Parameter estimation accuracy of Diameter- height relationship and volume models of *Entandrophragma angolensis* species in Forestry Research Institute Nigeria (FRIN) Onne.

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Abstract: Diameter at breast height (DBH) and tree height are important variables needed in volume estimation. Measurement of tree's height is usually costly, time consuming and chances of error by the observer is highly possible while DBH measurement is easier with less measurement error. Development of models involving tree height and DBH relationship is very vital in forest mensuration. Therefore this study was based upon determination of diameter – height relationship and volume equations parameters estimation accuracy developed for *Entandrophragma angolensis* species in Forestry Research Institute of Nigeria Onne. Tree growth variables data used for fitting the models were measured from temporary sample plots of 20m by 20m. Linear regressing technique was used to develop the models. The results reveal that positive correlations exist between DBH and height and also with volume. The developed model parameters were significant with high coefficient of determination and low standard error of the estimates. Diameter height relationship model is crucial in inventory because height can be predicted hence the high cost of determining tree height in forest inventories is reduced but the models are site and species specific.
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1. Introduction

Growth of trees is a continuous process which is characterized by changes in stem form and dimension over a period of time (Avery and Burkhardt, 2002*)*. Trees show considerably variation and flexibility in their growth characteristics such as height and diameter-at-breast. Diameter at Breast Height (DBH) and height are among the most important tree growth characteristics for any measurational and predictive data for modeling in sustainable forest management. And as such, accurate data on these two variables are quite important especially for reliable future management plans (Osman, *et al.*, 2013). Among these variables, height is not frequently measured though very significant in quantitative measurements because it is costly, time consuming and chances of error by the observer is highly possible during measurement.

Most reserves in Nigeria have back log data on DBH only or subsample total tree heights. In situations where total tree heights are required for decision making, the best approach is to use diameter-height relationship equations to predict the unknown tree heights. Specifically, these equations predict mean total tree height for a given diameter at breast height and species. Osman, *et. al*., (2013) stated that DBH and height relationship is a structural characteristic of a tree that describes key elements of stem form, and thus the volume of the harvestable stem. The research carried out by Afrifa and Adomako (2014) further emphasized that the relationships between tree height and stem diameter have been used for a variety of practical purposes in the realm of forestry. They have been used, for example, to estimate tree volume, to determine the social position of a tree within the stand, to find the dominant height and calculate an index of stand productivity (Jayaraman and Lappi, 2001), to estimate biomass production and carbon sequestration and to describe forest dynamics. Many growth and yield-projection systems also use height and diameter as the two basic input variables, with all or part of the tree heights predicted from measured diameters (Huang *et al*., 2000).

A good number of equations have been developed on diameter-height relationship and volume equation (Monserud 1975, Ek et al. 1984, Larsen and Hann 1987, Parresol 1992, Flewelling and de Jong 1994). Contrary to the costly and time consuming procedures involved in height measurement, allometric equations avoids such huddles and reduces observer error. Hence equations reflecting diameter-height relationship is preferred for easy prediction of height and volume estimation. The research seeks to test the accuracy of Diameter- height relationship and volume models of *Entandrophragma angolensis* species in Forestry Research Institute of Nigeria.

2. Material and Methods

Study Area

The study was carried out at the Forestry Research Institute, Onne. Onne is part of Nchia clan in Eleme Local Government Area of Rivers State, in Nigeria, which is situated on latitude 4°44' N and longitude 7°15' E (at an altitude of 1440 feet) to Bonny River. The area consists of rivers, creeks and estuaries while, stagnant swamp covers about 600 km2 with the area dotted, with mangrove swamps. The ecosystem of the area is highly diverse and supports numerous species of terrestrial and aquatic flora and fauna including human life. It is described as amongst one of the many large wetlands in Africa as well as a beehive of oil and gas activities.

Sampling technique

Data were collected from randomly selected temporary sample plots of 20m x 20m (0.04ha) in size. All the trees in the selected plots were enumerated and the number of trees in the plot was identified.

