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Regression Models for Tree Volume Prediction in Stands of *Tectona grandis* (Linn) at Federal College of Forestry, Jericho, Ibadan, Oyo State Nigeria

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ABSTRACT

The suitability of regression models for tree volume predictions in stands of *Tectona grandis* at Federal college of forestry, Ibadan was established in this study. Three regression models were developed each comprises of two models resulting into six models in all. Tree growth variables such as diameter at breast height (Dbh), diameter at the base (Db), diameter at the middle (Dm), diameter at the top (Dt) and tree height were measured to estimate the tree volume using Newton formula for tree volume estimation. The tree growth variable measured in the study area shows that the total basal area encountered per hectare was 610.64m^2 while the total volume was found to be 15135.63m^3 per hectare. The models developed showed that model 3a and 3b were found to be more suitable for tree volume prediction in the context of the data used. Models 1a and 1b were found inadequate and this cannot be used in tree volume prediction. Model 2a and 2b were found to be averagely adequate hence 3a and 3b proved best. Based on the evaluation of the models examined in this study model 3a and 3b were found to be more suitable and fit for volume prediction. The frequencies and yield prediction with the models are significantly different from their observed values according to the validation result with analysis of variance (ANOVA) and T-test values. Therefore, all categories of models generated in this study with good fit are recommended for volume prediction in *Tectona grandis* plantation at federal college of forestry Ibadan, Nigeria.

KEYWORDS: Model, volume prediction, *Tectona grandis*, residual plots.

INTRODUCTION

Sustainable management of forest resources requires a large amount of supporting information. Especially when managing a forest for production of commercially valuable materials, estimation of present growth of variables which are not possible to measure easily (such as timber volume) and to estimate the growth values in future are essential.

Vanclay (1994) defined stand growth models as abstractions of the natural dynamics of a forest stand, which may encompasses growth, mortality and other changes in stand composition and structure. Therefore Forest models can be used as very successful research and management tools. The models designed for research require many complicated and not readily available data, whereas the models designed for management use simpler and more readily accessible data (Nurudeen, 2011).The development of effective and accurate models to predict forest growth and products during the forest rotation is essential for forest managers and planners. Growth and yield models, which rely on functions to measurement data from a sample of the forest population of interest are the tools that have mainly been used to provide decision-support information that meets basic operational needs for evaluating various forest management scenarios (Avery and Burkhart, 2002). 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 Akca, 1997). The volume of the stem of a tree is considered a function of the independent variables, diameter, height, and form (Clutter *et al.,* 1983; Husch, *et al.,* 2003). Foresters need to know every detail about the forest they are managing in terms of location, size, quantity and quality of forest resources available and how these resources are changing over time. This information can be obtained through proper resource modeling. Growth and yield modeling are very useful tools for managing forest properties either large or small. They are used for operational and strategic planning in nations that own and manage forest lands.

Modeling is also good for decision making regarding buying, selling, and trading in forest resources. Forest management implies performing series of treatments in complex productive systems. The purpose of management planning is to provide a basis for the allocation of these treatments so that the desired result can be obtained. In order to do this, management goals must be formulated, effective treatment options capable of producing the desire results must be found and outcome of treatment in the productive system (predicting the result of various management activities) must be described. Lund (1985) noted that these treatments might be timber harvest, pasture improvement, pre-commercial thinning etc. All these components together form a forest management planning system and are made possible through growth and yield modeling.

METHODOLOGY

STUDY AREA

The study was carried out at Federal College of Forestry Ibadan, located on Longitude 3.51^{0}E and Latitude 7.28^{0}N. The annual temperature ranges from minimum of 18.07^{0}C to an average maximum of 34.4^{0}C.

SAMPLE PLOT LOCATION

The stand of *Tectona gradis* plantation was investigated. One hectare was selected at well stocked portion of the stand in the study site. Temporary sample plot of size 20m x 20m resulting in 25plots per hectare were laid. A complete enumeration of all the trees were carried out in the selected hectare for the stand making a total of 25 plots in the entire stand of *Tectona grandis* plantation examined.

