Gashua Journal of Irrigation and Desertification Studies
Available online at www.gjidsfugashua.org.ng
Maiden Edition: Vol 1, Nos. 1 & 2

DEVELOPING TREE VOLUME EQUATIONS FOR *AZADIRACHTA INDICA* (NEEM TREE) IN KATSINA STATE, NIGERIA

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Abstract

Volumes of current growing stock and future growth potentials are both important information for forest management. Tree volume equations are mathematical statements or expressions which relate tree quantity or volume to its measurable attributes such as base diameter, diameter at breast height, merchantable height and total height so as to obtain individual tree volume and the volumes of entire stands. This study seeks to develop tree volume equations using simple linear regression for *Azadirachta indica* in Sudano-sahelian region of Nigeria. A complete measurement of two hundred and forty-two (242) trees was carried out in some selected plantations of *Azadirachta indica* within two Local Government Areas of Katsina State situated within the Sudano-Sahelian eco-region (Katsina town in Katsina LGA and Dutsinma town in Dutsinma LGA). One hundred and thirty-six (136) trees and One hundred and six (106) trees were measured from Katsina town and Dutsinma town respectively. Data were collected through non destructive sampling method with the use of Spiegel Relascope and meter tape. Data consisted of stump diameter, diameter at breast height, top diameter, and merchantable height for the 242 trees. The results obtained revealed that the Stump diameter (Dst) of the sampled trees ranged from 41cm to 65cm; diameter at breast height (dbh) ranged from 32cm to 59cm; while the Top diameter ranged from 17cm to 46cm. Schumacher–Hall's volume function was fitted to the data of each of the sampled trees. Simple linear regression analyses were conducted with the Statistical Package for Social Scientists (SPSS) version 18 to generate the volume equations. Various criteria were used to evaluate the ability of each model to predict a specified dependent variable. Two (2) tree volume equations from the Six (6) equations developed were ranked the best. The two best volume equations among the generated equations are as follows: $LnV = 0.284 - 0.962Ln(D^2H)$; and $V = 0.019 + 0.737(D^2H)$; The R, R square, SEE, F-value and RMSE were 0.99, 99.7%, 0.01, 62214 and 0.0000001; 0.99, 99.6%, 0.01, 42637 and 0.00001 respectively. The equation developed was fitted to the data, and the resulting equations possessed desirable statistical properties and model behaviors.

Keywords: *Azadirachta indica, Data, Tree volume equations, Sudano-Sahelian, Katsina State*

INTRODUCTION

Azadirachta indica (Neem tree) belongs to *Meliacea* family. *Azadirachta indica* is a native of tropical, dry, deciduous evergreen forests of Burma, India and Srilanka, but has been cultivated throughout India, Malaysia and Pakistan for many years (Wikepedia encyclopedia). *Azadirachta indica* (Neem tree) is a fast growing, long-lived tree with unpleasant smelling wood that grows to the height of about 12 meters with a dense, round to oval crown. It has small fragrant yellow-white flowers followed by green-yellow berries. *Azadirachta indica* (Neem tree) is mostly found in Arid and Semi-arid regions and some parts of savanna region in Nigeria. *A. indica* is an extensively popular tree in Nigeria and is commonly referred to as Neem (English), "Dogon Yaro" (Hausa) and "Akun shorop" (Igbo) (Venugopalan and Visweswaran, 2013). The neem tree is an incredible plant that has been declared the "Tree of the 21st century" by the United Nations (UNEP, 2012).