Data Collection

Quantitative data on growth parameters (height, diameter, and volume) of standing tree species was collected from the plantation site of the Forest research institute of Nigeria, Onne. The height of each of the individual tree was measured using indirect method with the aid of a Spiegel relascope on each individual tree and recorded while Diameter at breast height was measured directly using a girth tape.

Data Analysis

The data collected from tree measurement was processed into suitable form for statistical analysis. Data processing included basal area estimation, tree slenderness estimation, crown projection area estimation and site index estimation.

Volume Estimation

The volume of individual tree sampled was estimated using Newton formula; given as:

V= $\frac{H}{6}(A_b + 4A_m + A_t)$……………Equation 1

Where,

V= Volume

A_b=Area at the bottom

H= Total height

A_m= Area at the middle

A_t= Area at the top

Basal area estimation

The basal area for each tree in the sample plot was estimated using the formula

G = $\frac{\pi D^2}{4}$ …………………………Equation 2

Where,

G = Basal area

D = Dbh

Π = 3.142 (a constant)

Tree slenderness co-efficient

The tree slenderness co-efficient is given as:

Tsc = $\frac{THT}{D}$ …………………Equation 3

Where,

TSC = Tree slenderness co-efficient

THT = Total height

D = Diameter at breast height

Correlation Analysis

This is among the simplest way of measuring the relationship existing between two or more variables. Correlation analysis measures the degree of relationships existing between two or more variables. There is no correlation when the variable tends to change with no connection to them. Two variables (X, Y) may have a positive correlation if X tends to decrease as Y increases. When it is positive, it is said that the variables are directly correlated and if negative, it is inversely correlated. This tool was used to determine the correlation between variables such as diameter and height, diameter and age, height and age, stem quality and age, volume and height. etc.

Residual analysis

Residuals are differences between the one-step – predicted output from the model and the measured output from the validation or observed data set. They represent the portion of the validation data not explained by the model. Given that regression models are established based on some assumptions, it then becomes pertinent that for any model to be valid, it has to keep this assumption. Thus residuals analysis aids in checking the validity of the assumptions of the models. In analyzing the models the residuals were plotted against the dependent variable. Therefore if the residual appear to behave randomly, it suggests that the model fits the data well. On the other hand, if non random structure is evident in the residuals, it is a clear sign that the model fits the data poorly. In other words, the smaller the variability, the better is our prediction. In addition, if the regression model represents the data correctly, the residuals are randomly distributed around the line of error with zero mean and equality of variance.

Model development

The following empirical models were developed on height-diameter relationship and volume for the studied species.

1. THT = $b_0 + b_1DBH$…………….Equation 4
2. lnTHT = $b_0 + b_1DBH$…………..Equation 5
3. lnTHT = $b_0 + b_1DBH^{-1}$………Equation 6
4. SV = $b_0 + b_1DBH$…………...Equation 7
5. lnSV = $b_0 + b_1DBH$…………Equation 8

3. Results

Growth characteristics for studied species

Table 1 below shows the summary statistic of the major growth characteristics of the tree species evaluated in the study area. The major growth characteristics as shown in the table include diameter at breast height (DBH), tree total height (THT), merchantable height (MHT), stem quality (SQ), stem volume (STEM VOL), tree slenderness coefficient (TSC) and basal area (BA).

Table 1: Summary statistics of growth characteristics for *Entandrophragma angolensis*

Growth characteristics	Mean ± SD
DBH	43.85±13.929
THT	8.36±2.261
MHT	4.77±1.747
SQ	4.47±1.747
STEM VOL	0.08±0.051
TSC	0.19±0.027
BA	0.02±0.011

DBH-diameter at breast height, THT- Tree Total height (m), MHT- merchantable height, SQ-Stem quality, STEM VOL- Stem volume, TSC- Tree slenderness coefficient, BA-Basal area

Result of the correlation analyses

Correlation analysis defines the association that exists between the variables of consideration. Square matrix correlation representing the entire data on *Entandrophragma angolensis* at a 5% significance level is presented in table 2. The association involving diameter at breast height and basal area, stem volume and total height were significantly high with coefficients of correlation (r) = 0.978, 0.939 and 0.893 respectively. These show that the diameter at breast height positively affected the ultimate values of basal area, stem volume and total height. The diameter at breast height however was negatively correlated with the tree slenderness coefficient which shows that as the diameter at breast height increases, the tree tapers up and the slenderness decreases (Table 2). Similar positive trend was also observed on the association between basal area and tree stem volume with coefficient of correlation (r) = 0.954; which was indicative of strong correlation at 5% level of significance.

