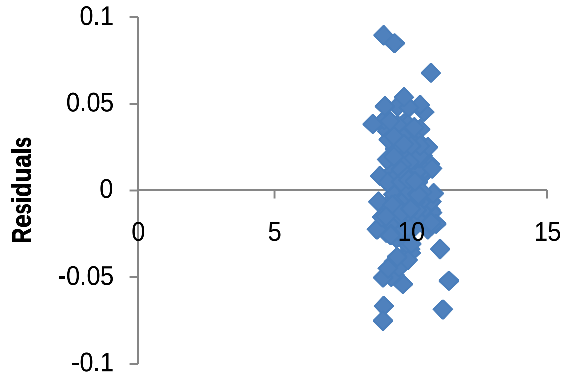

Figure 2b: Residual plot using LnTotal tree volume function based on Dst^2, Dst^{2}THT & lnDst^{2}THT

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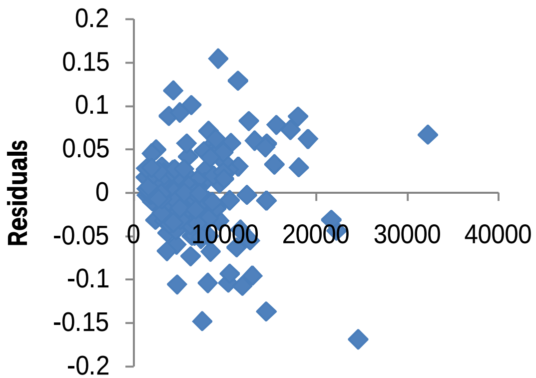

Figure 2c: Residual plot using Merchantable volume function based on Dbh^{2}MTH

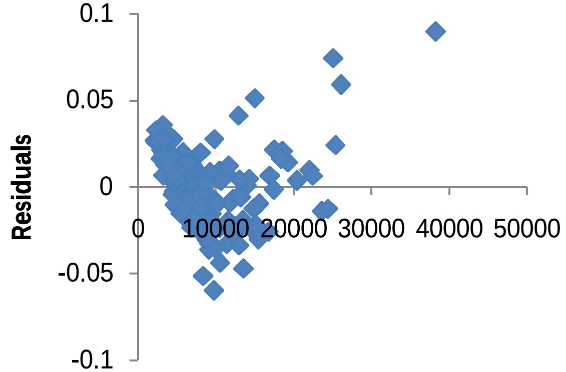

Figure 2d: Residual plot using Merchantable volume function based on Dst^{2}MHT

Table 7: Results of model validation fortree growth models in Ogwshi – Ukwu Forest Reserve

Model Form	t_{cal}	$t_{critical}$	$R_{o/p}$	M_o	M_p	Remark
$V = \alpha + \beta Dbh^2 H_T + \varepsilon_i$	0.0024	1.974	0.99	1.220	1.220	Ns
$lnV = \alpha + \beta_1 D_{st}{}^2 + \beta_2 D_{st}{}^2 H_T + \beta_3 lnD_{st} H_T + \varepsilon_i$	1.259	1.974	0.93	1.220	1.294	Ns
$V = \alpha + \beta Dbh^2 H_m + \varepsilon_i$	0.0801	1.974	0.99	0.5053	0.5055	Ns
$V = \alpha + \beta Dst^2 H_m + \varepsilon_i$	0.2522	1.974	0.99	0.5053	0.5049	Ns

t_{cal}- t calculated, $t_{critical}$- critical t, $R_{o/p}$- correlation between observed and predicted values, M_o- mean of observed values, M_p- mean of predicted values, ns – not significant at $p \geq 0.05$

Conclusion

This study revealed that Diameter at breast height and stump diameter had strong linear relationship indicating that one could serve as substitute for the other in tree volume estimation. This study also proved that the relationship between stump diameter/ tree volume and dbh/tree volume is not perfectly linear indicating that linear regression equations may not be appropriate in fitting individual tree volume equations for the forest reserve under investigation, which made data transformation necessary and needed. The volume model developed is recommended for use by the management of the reserves inregulating cut, a basis for establishing compartment as a management unit in the forest reserve,determination of the optimal allocation of timber resources to satisfy a given management objective when there are competing uses and also for allocation of forest land for harvest.

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