Volume is the common widely used measure of wood quantity in forest mensuration. An equation is a mathematical statement setting two algebraic expressions equal to each other (Edward, 1992). Volume equation is defined as various mathematical statements applied to the determination of quantities (Shuaibu, 2014). Simple linear regression tree volume equations are process of developing tree volume equations using the relationship between a dependent variable such as volume and one independent variable such as stump diameter, diameter at breast height, merchantable height, or total height. According to Avery and Burkhart, (2002), tree volume equations are used to estimate average content of standing trees of various sizes and species. Volumes of current growing stock and future growth potential are both vital information for forest management. According to Onyekwelu and Akindele (1995), effective scientific management of forest resources requires knowledge of growth and yield of various tree species in the forest. Management decisions are made based on information about both current and future resource conditions. An understanding of the most current state of the resource being managed is essential for building a plan of action (Shuaibu and Dagba, 2013). The development of effective and accurate models for *Azadirachta indica* is very necessary to forest managers and planners in the study area since the specie is one of the major tree species used for managing wind break; marginal land; effect of climatic change; and desertification.

Most forest plantations are established in arid and semi-arid regions in order to protect lands from desertification, improve the fertility of the soil, to conserve biodiversity, to protect the people, animals, crops, rivers and streams from hazards of climatic change such as drought, flood, and erosion and increase the green environment since the land in most part of the arid and semi-arid regions are marginal lands. Managing the forest stands in marginal lands for multiple purposes has greatly increased the demand for volume equations that can accurately estimate the present and future yield of forest stands in those regions. Proper management of forests in arid and semi-arid regions due to multiple uses necessitates the need to develop tree volume models that can monitor the changes in the tree stands over time.

The objective of this study therefore is to generate tree volume using simple linear regression equations for the stands of *Azadirachta indica* (neem tree), which is the one of the forest stands commonly found in arid and semi-arid regions of Nigeria.

MATERIALS AND METHODS

The Study Area

This study was carried out across plantations within two Local Government Areas of Katsina State (Katsina town in Katsina LGA and Dutsinma town in Dutsinma LGA). Katsina State lies within Latitude 12°15'N and Longitude 7°30'E with a population of 5,792,578 (2006 Census). Katsina State is located in North-Eastern region of Nigeria, it occupies 24,192 square kilometres. It is bounded in the East by Kano and Jigawa States, in the West by Zamfara State, in the South by Kaduna State and in the North by the Niger Republic. The indigenes are Fulani and Hausa. The main occupation of Katsina State indigenes is livestock production and farming. Forest trees commonly found in the area are *Adansonia digitata, Azadirachta indica, Mangifera indica, Eucalyptus camadulenses, Tamarindus indica, Acacia species, and Moringa oleifera.*

Data Collection

Complete measurements of two hundred and forty-two (242) trees were carried out in the selected plantation of *Azadirachta indica* within two Local Government Areas of katsina State which include Katsina town in Katsina LGA and Dutsinma town in Dutsinma LGA. One hundred and thirty-six (136) trees and One hundred and six (106) trees were measured from Katsina town and Dutsinma town respectively. Data were collected through non destructive sampling method with the use of Spiegel Relascope and meter tape to measure the diameter and height of Azadirachta indica stands in the study area.

Data Analysis

The data collected were arranged in excel and the statistical analysis of the collected dataset was performed using Microsoft Excel.

Estimation of Basal Area

Basal area of the sampled trees in the study area was calculated using the formula:

$$BA = \frac{\pi D^2}{4} \text{ ------------------------------ } 1$$

Where: BA = Basal area (m^2)
D = Diameter (cm)
π = Pie (3.142)

The total basal area for the sample trees was obtained by adding up the basal areas of all the trees measured in the study area.

Volume Estimation

The volume of individual trees was estimated using the Newton's formula by Husch *et al.* (2003)

$$V = \frac{\pi h}{24}\left(D_b{}^2 + 4D_m{}^2 + D_t{}^2\right) \text{ -----------} 2$$

Where:
V = Merchantable volume of tree (m^3)
Dst = Stump diameter (cm)
D_m = Middle diameter (cm)
D_t = Top diameter (cm)
H = Merchantable height (m)
$\pi = (3.142)$