Table 2: Correlation matrix for growth characteristics in *Entandrophragma angolensis*

	DBH	THT	MHT	SQ	BA	SV	TSC
DBH	1.000						
THT	0.893*	1.000					
MHT	0.549*	0.652*	1.000				
SQ	0.549*	0.652*	1.000	1.000			
BA	0.978*	0.844*	0.481	0.481	1.000		
SV	0.939*	0.892*	0.558*	0.558*	0.954*	1.000	
TSC	-0.516*	-0.067	-0.067	-0.067	-0.499	-0.347	1.000

***- significant at P<0.05**

DBH-diameter at breast height, THT- Tree Total height (m), MHT- merchantable height, SQ-Stem quality, SV- Stem volume, TSC- Tree slenderness coefficient, BA-Basal area

Regression models

Different equations were derived from the simple regression analysis. In Table 3 below a total of five simple regression models were established. Among them are two heights – diameter regression model, one height to diameter model with inverse of diameter at breast height and two stem volumes – diameter regression model. These models follow the simple linear regression formula:

$Y_1 = b_0 + b_1 x_1$……………….Equation 9

Where Y is the dependent variable, b_0 and b_1 are regression parameters and x_1 is the independent variable.

The results of the regression analyses revealed empirical relationship between total height, tree stem volume and various definitions of diameter at breast height in the species considered in this study. The Tables showed the estimated model parameters with their peculiar goodness of fit indices including coefficient of determination (R^2), root mean square error (RMSE) and probability of significance (P-value).

Table 3: Estimated model parameters in *Entandrophragma angolensis*

S/n	Model	Parameter	Estimate	R^2	RMSE	P-value
1	THT= $b_0 + b_1 DBH$	b_0 b_1	2.005 0.145	0.797	1.031	0.0000
2	lnTHT= $b_0 + b_1 DBH$	b_0 b_1	1.276 0.018	0.756	0.148	0.0000
3	lnTHT= $b_0 + b_1 DBH^{-1}$	b_0 b_1	2.742 -25.761	0.799	0.134	0.0000
4	SV = $b_0 + b_1 DBH$	b_0 b_1	-0.074 0.003	0.881	0.018	0.0000
5	lnSV = $b_0 + b_1 DBH$	b_0 b_1	-5.078 0.051	0.836	0.319	0.0000

Where RMSE = Root mean square error, N= Number of tree species, R^2 = Regression constant, P-value = Probability value

In general these equations are:

THT = 2.005 + 0.145DBH………Equation 9

lnTHT = 1.276 + 0.018DBH…….Equation 10

lnTHT = 2.742 + 25.761DBH^{-1}…....Equation 11

SV = -0.074 + 0.003DBH….......Equation 12

lnSV = -5.078 + 0.051DBH…........Equation 13

Result of the residual analysis

As a means of verifying the validation of the equations, residual plots were plotted for each equation to show the distribution pattern of the dependent variable against the predicted values. Hence, Figures 1 and 2 revealed the residual plot of tree total height with predicted diameter at breast height as well as residual plot of stem volume with predicted diameter at breast height. The residual plot between the total tree height and the predicted diameter at breast height in *Entandrophragma angolensis* showed a dispersed distribution along the horizontal axis while the plot of stem volume and predicted diameter at breast height in *Entandrophragma angolensis* showed a systematic downward curve (Fig. 1 and 2).

