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Allometric Volume Equations Using Stem Height and Diameter at Breast Height for *Pinus caribaea*, *Nauclea diderrichii* and *Tectona grandis* Plantations in Omo Forest Reserve, Nigeria.

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ABSTRACT

Volume equation plays a vital role in forest inventories and management as well as its importance cannot be overemphasized. Therefore, the volume of current growing tree species and future growth must provide vital information for forest management. The study developed volume equations for pine (*Pinus caribaea*), opepe (*Nauclea diderrichii*) and teak (*Tectona grandis*) plantations in Omo Forest Reserve using diameter at breast height (DBH) and merchantable height as estimating parameters. Four plots were selected from each stand (age class) of the three species using simple random sampling procedure. A sample plots size of 25m x 25m were laid in each stand. Data were collected from the sampled plots using DBH (1.3m above ground), total height, diameter at base, middle and the top. Data were analysed using descriptive statistics and regression analysis. Results in the sampled plots showed a total tree of 167, 71 and 172 for Pine, Opepe and Teak respectively. Results also showed that mean DBH in pine stand was 23.97cm while mean height was 18.18m. Opepe stand had mean DBH of 32.75cm while mean height was 14.84m. More so, Teak stand had mean DBH of 18.36 cm while mean height was 18.86m. Finally, the results for model fit using the coefficient of determination of R^2, root mean square error (RMSE) and F values in each of the plantation showed that *Pinus caribaea* had value of (R^2=0.7761, RMSE=0.1249, F=192.4), *Nauclea diderichii* had (R^2=0.5315, RMSE=0.5046, F=22.1) while *Tectona grandis* had (R^2=0.7475, RMSE=0.0449, F=171.7) indicating that the log-transformed model yielded better results when compared with the untransformed model. The study concluded that there was a strong and positive correlation between the total volume, height and DBH. Therefore, using height and DBH can give precise estimates of total volume of pine, opepe and teak tree. Also the volumes predicted by the two models out of three models were not too different from the observed volume in the three plantation stands.

Keywords: Volume Equation, DBH, Tree Species, Forest Reserve

Introduction

A forest reserve is a protected area of important renewable natural resources for scientific research, special purpose and future utilization. "It preserves genetic resources, tree species, ecosystems and landscapes; promotes sustainable economic and human development; and supports environmental education and training, research and monitoring related to local, national and global issues of conservation and sustainable development" (FAO, 2010). According to Akindele and LeMay, (2006), sustainable forest management requires estimation of growing species of trees that guides forest managers in wood assessment in time of harvest. For wood production, an estimate of growing stock is usually expressed in terms of timber volume, which can be estimated from measurable tree dimensions such as tree height and diameter at breast height. Therefore, volume of current growing tree species and future growth must provide vital information for forest management. In forest plantation in Nigeria, different species of trees can be found which include pine (*Pinus caribaea)*, opepe (*Nauclea diderrichii*) and teak (*Tectona grandis)* to mention but a few.

Pinus caribaea are evergreen conifers that belong to the genius *Pinus* and the family *Pinaceae*. Pine trees flourish in temperate and subtropical climates and grow well in sandy or well drained soil. They can be found growing in altitudes of up to 13,000 feet. The pine trees are fast growing species where 3 years old trees may reach heights of 6m to 8m, while 40 years old trees may grow up to 35m tall. Average temperatures are between 42^{o}F and 50^{o}F. *Nauclea diderrichii* is also an evergreen tree with a slight preference for drained soils. This species of tree belongs to genius *Nauclea* and member of the family *Rubiaceae*. The optimal temperature range for growth is 28-34^{o}C, although it can tolerate a range of 22- 38^{o}C (Fern, 2014). The tree grows up to 40m high and reaches a girth of about 5m with a cylindrical bole and can go as far as 27m with low buttresses. *Tectona grandis* is a tropical deciduous tree species, belonging to the family *Verbenaceae* and order *Laminales*. This species grows well in the regions having rainfall and temperature ranging from 900-2500mm and 17- 43^{0}C respectively (Die *et al.,* 2012). *Tectona grandis* is a very important and valuable multipurpose tropical hard word tree species. It is a fast growing tree species with the ability to regenerate and can be used for a variety of purposes.