Six (6) simple linear regression models were generated for the tree volume estimation. In this study, the volume of the stem of a tree is considered as a function of the independent variables: stump diameter, diameter at breast height and merchantable height, which is expressed as follows:

$$V = f(Dst, D \text{ and } H) \text{ -------------------- } 3$$

Where V = merchantable volume, Dst = stump diameter, D = diameter at breast height, and H = merchantable height. The simple linear model used one variable (Dst), (D), and combined variable (D^2H) to estimate the tree volume. The basic assumption is that trees of given specie, at a given location, with the same diameter at breast height (dbh), will have the same height and form. Because not all tree inventories include height, both types of equations are presented here to provide flexibility for the user. The simple linear models were of the form given in equations 4 and 5:

$$V = ß_0 + ß_1(Dst) \text{ ------------------------ } 4$$

$$V = ß_0 + ß_1(D) \text{ ------------------------ } 5$$

Including height in the equation generally provides a better estimate as it helps account for soil, climate and some cultural variations.

$$V = ß_0 + ß_1(D^2H) \text{ ----------------- } 6$$

The logarithmic transformation of the variables in equation (4 - 6) was also use to estimate the parameters:

$$lnV = ß_0 + ß_1\ln(Dst) \text{ ----------------- } 7$$

$$lnV = ß_0 + ß_1\ln(D) \text{ -------------------- } 8$$

$$lnV = ß_0 + ß_1\ln(D^2H) \text{ --------------- } 9$$

Where: V = Tree volume in m^3, Dst = stump diameter, D = diameter at breast height, H = tree height in meter; $ß_0$, $ß_1$ and $ß_2$ = regression parameters. SPSS 18.0 for Windows was used to conduct regression analysis to generate equations that express tree volume as a function of stump diameter; dbh; and combined dbh and merchantable height. Simple regression analysis (equations 4 - 9) was used to develop the volume prediction equations (Husch *et al.*, 2003; Akindele and LeMay, 2006).

Evaluation of the Models

The models were evaluated in order to test their plausibility and also recommend them for onward use. These statistical principles below were used:

Significance of Regression
This was used in testing the overall significance of the regression equation. The critical value of F (that is, F-tabulated) at $p < 0.05$ level of significance was compared with the F-ratio (F-calculated). Where the variance ratio (F-calculated) is greater than the critical values (F-tabulated) such equation is considered significant and can be accepted for prediction.

Multiple Correlation Co-efficient (R): The (R) measures the degree of association between two variables (Y-Dependent variable and X-Independent variable. The R- value must be high (> 0.50) for the model to be considered good fit (Mead *et al.* 1994).

$$R_{z,xy} = \sqrt{\frac{r^2{}_{xz} + r^2{}_{yz} - 2r_{xz}\, r_{yz}\, r_{xy}}{1 - r^2{}_{xy}}} \quad \text{---} \ 10$$

Where Z = dependent variable, x and y = independent variables, R = multiple correlation coefficient

Coefficient of Determination (R^2)
The (R^2) measures the proportion of variation in the dependent variable that is explained by the behavior of the independent variable. In order for the model to be accepted, the R^2 value must be high i.e >50% (Thomas, 1977). The formula below was used to compute it.

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \quad \text{--------------------} \ 11$$

Where R^2 = Coefficient of determination, SS_{res} = residual sum of squares, SS_{tot} = total sum of squares, and 1= regression line

Regression Standard Error of Estimate
The value must be relatively small for the model to be considered valid.

$$\sigma_{est} = \sqrt{\frac{\sum(Y - \bar{Y})^2}{N}} \quad \text{------------} \ 12$$