TREE GROWTH VARIABLE MEASUREMENT

Measurements were limited to *Tectona gradis* plantation established at Federal College of Forestry 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 top, middle and base

iii. Total height of all trees in the stand using Spiegel relaskop.

iv. Mean dominant height (i.e. height of four largest trees in a plot representing the largest trees per hectare).

DATA ANALYSIS

Basal Area Calculation

The basal area of each tree was calculated using the formula:

$$BA = \frac{\pi D^2}{4}$$

Where BA = Basal area (m^2), D = Diameter at breast height (cm) and л = pie (3.142).

The total BA for each plot was obtained by adding all trees BA in the plot

$BA_p = \sum BA_{tree}$

The mean BA for the plot was calculated with the formula

$$BAp = \frac{\sum BA}{n}$$

Where BA_p = mean Basal area per plot,

n = number of plots or sampling unit.

Basal area per hectare were obtained by multiplying mean basal area per plot with number of plots in an hectare (25 plots)

$BA_{ha} = BA_p \times 25$

VOLUME ESTIMATION

The volume for each tree in each sample plot were estimated using Newton's formular of Hustch et al (2003).

$$V = \pi H \left[\frac{Db^2 + 4Dm^2 + Dt^2}{24} \right]$$

Where V = Volume (m^3)

H = height (m)

Db = Diameter at the base

Dm = Diameter at the middle

Dt = Diameter at the top and

π = 3.142

The plot volumes were obtained by adding the volumes of all the trees in the plot (Vp) while mean plot volume were obtained by dividing the total plot volume by number of sample plots.

Volume of trees per hectare (V_{ha}) was estimated by multiplying the Vp by the number of plots in an hectare.

$V_{ha} = V_p \times 25$

MODELS ADOPTED

1a. $V = b_0 + b_1Ba + b_2Ba^2 + b_3Ba^3$

1b. $V = b_0 + b_1\ln Ba + b_2(\ln Ba)^2 + b_3(\ln Ba)^3$

2a. $V = b_0 + b_1Dbh + b_2Dbh^2 + b_3Dbh^3$

2b. $V = b_0 + b_1(\ln Dbh) + b_2(\ln Dbh)^2 + b_3(\ln Dbh)^3$

3a. $V = b_0 + b_1H + b_2H^2 + b_3H^3$

3b. $V = b_0 + b_1(\ln H) + b_2(\ln H)^2 + b_3(\ln H)^3$

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Where V=Volume (m^3), Ba=Basal area (m^2), Dbh= Diameter at breast height (m), H= Tree height (m), ln=Natural logarithm and b_0,b_1,b_2 and b_3 are regression constants estimated.

ASSESSMENT OF THE MODELS

The volume models were assessed with the view of recommending those with good fit for further uses. The following statistical criteria were used:

1.Significance of Regression (F-ratio)

This is to test the overall significance of the regression equations. The critical value of F (i.e., F-tabulated) at $p<0.05$ level of significance will be compared with the F-ratio (F-calculated). Where the variance ratio (F-calculated) is greater than the critical values (F-tabulated) such equation is therefore significant and can be accepted for prediction.

2. Coefficient of Determination (R^2)

This is the measure of the proportion of variation in the dependent variable that is explained by the behavior of the independent variable (Thomas, 1977). For the model to be accepted, the R^2 value must be high (>50%).

3. Standard Error of Estimate (SEE)

This is also referred to as the standard deviation or residual of the error variance of the estimate. It measures the spread of data and is a good indicator of precision. The value must be small.

MODELS VALIDATION

The validation process also examines the usefulness or validity of the models (Marshall and Northway, 1993). The original data from the study site will be divided into two. The first set (calibrating set), which comprised tree data from six plots, will be used for generating the models while the second set (validating set) which comprised tree data from two plots was used from the plantation for validating the models (Reynolds *et al* 1981 and Cooper and Weekes 1983). The models' output will be compared with observed values obtained from the field with student t-test and simple linear regression for any significant difference.

1. **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).