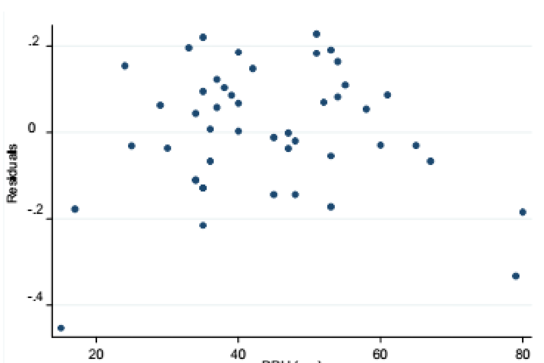

Fig 1: Residual plot of ln of total height and predicted diameter at breast height in *Entadrophragma angolensis*

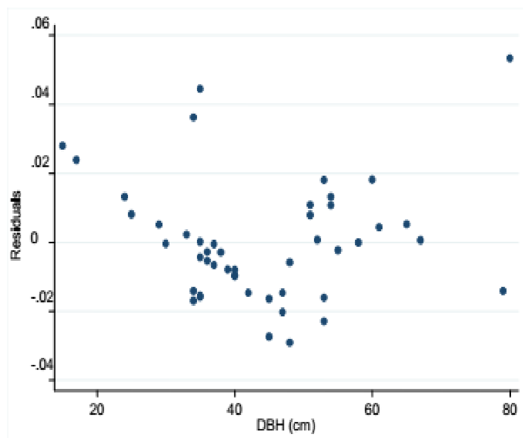

Figure 2: Residual plot of stem volume and predicted diameter at breast height in *Entandrophragma angolensis*

4. Discussions

The high and positive value of the correlation coefficient between total height and diameter at breast height implies a strong correlation and a directly proportional relationship between the two variables respectively (table 2). In other words, the positivity of the correlation coefficient depicts that an increase in the total height implies an increase in the diameter at breast height. This is also the same for stem volume and diameter at breast height, with a correlation coefficient of 0.92 depicting a strong directly proportional relationship Research carried out by Dauda, (2004) also observed the same trend. As opposed to the directly proportional relationships the inversely proportional relationship that exists between the slenderness coefficient and other variables (table 2), displayed by the negative sign indicates that an increase in one variable will result to a decrease in the other. Despite the strength of the correlation it is noted that this analysis neither explain any variable to be the cause or the effect rather than in any relationship, this two variables has various characteristics or factors that affect them in some order and make them co-vary.

Using the least squares method the strong correlated relationship between height and diameter at breast height as shown by table 2 was limited to a simple linear equation. This was done by determining the unknown parameters (i.e. the slope and gradient) chosen to minimize the sum of squares error over the whole observation. The equations 10-14 derived to depict the functional relationship between total height and diameter at breast height of the species all shows high value for coefficient of determination. This high value explains that the proportion of the variation present in the total height (the dependent variable) that is as a result of changes in the values of diameter at breast height is high. In other words, approximately the percentage ranging from 75- 88 of the variation in the total height (the dependent variable) of the above equations can be explained by unknown, lurking variables or inherent variability. The high R^2 values indicate that the regression line though not perfectly but highly fits the data. This affirms that the diameter at breast height of the species can well be made a function of its total height (Peng *et al*, 2001). From the characteristics of the equations as shown in Table 3 with the lowest root mean square error and high R^2 value, is a good model for height prediction (Avery and Burkhart 2002).

The developed volume models also have high R^2 indicating that the percentage variations present in the volume can be explained by the changes that occur in the diameter at breast height in all the equations respectively. This implies the possibility of a functional relationship between stem volume and diameter at breast height for the species. In addition the residual plots shows a random behavior along the horizontal axis (though have few outliers) indicating that the model fits the data well.

Conclusion

The knowledge of height – diameter relationship and volume of tree species is very crucial to the management of tree stand. This study has evaluated the accuracy of parameter estimation of Diameter-height relationship and volume models of *Entandrophragma angolensis* species in the unthinned plantation in the forest research institute of Nigeria. The study estimated the growth characteristics, evaluated the relationship of height and diameter of the tree species in the study area and showed the best equation. The height-diameter model and volume developed in this study gave reasonable precise estimates of tree heights and is recommended for use in the plantation within the range of conditions defined above. Quantitatively, the study has shown tree status and has created awareness as to the recognition of tree characteristics of the species in the study area. It has brought about concise information about the attributes of the tree as it provides adequate strategy for proper management, and creates opportunity for further research and study by forest biometrics conscious minds.

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