Where (Y-Y')² = the squared errors of prediction, N = observation

Models Validation: The validation process according to Marshall and Northway (1993), examines the usefulness of the models or validity. Marshal and Northway, 1993 maintained that for models with good fit, there should be no significant difference (p>0.05 or t-statistic < t-tabulated/critical) between the mean of the observed and predicted values with the result of the student t-test. Observed volume was individually compared with predicted volume using paired-samples T-Test, simple linear regression models and ANOVA single factor. The observed volume was the dependent variable while the predicted volume was the independent variable.
Statistical indices such as Absolute Bias (AB), percentage Absolute Bias (AB %), Root Mean Square Error (RMSE) as given in equations 13 to 15 were used to assess the goodness of fit for the models

$$RMSE = \sqrt{\frac{1}{n}\sum_{i-1}^{n}(y_i - \hat{y}_i)^2} \quad \text{-------------} \ 13$$

$$Bias = \frac{1}{n}\sum_{i-1}^{n}(y_i - \hat{y}_I)^2 \quad \text{-------------------} 14$$

$$\%Bias = 100 = \frac{\sum_i^n = 1(y_i - \hat{y}_I)/n}{\sum_i^n = 1\hat{y}_I/n} \quad \text{----------} \ 15$$

Where y_i = observed value and $\hat{y}_I$ = predicted value. The Root Mean Square Error (RMSE) must be relatively small for the model to be acceptable for volume estimation and for management purposes (Adekunle *et al.* 2013).

RESULTS AND DISCUSSION
Six (6) forms of simple volume models were generated for *Azadirachta indica* tree volume prediction and estimation in this study. The models were evaluated and

validated to ensure their adequacy for prediction of tree volumes.

The results of the assessment criteria shows that two (2) models (models 3 and 6) out of the six (6) models was rated the best for estimation of merchantable volume of neem tree. The combined linear models with D^2H as the predictor variable which was ranked as the best had a coefficient determination (R^2) of 99.6% and 99.7% for the logarithmic transformation; low standard error of estimate (SEE) 0.01 and 0.01; low value of RMSE (0.00001 and 0.000001); and very high F-value (42,637 and 62,214 respectively). The F-ratio for all the models were significant ($p<0.05$).

Statistical Indices

The statistical indices which include relative BIASES, %BIASES, and RMSE were used to determine the accuracy of the models and the results obtained were very low. These values were relatively very low confirming that the models gave accurate predictions with manageable error (Adekunle *et al.* 2013). All volumes predicted were compared to observed volume using one-way analysis of variance (ANOVA); T-test; simple linear regression equation; and graphical analyses of residuals. The ANOVA results for the models are shown in Table 4.

The results of single factor ANOVA used in comparing the observed values and the predicted value showed that there were no significant differences ($p>0.05$) between the observed and predicted models generated, meaning the volume model generated is adequate for the estimation of volume of neem tree. Table 3 shows the T-test result, a paired Student's t-test applied on the measured and predicted volume showed that all the twelve models generated have p-values > 0.05 indicating that the difference between observed and predicted volumes are not significant. The results also show that the t-test statistics for the models are less than t-critical (t-stat < t-critical), the models therefore, have good fit.

There was high and very high correlation coefficient and coefficient of determination (R^2) for all the six models, the results are presented in Table 5. There were no significant differences in the observed versus predicted volumes for all the models. Simple linear regression confirmed that the models had adequate fit. The residual plots of the observed volumes versus the predicted volumes of the two (2) best models from the six (6) models from validation were analyzed using simple regression analysis. Graphic presentation of residual plots against two (2) best predicted values shown in Figure 1-2 indicated homogenous variance. There was no identifiable trend of scatter-plots. This showed that the models did not violate any assumptions and there were no heteroscedasticity problems. These statistics evaluation principle revealed the plausibility of these models. They are hence adequate for neem tree volume prediction.