2. Percentage Bias Estimation

The absolute percentage difference (% bias) will be determined by dividing the difference between volumes obtained with Newton's formula (observed volume) and models output by the same observed volume and multiplied by 100.

$$\%bias = \left[\frac{Vo - Vp}{Vo} \right] \times 100$$

Where: Vo =The observe volume

Vp =The predicted volume (models output)

The value must be relatively small for the model to be acceptable for management purpose

RESULTS AND DISCUSSION

Table 1, Descriptive statistics of tree variables in the plantation.

Variables	*Tectona grandis* plantation Values
Basal area (m^2)/ha	610.64
Volume (m^3)/ha	15135.63
Average Dbh (m)	1.24
Average total height (m)	16.56
volume estimate /ha(lower limit)	8.46
volume estimate /ha(upper limit)	68.19
No of stems per hectare	502

Table 2, Descriptive statistics for tree Height and Dbh (m) in the study area.

Parameters	Variables	
	Height	**Dbh**
Mean	16.56	1.24
Standard Error	0.10	0.00
Median	16.50	1.24
Mode	16.90	1.24

Standard Deviation	2.32	0.05
Sample Variance	5.41	0.00
Kurtosis	2.70	-0.39
Skewness	0.13	0.29
Range	18.5	0.3
Minimum	7	1.13
Maximum	25.5	1.43
Sum	8317.4	623.68
Count	502	502

Table 3: Tree volume predictions from the models

Models	Observe (m^3)	Predicted (m^3)
Model 1a	15135.63	9034.05
Model 1b		9136.21
Model 2a		9326.44
Model 2b		10985.72
Model 3a		17777.16
Model 3b		17352.51

Table 4. Diameter distribution into diameter classes in the study area

Diameter classes	*Tectona grandis* plantation	
cm	Freq/ha	% Distribution/ha
0 - 19	0	0.00
20-39	4	0.80
40-59	7	1.40
60-79	84	16.70
80-99	60	12.00
100-119	160	31.90
120-139	64	12.70
140-159	118	23.50
>160	5	1.00
Total	502	100

Table 5: The (developed) models for volume estimation in *Tectona grandis* plantation.

Model 1a	$V = -20.29+1.27Ba-1.18Ba^2+2.56Ba^3$	($R=0.37$, $R^2=0.28$)
Model 1b	$V = 4.45-3.31(\ln Ba)+0.74(\ln Ba)^2+0.09(\ln Ba)^3$	($R=0.16$, $R^2=0.29$)
Model 2a	$V = 2.21+1.07Dbh-2.18Dbh^2+2.36Dbh^3$	($R=0.64$, $R^2=0.58$)
Model 2b	$V = 2.56+2.48(\ln Dbh)+3.53(\ln Dbh)^2+6.51(\ln Dbh)^3$	($R=0.60$, $R^2=0.52$)
Model 3a	$V=3.36+5.98H-2.48H^2+2.71H^3$	($R= 0.86$, $R^2= 0.76$)
Model 3b	$V=-1.55+2.22(\ln H)+1.47(\ln H)^2+3.41(\ln H)^3$	($R= 0.83$, $R^2=0.75$)

Table 6: Parameters estimates from the models.

Model	b_0	b_1	b_2	b_3
Model 1a	-20.29	1.27	-1.18	2.56
Model 1b	4.45	-3.31	0.74	0.09
Model 2a	2.21	1.07	-2.18	2.36
Model 2b	2.56	2.48	3.53	6.51
Model 3a	3.36	5.98	-2.48	2.71
Model 3b	-1.55	2.22	1.47	3.41

Table 7: Model assessment results

Model	R^2	SEE	F-ratio	Remarks

Model 1a	0.28	8.47	0.00	Significant
Model 1b	0.29	8.98	0.00	Significant
Model 2a	0.58	6.28	0.00	Significant
Model 2b	0.52	7.13	0.00	Significant
Model 3a	0.76	3.02	0.00	Significant
Model 3b	0.75	4.73	0.00	Significant

Table 8: Models validation results

Model	T-test value	Significance	Bias (%)	Remarks
Model 1a	1.98	0.68	40.31	Not significant
Model 1b	1.66	0.32	39.63	Not significant
Model 2a	2.18	0.05	38.38	Significant
Model 2b	2.04	0.04	27.42	Significant
Model 3a	1.72	0.00	17.45	Significant
Model 3b	1.64	0.00	14.64	Significant

