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REGRESSION MODELS FOR STEM VOLUME PREDICTION OF ON-FARM TREES IN OGUN STATE, NIGERIA

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ABSTRACT

Appropriate stem volume equations are essential for forest resources monitoring to ensure sustainable forest management. Despite the importance of volume equations in yield estimation, there is paucity of information on stem volume equations for on-farm trees in Ogun State. The aim of this study was to develop stem volume equations for predicting merchantable volume for on-farm trees in the study area. Complete enumeration of seven hundred and seventeen on-farm trees was carried out from the randomly selected farmlands. Tree growth variables considered for data measurement were merchantable heights and diameter at breast heights for trees having diameter at breast height greater or equal to ten (10cm) centimeters. Linear and multiple linear regression analyses were performed on the data with Statgraphics Centurion 18thversion. Eight (8) regression equations were developed and various criteria were used to assess the reliability of each equation to predict an acceptable volume estimation. The most appropriate stem volume equation chosen is: lnVol=-8.41+1.56(lnDbh)+0.14(Mht)with R^2Adjusted=98.53%, SEE=0.01, MAE =0.07. This model revealed high accuracy and it is recommended for on-farm trees inventory in the study area.

Keywords: Regression model, On-farm forest trees, merchantable, Sustainable management

Introduction

The retention and deliberate planting of forest trees within farming systems have been a traditional land use method common among subsistence farmers in Nigeria (Ajake,2012). Ogun State is one of the States that are endowed with forest resources and productive farmlands in the Southwest region of the country (AinaandSalau,1992). The Foods and Agriculture Organization of the United Nation (2001) defined Trees Outside Forests (TOF) as all trees excluded from the definition of forest and other wooded lands. In the Sub-Saharan Africa, it has been estimated that a third of the agricultural land contained at least 10% forest trees cover during the period of years 2008 and 2011(Zomer *et al*., 2014). On-farm trees are beneficial components of farmlands which have been found to play ecological functions, such as provision of soil nutrients, habitat for wild animals and serve as a key basis for biodiversity conservation (Bhagwat *et al.*,2008).

Tree volume and biomass estimates are essential for sustainable management and utilization of forest resources as well as carbon cycle dynamics in the ecosystem. (Mohren*et al.*,2012). According to Avery and Burkhart (2002), tree volume equations are useful for estimating average wood content of standing trees of various sizes and species and these equations rely on the relationship between the volume and growth variable, such as height and diameter at breast height. In addition, Vanclay (1994) described stand growth models as abstractions of the natural dynamics of a forest stand, which may encompass growth, mortality and other changes in stand composition and structure. As observed by Pillsbury *et al.* (1998), there are two types of volume equations that exist for tree volume prediction in forest resources management and they include local and standard volume equations.

Local volume equation is commonly used to predict tree volume using the diameter at breast height only, while a standard volume equation uses both the tree height and diameter at breast height. Tree volume equations are further classified into linear and nonlinear functions (West, 2009), the two basic forms allow the estimation of total stem volume from ground to tip over or under bark from the measurement of stem diameter at breast height, usually over bark and total height of the tree. Nonlinear regression models have been extensively used for natural forest reserves and plantations. According to Adesuyi, *et al.* (2020), Ratkowsky model of the form; V = a / (1+exp(b-c*x)), was found suitable for tree volume estimation in a strict nature reserve in the south west of Nigeria. More so, a study carried out by Adekunle (2007) on the tree species diversity and the efficiency of nonlinear regression models for timber volume estimation, the author recommended the use of nonlinear models for volume estimation in natural forest reserves. Similarly, Oyebade, *et al.* (2020) developed models for forest plantation and observed that the equations developed were efficient and reliable for tree volume estimation in *Gmelina arborea* plantation.

However, despite the importance of regression models for tree volume prediction, few or no such models have been developed for on-farm trees in Ogun State, this may be due to the fact that government places more emphasis on managing only government forest reserves in the State. Therefore, the objective of this research is to develop regression model for estimating the quantity of merchantable on-farm-trees that are available in the study area.