Tree volume is one of the variables that are measured to estimate the size of individual trees. Volume is the popularly used measures of the quantity of wood in forest menstruation (Shuaibu, 2015). Volume equation can be defined as various mathematical expressions applied to determine the quantity. However, tree volume equation on the other hand is a method that is used to estimate individual tree volume as well as the volume of the whole stand. Tree volume equations also refers to the mathematical expressions that relate tree volume to tree's quantifiable variables such as diameter and height. According to Avery and Burkhart (2002), volume equations are used to estimate average content of standing trees of various sizes and species. Height (H) and diameter at breast height (DBH) are the most important measures of tree growth and their relationship is useful in determining site-index, calculating tree volume, evaluating site-quality and predicting future growth of the stand (Jayaraman and Zakrzewski, 2001; Wagle and Sharma, 2012). These equations can also help in predicting H from DBH, as Hs are often sub-sampled due to the complexity in measurement (Coble and Lee, 2011). Despite the increasing use of biomass and density, volume is also a widely used traditional measure for tree quantity. In forest management, tree heights and dbh have been used to estimate the total and merchantable tree volume. These variables are preferred due to the ease of acquiring data and the relative accuracy provided by methods employing them.

Volume models that are able to measure tree volume are indispensable if trees are subjected to felling for commercial uses (Mugasha *et al.,* 2016). There have been many developments of volume equations since the sequential development of forest

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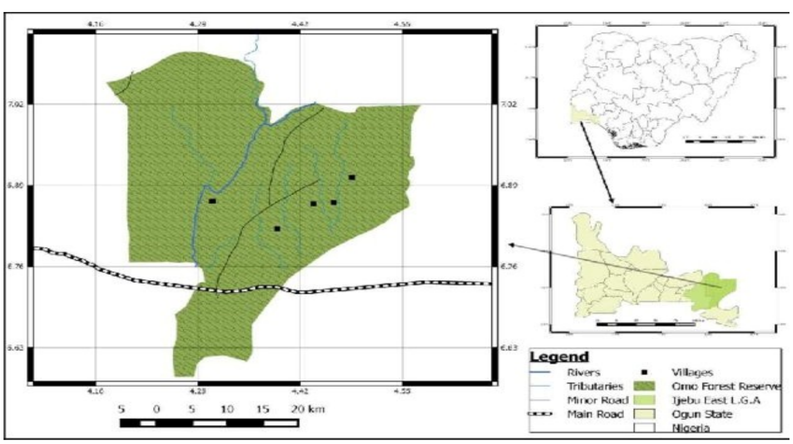
measurements and this trend has highly increased and has also been of interest to many researchers.

Also, these species (*P. caribaea, N. diderrichii* and *T. grandis)* are among the most fell trees most especially in the southwestern part of Nigeria, therefore the need to adequately determine its volume and improve the quality and quantity of its stands is very also important. In general, allometric models are commonly used to estimate timber volume in many regions. These models are designed to cover wider spatial dimensions or extended to conditions that are sometimes dissimilar from localities of their origin. It is important to note that different timber species exhibit different growth responses to different site conditions and associated management prescriptions (Skovsgaard and Vanclay, 2013). Also, generalized models are not without some limitations for effective decision support in forest management. The study therefore, developed tree volume equations that will evaluate and estimate the yield of *Pinus caribaea, Nauclea diderrichii* and *Tectona grandis* stands in Omo Forest Reserve.

Material and Methods

The Study Area

Omo Forest was created in 1916, and it covers an area of 460km^2, located along 135km north-east of Lagos and 20km from the coast, situated between latitudes 6^o 35' and 7^o 05' N and longitudes 4^o 05' and 4^o 40' E. The vegetation of Omo Forest Reserve is a mixed moist semi-deciduous rainforest. This can be distinguished into a dry evergreen mixed deciduous forest in the northern part and a wet evergreen forest in the southern part. With the exception of the 640 hectare Strict Nature Reserve, now a Biosphere Reserve at the centre of the forest reserve, most of the forest are disturbed with a substantial parts converted to mostly exotic forest plantations.