Table 9: Follow up test carried out to separate the mean different between the observed volume and models output

Model	Mean	SE	DMRT rating
Observed	30.15	3.14	b
Model 1a	17.99	5.13	d
Model 1b	18.19	4.09	d
Model 2a	18.57	3.45	d
Model 2b	21.88	2.11	c
Model 3a	35.41	3.26	a
Model 3b	34.56	2.99	a

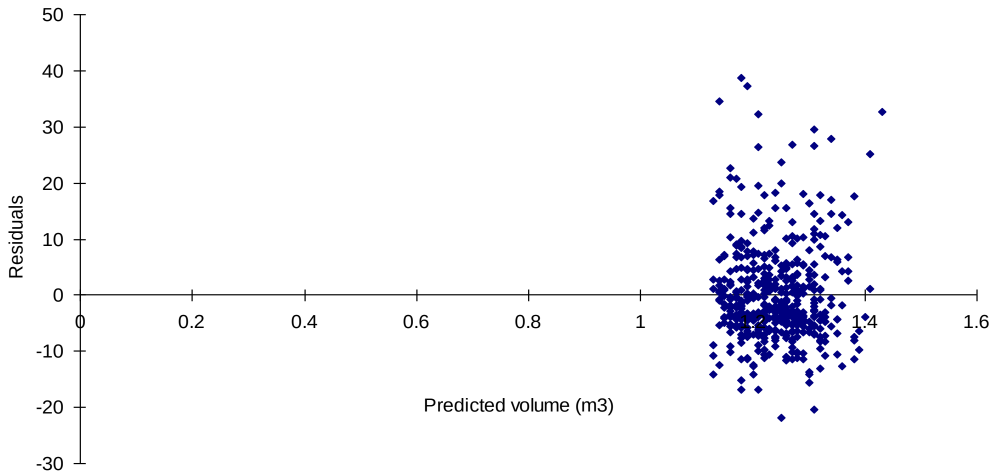