Materials and Methods

Study Area:

Ogun State is situated in the Western part of Nigeria and lies within latitudes 6° N to 8° N and longitudes 3° E to 5° E, and covers an area of about 16,762 square kilometers, representing, approximately 1.81 percent of Nigeria's total land mass of 923,768 square kilometers. The State is bounded by Oyo and Osun states to the north, Lagos state to the south, Ondo state to the east and Republic of Benin to the West. It is covered predominantly by tropical rain forests and has wooded savanna in the northwestern part of the State. (Ogun State Government, 2016).

Sampling Techniques and Data Collection: Data were collected through the adoption of 3-stage random sampling in the selection of the inventoried farmlands. Eight (8) Local Government Areas (LGA) were randomly chosen from the 20 LGA in the study area and four (4) villages were selected at random from each of the selected 8 LGAs. The final stage of the random sampling entailed the selection of 10 farmlands from each of the selected villages that gave a sample size of 320 farmlands. From each farmland, farm size was determined using a measuring tape, prismatic compass and ranging poles, while data on merchantable heights (h) and diameters at breast height (dbh) were obtained from all living forest trees, having dbh of at least, ten centimeters (dbh = 10cm) with the aids of Suunto and Vertex hypsometers and diameter tape respectively. Tree species identification was carried out on the spot and recorded accordingly.

Over bark volume estimation:

Basal Area (BA) and stem volume estimation of individual trees were carried out using the formulae prescribed by Husch *et al.* (2003) as indicated by equations 1 and 2

$BA = \frac{\pi d^2}{4}$ ………………….. Equation 1

V = BA * h …………………. Equation 2.

Where, BA is basal area (m), d = diameter at breast height (cm), p = pie (3.142),

V = stem volume, h = merchantable height.

Data Analysis

Descriptive statistics was used to summarize the results while inferential statistics (linear and non-linear regression models) was used to estimate the merchantable volume as a function of dbh alone and dbh and merchantable height.

Models Fitting and Assessment

Linear and nonlinear equations of various forms were tried for the best model fit and the equation comprised of easily measured tree growth variables as independents variables. These types of models had been previously used to estimate standing stem volume in the field of forest inventory (Schumacher and Hall, 1933; Spurr (1952). A total of 8 regression equations, which comprised of 5 local and 3 standard volume equations, were tried on the data collected (Table 1).

The selection of the best model for stem volume prediction was achieved through the examination of model residuals and regression statistics as recommended by Von Gadow and Hui, (1999). Residual analysis was performed on every fitted equation, using the scatter plot of residuals over independents variables, to examine the variance homogeneity. Model parameters were estimated by regression analysis using Statgraphics Criterion 18 Software. Model choice and validation for the best fit depended on the Coefficient of Determination (R^2 and R^2 adjusted), which is the statistic that measures the proportion of variation in every dependent variable that is captured by independent variable (Thomas, 1977). In regression analysis, a model will be considered to be reliable if its R^2 is equal or greater than 50%. Other regression statistics used for model assessment were; Standard Error of Estimate (SEE) and Mean Absolute Error (MAE).

Table 1. Stem volume equations using Dbh and height as independent variables.

Model Form.	Model Number.	Proposed Volume Equations.	Number of coefficients.
Vol = f (Dbh)	[1]	$Vol = a+b(Dbh)$	2
	[2]	$Vol = a(Dbh)^b$	2
	[3]	$Vol = \exp(a+b(\ln Dbh))$	2
	[4]	$Vol = \exp(a+b(Dbh))$	2
	[5]	$Vol = a+b(Dbh)^2$	2
Vol = f (Dbh, Height)	[6]	$\ln V = a+b(Dbh)+c(Mht)$	3
	[7]	$\ln V = a+b(\ln Dbh)+c(Mht)$	3
	[8]	$V = a(Dbh)^b(Mht)^c$	3

Note: Vol. is Tree Volume (m^3); Dbh is diameter at breast height (cm); Mht is merchantable tree height(m); ln is natural logarithm; exp is exponential; a, b, c are parameters estimated in this study.