Source: Chukwu and Osho (2017)

Figure 1. Omo Forest Reserve, Nigeria.

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Data Collection

The age classes of the 3 selected plantations i.e. *Tectona grandis* (9 years), *Pinus caribaea* (24 years), *Nauclea diderrichii* (46 years) spanned from the youngest to the oldest stand. Four plots were randomly selected from each stand (age class) of the three species for the study. A 25m × 25m temporary sample plot size was laid in each stand of plantation. Measurements taken on all trees within each plot were diameter at breast height (dbh, 1.3m above ground), total height, diameter at base, middle and the top. Preference was given to the enumeration of healthy trees with more typical growth forms; dead trees and trees with abnormal form were avoided, because the volume equations developed in this study are for the growing stock defined as living trees of commercial value classified as sawn-timber or poles, and which must meet grade, soundness and size requirements for commercial logs or poles and require volume computation. The horizontal distance (HD) used varied from 10m, 15m and 20m based on the visibility of the tree top.

Data Analysis

Volume models are mathematical expression which relates tree volume to tree's measurable attributes such as diameter at breast height. They are used to estimate the average content for standing trees of various sizes and species (Avery and Burkhart, 2002). For volume model generation, the field inventory data were divided into two. The first set (calibrating set), which comprises 70% of the tree data of each selected plantations were used to generate the models and the individual tree growth variables across all the sample plots. The generalized allometric equation for mathematics and science and the linear regression models that followed the general Schumacher (1939) yield models were used. The Schumacher model is of the form:

$$Y = B_0 + B_1 X \qquad (1)$$

Y= tree volume for each plot
B_0 = intercept for each plot
B_i = slope for each plot
X = tree height for each plot
Then linear regression models that were adopted in this study followed the Schumacher function:
Simple Linear model: Y = ß0 + ß1x
Binomial Model: Y = ß0 + ß1(x) + ß1(y)
Polynomial Models: Y = ß0 + ß1x^1 + = ß2x^2 + ß3x^3
Logarithm transformed Models: LnY = ß0 + ß1 ln(x)

Assessment of the Models

In this study, an equation ($Y=b_0+b_ix$) was generated to estimate true volume for three plots in *Pinus caribaea* plantation. Regression analysis was used to generate the equations relating tree volume (as dependent variable) to merchantable height while b_0 and b_i are parameters of the functions. Other tree volume was computed using Newton's formula. The formula requires the use of tree height as well as the diameter at base, middle and top along the stem. Measuring tree diameter at these points ensures that tree form is taken into consideration, and this makes the Newton's formula more accurate than other common formulas such as Huber's and Smalian's formulas (Avery and Burkhart, 2002). According to Husch *et al.* (2003), Newton's formula is expressed as $V=\frac{\lambda H}{24}+(Db2+4Dm2+Dt2)$ while Db, Dm, and Dt are tree diameters at base (45cm above ground level), middle and top positions (7cm upper limit diameter) respectively.

Regression analysis was also conducted to generate equations relating tree volume (as dependent variable) to diameter at breast height and merchantable height (as independent variables). Linear ($V = a + bDbh^2H$), ($V = a + bDbh + bH$) and logarithmic ($LnV = a + bLnDbh^2H$) functions were adopted.

The height of all trees in the sample plots were further calculated using the formulas:

$$H = \frac{R_t - (R_b)}{100} \times HD \quad \text{(for Relaskop)} \quad (2)$$

$$H = \frac{R_t - (R_b)}{HD} \times scale \quad \text{(for Hagal altimeter)} \quad (3)$$

Where H= Height, R_t = Reading at the top, R_b = Reading at the base, HD = Horizontal distance. Statistics generated from the regression analysis were used to evaluate the equations. These statistics include coefficient of determination (R^2) and overall standard error of estimate (also called Root Mean Square Error). In addition, residual analysis was also performed to examine any violation of statistical assumptions regarding residuals.