Fig 2 , Residuals plot for model 1a in the study area

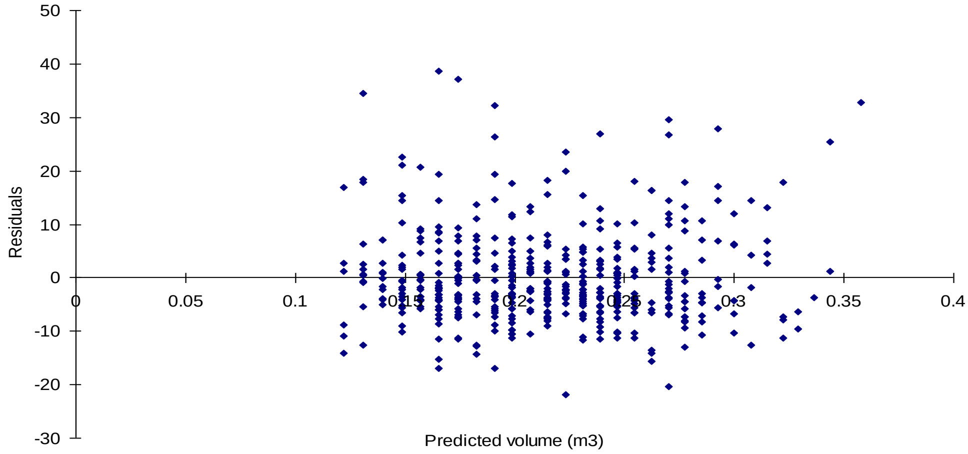

Fig 3, Residuals plot for model 1b in the study area

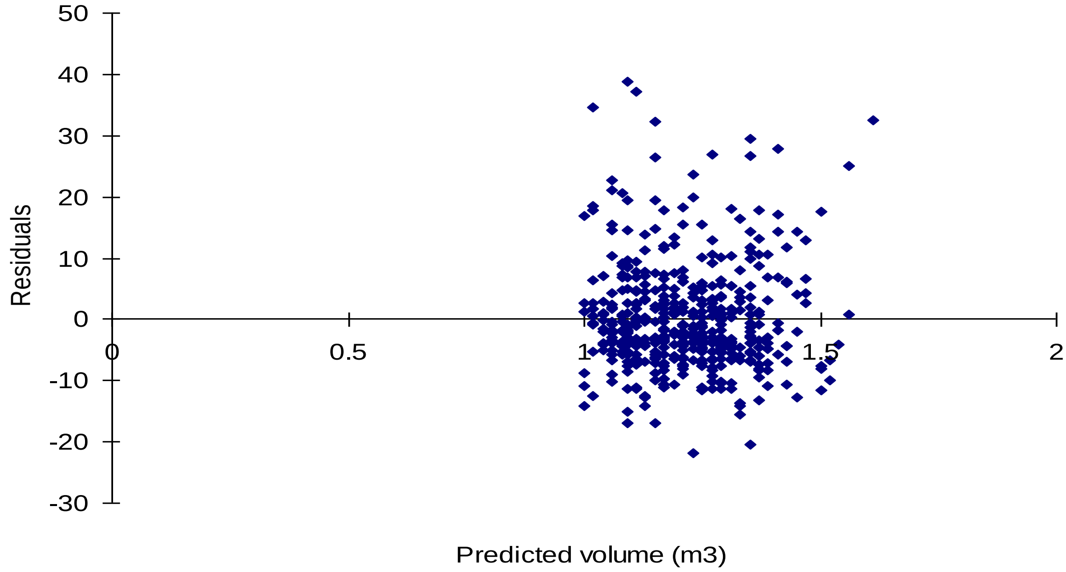

Fig 4 , Residuals plot for model 2a in the study area

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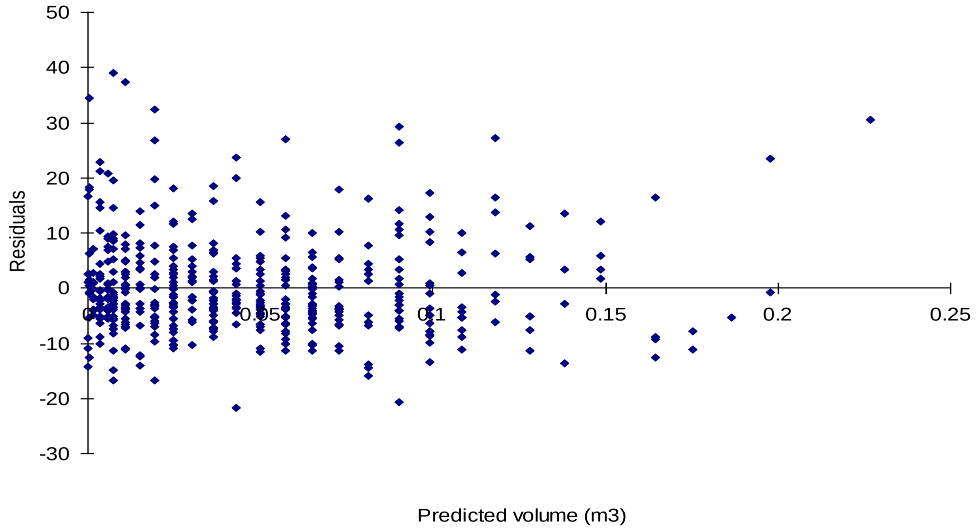