Results and Discussion

A total of seven hundred and seventeen (717) on-farm trees belonging to 39 species and 22 different tree families were encountered in the selected 320 farmlands. The surveyed farmlands covered an area of 377.9 hectares (ha) with mean farm size of 1.6 ha±0.25ha and this gave an average number of 2 on-farm trees per hectare from the study area. Total volume estimated from the study area was 714.68m^3 with 0.53m^3 per hectare. The farmlands showed a lower quantity of trees per ha when compared with the findings of Shrestha *et al.* (2020) who reported an average of 2700 trees per hectare from aerial survey of trees outside forests in Nepal. However, from a study on inventory of farmland trees, carried out by Niang-Diop *et al.* (2020), the result showed an average of 2 trees per hectare which is similar to the result obtained from this study.

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The descriptive statistics for all measured tree growth variables encountered is presented in Table 2. The table showed that the merchantable height ranged from 0.37m to 17.8m with mean value of 6.43±0.08m while its diameter at breast height ranged from 10cm to 150cm with mean value of 40.1±0.63cm. Basal area and stem volume ranged from $0.01m^2$ to $1.77m^2$ and 0.04 m^3 to 7.35 m^3 with mean values of 0.15±0.01 m^2 and $0.99m^3$±$0.04m^3$ respectively. From a similar study on farmland tree sizes by Olanrewaju and Jimoh (2018), in Ijebu North of Ogun State, taller tree heights that ranged between 2.75m and 24.6m and tree diameter at breast height of 69.25cm were reported.

Table 2. Descriptive Statistics for major tree growth variables

Variables	Total Trees	Mean ± S.E.	Maximum	Minimum
Merchantable height(m)	717	6.43±0.08	17.8	0.37
Diameter at breast height(cm)	717	40.1±0.63	150.0	10.0
Basal Area(m^2)	717	0.15±0.01	1.77	0.01
Volume(m^3)	717	0.99±0.04	7.35	0.04

Note: S.E. is Standard Error

The results obtained by fitting 8 stem equations are presented in Tables 3 and 4. From the two basic models discussed before and adopted for this study; Vol = f (Dbh) and Vol = f (Dbh, Height), all equations performed well by attaining R-squares greater than 50%. Using stem volume as dependent variable and Dbh as independent variable, all equations in this category had R-squares situated between 55.61% and 71.38% while those equations having merchantable heights and Dbh as independent variables gave R-square adjusted between 92.22% and 98.53%. In both cases, all regression parameters were found to be statistically significant at 5% level. The values of all the R-square were considered acceptable for use in stem volume prediction since R-squares were greater than 50% based on the recommendation of Thomas (1977).

Table 3. The fitted equations for stem volume in the study area.

Model No	Developed Equations	R^2(%)	R^2Adj. (%)
1	Vol = -1.07 + 5.16(Dbh)	71.09	-
2	Vol = 4.62(Dbh)1.755	71.38	-
3	Vol= exp (1.68 + 2.11(lnDbh))	86.80	-
4	Vol= exp(-0.90+2.24(Dbh))	55.61	-

5	$Vol = 0.082+4.82(Dbh)^2$	69.84	-
6	$lnVol = -3.28+4.59(Dbh)+0.15(Mht)$	-	92.22
7	$lnVol = 0.60 + 1.95*lnDbh + 0.14(Mht)$	-	98.54
8	$lnVol = -8.41+1.56(lnDbh)+0.14(Mht)$	-	98.53

Tree Volume (m^3); Dbh is diameter at breast height (cm); Mht is merchantable tree

Table 4. Parameter estimates for the fitted equations.