Results and Discussion

The results of the study were however presented below. The summary statistics of tree data from the four (4) randomly selected plots in each plantation stand which include mean dbh, height and volume as presented in Table 1. Three plantations were selected for the studies which include *Nauclea diderrichii*, *Pinus caribaea* and *Tectona grandis*. A total number of 410 trees were enumerated. The table shows that 9 years old *Tectonagrandis* plantation had the highest number of trees per hectare (172) followed by 24 years old *Pinus caribaea* with (167) and the least number is obtained from 45 years old *Nauclea diderrichii* with 71. The density of each stand was as a result of planting spacing (3x3 to 4x5) and poor management of the plantation at the growing stage. The dominant DBH ranged between (33.79 cm and 29.94 cm) was highest at 45 years *Nauclea diderrichii* follow by 24 years *of Pinus caribaea* and lowest at 9 years old of *Tectona grandis* plantations, respectively. The result of the dominant tree height reveals those 24 years old *Pinus caribaea* had the highest value of 19.79m and the lowest values was obtained for *Tectona grandis* plantation with 12.29m, this revealed that the plantations follow an increasing order from 8 to 24 years but *Nauclea diderrichii* was not yielded. Also, the result of the volume per hectare followed the same trend of age which ranged from 1.03 m^3 /ha for *Nauclea diderrichii* plantation to 0.09 m^3 /ha of 9 years for *Tectona grandis* plantation respectively.

Table 1: Mean Dbh, height and volume in each Plantation Stand

Plantation Stand	Plots No	No of Trees	Mean Dbh	Mean Height	Mean Volume
Pinuscaribaea	1	51	24.51	18.16	0.58
	2	51	24.57	19.76	0.62
	3	41	22.75	16.81	0.44
	4	24	24.06	17.97	0.51
		167			
Naucleadiderrichi	1	14	33.79	16.31	0.95

	3	13	34.02	16.06	1.03
	7	17	33.07	14.51	0.88
	1	27	29.94	12.47	0.55
		71			
Tectonagrandis	2	18	12.07	12.29	0.09
	5	34	13.64	13.33	0.14
	6	60	16.21	16.31	0.67
	8	60	13.51	13.52	0.42
		172			

Table 1 showed that mean Dbh in *Pinus caribaea* plantation ranged from 22.75cm to 24.57cm, mean height ranged from 17.97m to 19.76m and mean volume ranged from 0.44m^3 to 0.62m^3, while in *Nauclea diderichii* stand the mean Dbh ranged from 29.94cm to 33.79cm, mean height ranged from 12.47m to 16.31m with mean volume ranges from0.55m^3 to 1.03m^3 and finally in *Tectona grandis* stand mean Dbh ranged from 12.07cm to 31.15 cm, mean height ranged from 12.29m to 33.52m, and mean volume ranged 0.09m^3 to 0.67m^3. The results of volume equation developed on the three plantation stand using linear, quadratic and log-transformed regression models was presented in Table 2.

Table 2: Volume equations using Dbh and height in the three plantation stand

Plantation Stand	Volume Equations	R^2	RMSE	F(Value)	RANK
Pc	V= -0.68659+2.28313Dbh+ 0.038051H	0.7761	0.1249	192.41*	1st
	V= 0.24326+0.27870Dbh^{2}H	0.6738	0.1501	231.30*	3rd
	LNV= -1.10893+0.79027LNDbh^{2}H	0.7704	0.2329	375.85*	2nd
Nd	V= -0.79087+1.10092Dbh+ -0.00116H	0.5315	0.5046	22.12*	3rd
	V= 0.33439+0.012208Dbh^{2}H	0.5384	0.4945	46.66*	2nd
	LNV= -2.88903+0.71395LNDbh^{2}H	0.6035	0.5589	60.90*	1st
Tg	V= -0.21928+1.61148Dbh+0.00871H	0.7475	0.0449	171.73*	3rd
	V= 0.02795+0.33136Dbh^{2}H	0.7914	0.0407	443.86*	2nd
	LNV= -1.10893+0.79027LNDbh^{2}H	0.8011	0.2442	471.28*	1st

* *significant effect (p>0.05).*
Legend: Pc = Pinus caribaea, Nd = Nauclea diderichii, Tg = Tectona grandis