Fig 5 ,Residuals plot for model 2b in the study area

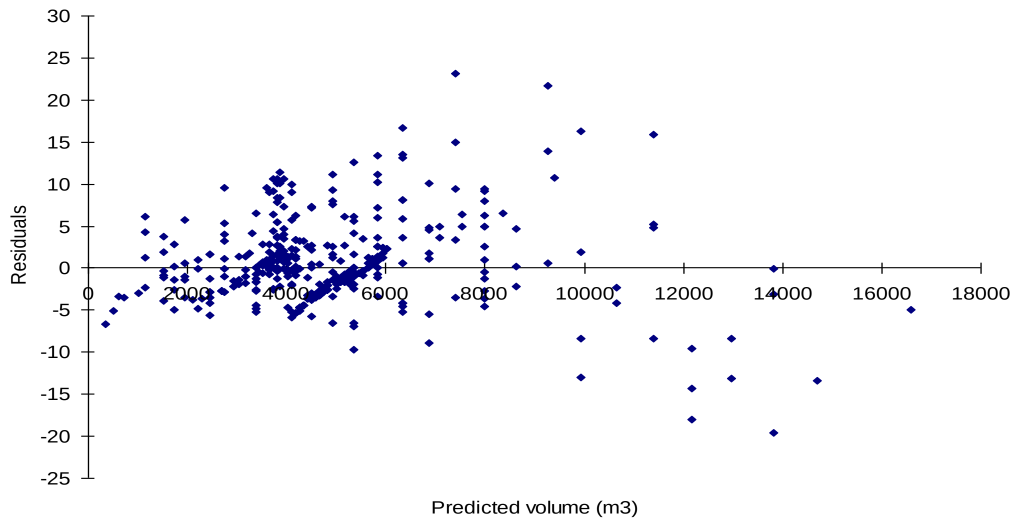

Fig 6, Residuals plot for model 3a in the study area

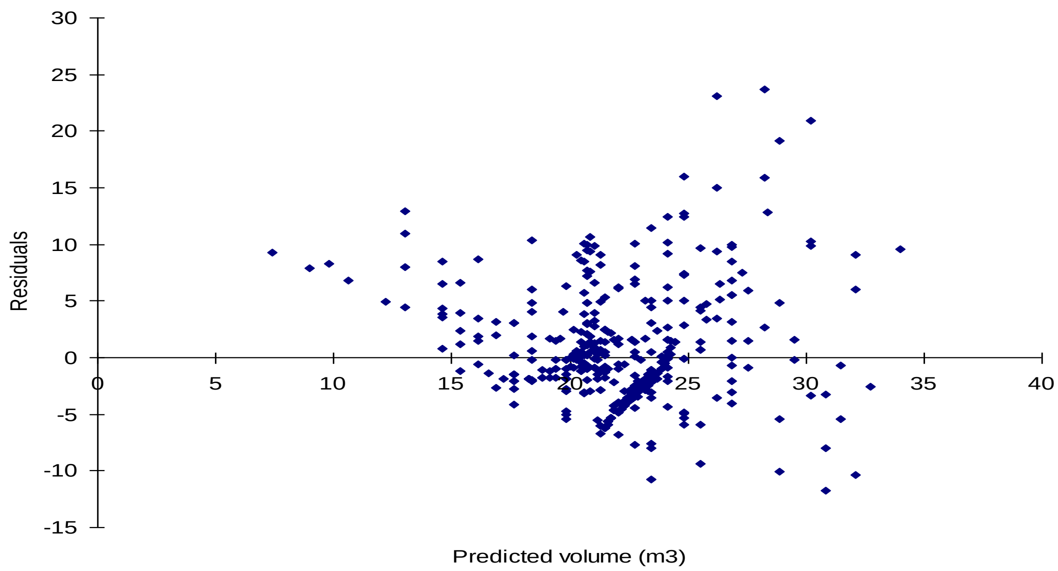

Fig 7, Residuals plot for model 3b in the study area

DISSCUSSION

The efficiency of regression models for estimating timber volume in the stands of *tectonia grandis* plantations at Federal College of Forestry, Ibadan was obtained in this study. The tree growth variables measured in the study area shows that the total basal area encountered per hectare was 610.64m^2 (Table 1) while the total volume were found to be 15135.63m^3 per hectare. Average Dbh and average height were found to be 1.24 m and 16.56m respectively. The value obtained for basal area is an indication of a well stocked forest (Alder and Abayomi 1994).