Model No	a	b	C	SEE	MAE	P-Values
1	-1.07	5.16		0..56	0.31	0.0000
2	4.62	1.75		0.55	0.31	0.0000
3	1.68	2.11		0.34	0.26	0.0000
4	-0.90	2.24		0.69	0.45	0.0000
5	0.084	4.82		0.57	0.30	0.0000
6	-3.28	4.59	0.16	0.26	0.18	0.0000
7	0.60	1.95	0.14	0.11	0.06	0.0000
8	-8.41	1.56	0.14	0.01	0.07	0.0000

Note: a, b,c are parameters estimated, SEE is Standard error of estimates while MAE is Mean

The small values of standard error of estimate, (SEE) and mean absolute error (MAE) obtained in the analysis confirmed predictive, accuracy, precision and reliability of all developed equations. These observations are in supports of the findings by Glantz and Slinker (2001) who noted that SEE is a common measure of goodness of fit in regression models with low values indicating useful model fit, Similarly, MAE, is an acceptable natural measure of average error and the lower the value of MAE the better the regression model fitted. Therefore, the equation of the form; $lnVol = -8.41+1.56(lnDbh)+0.14(Mht)$ was selected.

A scatter diagram of the residuals over the predicted stem volume as independent variable from the selected model is shown in figure 1. The diagram revealed that the assumption of independence of residuals has been achieved and also in line with the condition of independence of errors in regression analysis.

The relationship between the observed stem volume and predicted stem volume, which were generated from the chosen model, is shown in figure 2, with majority of the predicted values fall in almost similar straight line with the observed values.

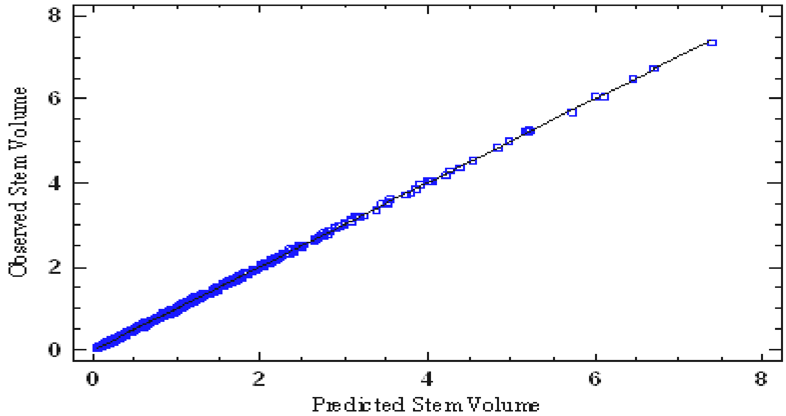

Figure 1. Plot of observed stem volume and predicted stem vlume.

Figure 2 shows the residual plot of volume which indicates an even spread of residuals above and below the zero of line no pattern. These residual pattern and other parameters estimated for this selected equation are very suitable and supported the findings of Adekunle *et al.*(2013) who pointed out that such equation gave reliable stem volume prediction.

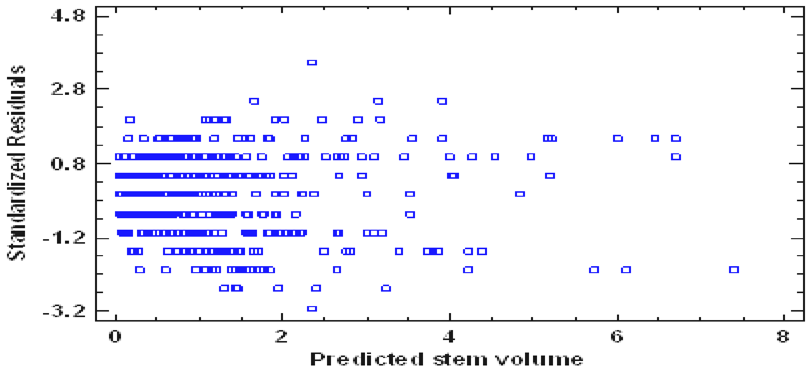

Figure 2. Plot of Standardized Residuals versus Predicted Stem Volume

Conclusion

This research work tested the suitability of linear and nonlinear regression equations for estimating stem volume of on-farm trees in Ogun State. A total of seven hundred and seventeen (717) trees were used for model building. The study showed that all stem equations that had their diameter at breast height and merchantable height as independent variables fit the observed data well. This double entry stem volume equations had higher precision and more reliable for prediction. The best stem volume equation is hereby presented for use in the management of on-farm trees in the study area: lnVol = -8.41+1.56(lnDbh)+0.14(Mht).

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