Table 3: Result of correlation matrix for the parameters function in the study area

	Observed Vol (m^3)	Predicted Vol (m^3)	Predicted LNVol (m^3)
Pinus caribaea			
Observed Vol	1		
Predicted Vol	0.8208	1	
Predicted LNVol	0.8552	0.9455	1

Nauclea diderichii				
	Observed Vol	1		
	Predicted Vol	0.6341	1	
	Predicted LNVol	0.6457	0.9076	1
Tectona grandis				
	Observed Vol	1		
	Predicted Vol	-0.1772	1	
	Predicted LNVol	-0.2310	0.9599	1

Results in Table 3 showed the correlation matrix among variables in the three plantation stands. *Pinus caribaea* stand showed strong positive (95%) relationship between predicted volume and predicted LN Volume, *Nauclea diderrichii* stand showed strong positive (91%) relationship between predicted volume and predicted LN Volume, and finally, *Tectona grandis* stand showed strong positive (96%) relationship between predicted volume and predicted LN Volume. This implied a strong relationship between the predicted volume and predicted volume of logarithm regression in the three selected plantation stands.

However, to confirm the validity of using these equations, a residual analysis using t-test statistic was conducted as pointed out by Husch *et al.* (2003) was presented in Table 4.

Table 4: Paired t-test of selected equations in the each plantation stand

Plantation Stand	Equations	t(stat)	t(critical)
Pc	V= -0.6536+1.4728Dbh+0.0463	-0.0014	0.9998
	LNV= -0.7156+0.7126LNDbh^2H	-0.0002	0.9998
Nd	V= 0.2678+0.0124Dbh^2H	0.0000	0.9998
	LVN= -3.0426+0.7405LNDbh^2H	0.0072	0.9942
Tg	V= 0.0279+0.3313Dbh^2H	0.0098	0.9921
	LVN= -1.0891+0.7899LNDbh^2H	-0.0006	0.9994

($P<0.05$)

Legend: Pc = Pinus caribaea, Nd = Nauclea diderichii, Tg = Tectona grandis

Table 4 showed the residual analysis conducted on the three equations in the three plantation stands. Hence, the efficiency of using the selected equations was significant. The volumes were tested for significance using t-test, and the result showed no significant differences. This is an indication that the developed models were valid for use. The same procedure was supported by Akindele and LeMay (2005), Shamaki and Akindele (2011). The residual plots of the regression relationship with predicted volume and predicted log volume in three plantation stands are shown in Figure 2, 3 and 4 respectively.

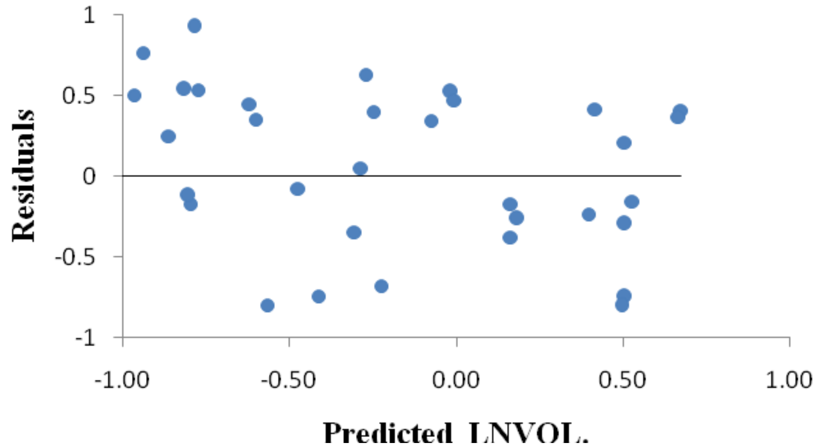

Figure 2: Residual Plot against predicted LNVol. in *Pinus caribea* Stand

Figure 1 showed the residuals plot of the regression relationship with predicted volume and predicted log volume in *Pinus caribaea* plantation stand (LNVol.=-0.7156+0.7126LNDbh^{2}H).This implied that the residuals are randomly distributed with a constant variance in the distribution and thus, the regression equations is a good fit and can adequately predict volume of *Pinus caribaea* tree in the plantation forest.