In this study the observed volume of the sample trees was calculated by applying Newton's formula: Volume = $\frac{\pi h}{24}(Db^2 + 4Dm^2 + Dt^2)$. Six (6) volume models that could be used for merchantable volume estimation were developed and tested for neem tree. All the models developed performed very well with the data set. Most models tested performed similarly to each other. Residual plots for the two best volume equations generally indicate an even spread of residuals above and below the zero line, with no systematic trend (Fig. 1-2). These models use D^2H; and Ln D^2H as input variables, this suggests that using D^2H as entry variable appeared to be appropriate for reducing heteroscedasticity and multicollinearity problems. The result of SEE, RMSE, and F-value shows that the models have good fit and are therefore recommended for tree volume estimation for *Azadirachta indica*. The logarithmic transformation of the models was very efficient. This was in line with the studies of several authors including Akindele and LeMay (2006) which stated in their studies in the development of tree volume equations for common timber species in the tropical rain forest area of Nigeria that the generalized logarithmic volume function (also termed Schumacher's volume function) performed better than other forms of volume functions; also Louis, (2005) in developing total volume model for teak in Tanzania stated that the logarithmic transformed Schumacher and Hall (1933) provided an excellent fit to the sample data by means of linear regression.

Assessment of the Volume Models

All the assessment criteria revealed that the generated models had good fit. The statistical fits were generally good. The use of these equations is recommended based in part on the results of the one way analysis of variance; a paired Student's t-test; and Simple linear regression equation of the observed and predicted volumes. There were no significant differences between observed and predicted volumes. There was a strong relationship (high R values) between the observed and predicted volumes, high R^2, significant F-ratio and small standard error of estimate. SE, RMSE, Biases and % Biases also confirmed predictive precision, accuracy, and normality. The values were very small and similar to what were obtained by Sonmez *et al.* (2009) and Adam and Csalovics (2010). This was supported by the report of Adekunle (2006) that standard error of estimate is a good measure of overall predictive value of regression equations. (Glantz and Slinker (2001) also noted that it is a common measure of goodness of fit in regression models, with low values indicating better fit. The scatter-plots were consistent with the results of other statistical indices for validation. This shows that the regression assumptions were not violated.

Validation of the Models

The validation dataset included measurements of Seventy (70) trees other than those used to develop the newly-generated equations. The data are within the ranges or the representative of the fitting data set. The level of multicollinearity of the equations was tested with respect to both the fitting and validation data to ensure that no potential problem of multicollinearity was present. Results from the simple linear regression of the observed versus predicted volume on both the fitting and validation data show that the equations generated is suitable when there is a need for high precision and accuracy.

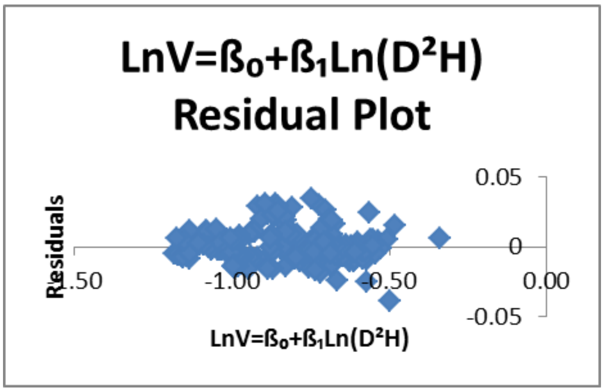

Figure 1: Residual Plot for the Observed versus Predicted for the Logarithmic Single Combined entry

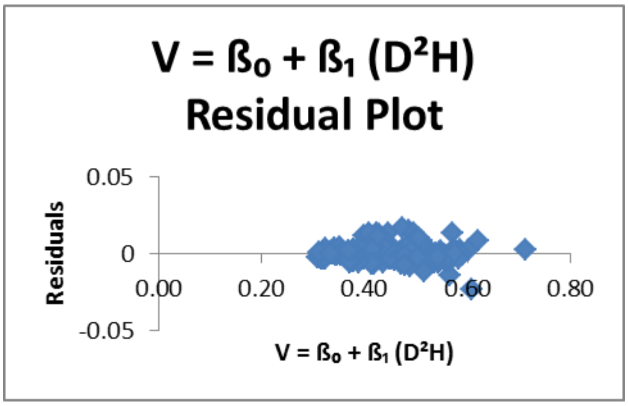

Figure 2: Residual Plot for the Observed versus Predicted for the Single Combined entry