The mean Dbh and height encountered (1.24m & 16.56m) is an indication that most of the trees encountered in the study area are above minimum merchantable size of 48cm stipulated by logging policy of south western Nigeria.The skewness and kurtosis (table 2) for Dbh and height were found to be very low, for Dbh skewness and kurtosis were found to be 0.13 and 2.70 while that of height was 0.29 and - 0.39 for skewness and kurtosis respectively. This agreed with the findings of (Nurudeen 2011) who reported low skewness and kurtosis as an indication of right tailed distribution and also the evidence of a good stock of a stand. In this study co-efficient of determination (R^2) significant of regression and standard error of estimate was computed in order to select the best models. The assessment criteria revealed that for *Tectonia grandis* plantation model 3a and 3b were discovered best to have good fit and are very suitable for tree volume estimation in the study area. Model 2a and 2b were found to be averagely good with their coefficient of determination (R^2) to be 0.58 and 0.52 respectively (Table 5).

The good fit exhibited by model 2a, 2b, 3a and 3b were similar to those used by Adegbehin (1985) for *Pinus carribea* and *Eucalyptus cloeziana* stands and Nokoe (1980) for some plantations species. The parameter estimate from the model (Table 6) shows that model 1a and 3b have negative intercept. This is in accordance with the findings of Avery and Burkhart (2002) who reported that volume predictions usually give negative intercept. Similar findings were observed by Adekunle (2007) who reported that index of fit, R and R^2 values were high and significant f- ratio at $P \leq 0.05$ was obtained for non linear models for volume estimation in natural forest and thus found to have good fit and therefore suitable for use within the context of field data used.

The model 1a and 1b were found not suitable even though basal area was used as independent variable. This disagreed with the findings of Osho 1998 and Daniel *et al* (1979) who replace age with diameter during model generation in their study.

Model 3a and 3b are found to be more suitable despite the fact that height was used as independent variable Laiho *et al* (1995) noted that the height structure is highly heterogeneous and so its determination in practical forestry is not meaningful and also very rare on research plot.

The validation result for selected models using T- test and percentage bias shows that most of the models are significant and have a low percentage bias varying from 14.64 – 40.31% (Table 8). Similar findings was observed by Adekunle (2007) who reported that the percentage bias less than 30% is an indication of good fit models.

This result suggests that all the models with good fit are suitable for volume estimation within the context of the field data used. In view of the above, analysis of variance conducted showed that there is a significant difference ($P \leq 0.05$) between the observed volume and model output and further test was carried out using Duncan Multiple Range Test to separate the mean difference (Table 9).

Model 3a and 3b were discovered to have the highest mean value among the model tested, followed by observed volume, Model 2b, model 2a, 1b and 1a respectively. The residual plots (Fig 2-7) were constructed for model 1a, 1b, 2a, 2b, 3a and 3b respectively.

The figures plotted for the models indicated an even spread of residual above and below the zero line with no systematic trend. The positive and negative sides of the plot have a constant breadth and are horizontal. The derivation of the predicted values from the observed values could be said to be random. This is an indication that the assumption of normality in the distribution of residual is not violated. This trend was similar to the findings of Soares and Tome (2001) and Adekunle (2007). Meanwhile, all the regression models developed in this study were six in all (model 1a, 1b, 2a, 2b, 3a and 3b). Model 3a and 3b were discovered to be very adequate in the context of the study area.

CONCLUSION

Regression models for volume estimation was develop and validated for *tectonia grandis* at Federal College of Forestry, Ibadan, Oyo State. The tree growth data was collected from temporary sample plot in the study area.

Based on the evaluation of the models examined in this study model 3a and 3b are found to be more suitable and fit for volume prediction. The frequencies and yield predicted with the models are significantly different from their observed values according to the validation result with Anova and T- test values.

Evans (1992) stated that many tropical countries afforestation programmes tends to emphasis plantation establishment and neglecting subsequent siviculture management decision. This study should help promote the development of tree volume predictions for multi species stand. It will also help to promote a basis for further investigations on the relationship between volume and other growth parameters. It is hoped that this study will

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be of value to forest managers, policy makers and growth modelers. It is believed that this study will provide a basis for further data collection management at Federal College of Forestry, Ibadan.

Therefore all categories of regression models generated in this study with good fit are recommended for tree volume estimation in plantation of *tectonia grandis* at Federal College of Forestry, Ibadan South Western Nigeria.

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