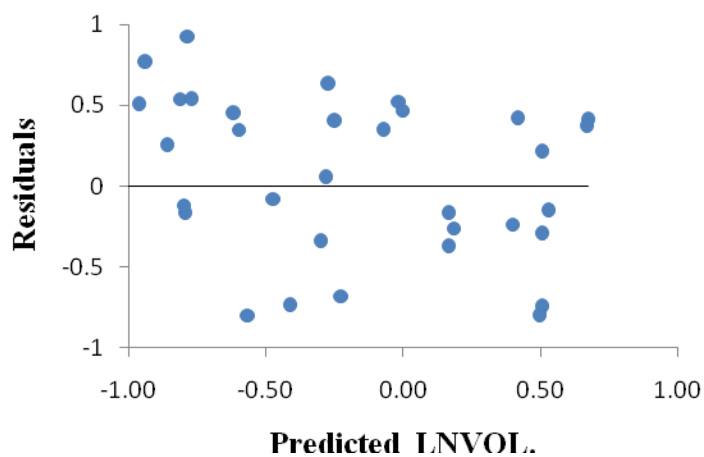

Figure 3: Residual Plot against predicted LNVol. in *Nauclea diderrichi* Stand

Figure 3 showed the residuals plot of the regression relationship with predicted volume and predicted log volume in *Nauclea diderrichii* plantation stand (LNV= -2.88903+0.71395LNDbh^{2}H). This implied that the residuals are randomly distributed with a constant variance in the distribution and thus, the regression equations is a good fit and can adequately predict volume of the forest.

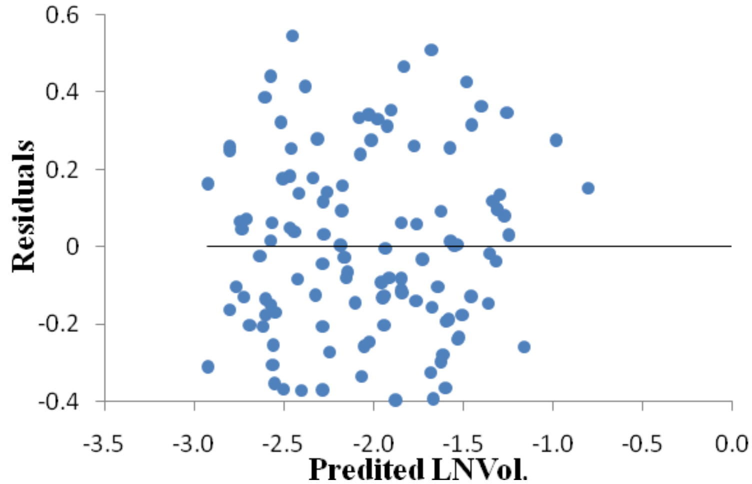

Figure 4: Residual Plot against predicted LNVol. In *Tectona grandis* stand

Figure 6 showed the residuals plot of the regression relationship with predicted volume and predicted log volume in *Tectona grandis* plantation stand (LNV= -1.10893+0.79027LNDbh^{2}H).This result implied that the residuals are randomly distributed with a constant variance in the distribution and thus, equations is a good fit and can adequately predict volume.

Conclusion

The study revealed that using diameter at breast height and total height can give precise estimates of total volume of tree species. Also the volumes predicted by the two models out of three models were not too different from the observed volume in the three plantation stands which suggests that the equation is reliable and can predict tree volume of *Pinus caribaea*, *Nauclea diderrichii* and *Tectona grandis* plantations.

Recommendations

Similar studies should be conducted for other tree species available in Omo Forest Reserve region. Findings of this study showed that linear and non linear models are needed to assess the growing stands and provide information that are relevant for management plan and decision making. It is also recommended that permanent sample plots are established and managed in this region to ensure regular data collection for future linear and non-linear model for silvicultural management practice. The models generated in the study are recommended for use in estimating the growth characteristics of the plantation in the future.

Acknownledgemets

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