CONCLUSION

Findings of this study confirmed that there was a strong positive correlation between the merchantable volume as dependent variable; and stump diameter, diameter at breast height (dbh) and merchantable height as independent variables. Therefore, using Dst, dbh and merchantable height can give precise estimates of neem tree volume. In all, Logarithmic transformation gives better results compared with other untransformed values. The regression residuals were normally distributed, with constant variance and zero mean. The models were therefore efficient from the validity standpoint.

RECOMMENDATION

The merchantable volume of *Azadirachta indica* have been adequately described by the equations generated in this study, and the equation can be applied with relative ease.

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Table 1: Summary of Tree Variables Measured for Model Generation

Tree variables	Tree No	Minimum	Maximum	Mean	StDv
Merchantable Height	242	1.65 m	4.14 m	3.16	0.64
Dbase (m)	242	0.41	0.65	0.51	0.07
Dbh (m)	242	0.32	0.59	0.44	0.08
Top diameter	242	0.17	0.46	0.3	0.08
BA Dbase m^2	242	0.13	0.33	0.21	0.06
Ba Dbh m^2	242	0.08	0.27	0.15	0.05
Volume (m^3)	242	0.31	0.72	0.44	0.08

Table 2: The Six (6) Volume Equations Generated for *Azadirachta indica*

No.	Linear Models	R	R^2 (%)	SEE	RMSE	F-value	Biases	%Biase
1	V=0.027 - 0.917 (Dst)	0.78	61	0.1	0.003	374	4.1E-07	0.00931
2	V = 0.073 + 0.853 (D)	0.82	67	0.1	0.002	487	5.0E-05	-0.1024
3	V=0.019+0.737(D^2H)	0.99	99.6	0.01	0.00001	42637	0.00013	-0.1676
4	LnV = 0.063-1.134 Ln (Dst)	0.82	67	0.1	0.1	495	3.7E-06	-0.0149
5	LnV=0.092+0.869Ln (D)	0.85	73	0.1	0.01	635	1.0E-05	0.02493
6	LnV = 0.284 - 0.962 Ln (D^2H)	0.99	99.7	0.01	0.000001	62214	9.3E-05	-0.0748

Table 3: T-test for the observed versus predicted volumes

Model	df	t-Stat	t-crit	p-value	p-correl
1	241	0.02	1.97	0.99	0.78
2	241	-0.15	1.97	0.88	0.82
3	241	-2.32	1.97	0.12	0.998
4	241	0.02	1.97	0.99	0.82
5	241	-0.03	1.97	0.97	0.85
6	241	0.97	1.97	0.33	0.998

Table 4: Anova Result for Observed versus Predicted Volume

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Observed volume	242	107.4314	0.443931	0.00647
V = $ß_0 + ß_1$ (Dst)	242	107.4176	0.443874	0.003943
V = $ß_0 + ß_1$ (D)	242	107.54	0.44438	0.004373
V = $ß_0 + ß_1$ (D^2H)	242	107.6082	0.444662	0.006442

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000336	6	5.59E-05	0.010652	0.999995	2.103948
Within Groups	8.856265	1687	0.00525			
Total	8.8566	1693				

Table 5: Simple Linear Regression Result for Observed versus Predicted Volume

No	R	R^2	SEE	RMSE	F	P-value	t-Stat
1	0.78	61%	0.05	0.002	373	0.99	0.01
2	0.82	67	0.05	0.002	487	0.94	0.08
3	0.99	99.6	0.005	0.00002	64,706	0.62	-0.49
4	0.82	67	0.1	0.01	489	0.97	-0.03
5	0.85	73	0.1	0.01	639	0.97	0.03
6	0.99	99.7	0.01	0.0001	73,140	0.9	-0.12