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# Tree volume equation for Sahelian ecosystem in northern Nigeria

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**Abstract**
Tree species has potential commercial value which can have important contribution to the economy. The need for developing volume equations that can be use in managing these tree species becomes very important. Volume equation was developed for timber species in sahel ecosystem of northern Nigeria. Data were collected through non destructive procedure with the use of Spiegel Relascope and meter tape. The data consisted number of trees species and families, diameter at breast height (D.B.H) and merchantable height for eight (8) timber species. A total of one hundred and eighty one (181) trees from different families and species were recorded as shown in table 1. The result from the study showed that the DBH ranged from 0.10m to 1.05m with a mean of 0.2914, and merchantable height ranged from 14.30m to 3.20m respectively. The merchantable volume ranged from 0.05m$^3$ to 1.55 m$^3$ in the study area. The Schumacher–Hall's volume function was fitted to the data of the sampled tree species. Two equations were rated the best among others. Validation of the equations was conducted to confirm the goodness of fit and the resulting equations have the needed statistical properties.

**Keywords:** Sahel ecosystem, tree species, volume equations, merchantable volume

## 1. Introduction

Nigeria is found in the Tropics, where the climate is seasonally damp and very humid. The natural vegetative zones that exist in the country are governed by the combined effects of temperature, humidity, rainfall and particularly, the variations that occur in the rainfall. This forms a major influence on the type of indigenous plants that grows successfully in different parts of the country. The tropical rain forest is one of the major vegetation types of the globe (Richards, 1996; Whitmore, 1998) [8, 16], occupying a total area of 1818.43 million hectares and representing 47% of the total land area occupied by all forest types of the world (FAO, 2003) [4]. According to Turner (2001) [13], the tropical rain forest is the most diverse of all terrestrial ecosystems, containing more plant and animal species than any other biome. In Nigeria alone, over 4600 plant species have been identified (Sarumi *et al.,* 1996) [9]. Savannah zone in Nigeria was categorized into Guinea savannah, Sudan savannah and Sahel savannah (Iloeje, 2001). Difference in precipitation is the major factor that determines the type of plant that grows and those that would thrive when introduced to each zone (Aregheore, 2009) [2].

Sustainable forest management requires estimates of growing stock. Such information guides forest managers in timber valuation as well as in allocation of forest areas for harvest (Akindele and LeMay, 2006). For timber production, an estimate of growing stock is often expressed in terms of timber volume, which can be estimated from easily measurable tree dimensions. Tree volume is one of many parameters that are measured to document the size of individual trees. Volume is the common widely used measure of wood quantity in forest mensuration (Shuaibu *et al.*, 2015) [11]. An equation is a mathematical statement setting two algebraic expressions equal to each other (Edward, 1992). The most common procedure is to use volume equations based on relationships between volume and variables such as diameter and height (Akindele and LeMay, 2006). According to Avery and Burkhart (2002) [3], volume equations are used to estimate average content of standing trees of various sizes and species. The reliability of volume estimates depends on the range and extent of the available sample data and how well volume equations fit this sample data. In developing tree volume equation, there are challenges that are pronounce on the process such challenges are the heterogeneity in species composition and structure (Akindele and LeMay, 2006). However according to Akindele and LeMay, 2006 these challenges can be overcome by; using data for each species separately to develop equations for individual species; combining data for all species and developing a single set of equations for all species combined; and/or classifying species into groups and combining data for all species within each group to develop equations for the group. The number of equations will depend on the number of groups into which species are classified. The most common procedure for grouping tree species in growth and yield studies is the use of cluster analysis or other classification procedures (Vanclay, 1991; Phillips *et al.*, 2002; Picard and Franc, 2003; Zhao *et al.*, 2004) [14, 7, 17]. For proper management and sustainable utilization of forest resources in sahel ecosystem, development of tree volume equation become necessary to monitor the kind of changes that occurs in tree stand over time. Growth modelling is an essential prerequisite for evaluating the consequences of a particular management action on the future development of a forest ecosystem and is now a central theme of forest management (Singh and Tewari, 2015). Sampling Growth models are not available for many species in Nigeria hence necessitated the development of tree volume equation for proper management of forest stock. There is a lack of evaluation concerning number of trees to be sampled and how this affects volume model capabilities. Perhaps such recommendations are conclusions of empirical methods and stabilization of coefficient of variation (Davide *et al.*, 2016). The objective of this study is to aggregate the timber species of sahelian ecosystem of northern Nigeria into their various families, estimate volume and to develop a tree volume equation.

## 2. Materials and Methods

### 2.1 Study Area

Gashua is located in Bade Local Government Area, Yobe State, Nigeria. Gashua lies between 12052' 5"N and 1102'47"E. The average elevation is about 299m A.S.L. (above sea level) (Wakawa *et al.*, 2017) [15]. The hottest months are March and April with temperature ranges of 38-40°C. In the humid season, June-September, temperatures fall to 23-28°C, with rainfall between 500 and 1000mm. The vegetation zone of Yobe State is divided into two; Sahel Savanna to the north and Sudan Savanna to the south (Naibbi *et al.*, 2014). Gashua falls within the Northern zone therefore the vegetation zone is Sahel. The common trees found in the area includes; *Acacia seyel, Balanite aegyptiaca, Azadiracta indica, Adansonia digitata, Faidherbia albida, Tamarindus indica, Hyphaene thebaica, Anogeissus leiocarpus* (Wakawa *et al.*, 2017) [15]

### 2.2 Data collection

The study area was stratified into three (3) sites. Sampling technique was used in the laying of the temporary sample plots (Quadrats) in the study area. In each of the strata (site), transects of 1000m length were laid. Sample plots of 40m x 40m in size were established in alternate position along each transect at 40m interval. Trees in the quadrats were counted and recorded according to their species and families. Data were collected through non destructive procedure with the use of Spiegel Relascope and meter tape. The data consisted of the species name, families, diameter at breast height and merchantable height.

### 2.3 Data analysis

Data collected for the present study were entered and computed in the Microsoft excel, the volume was computed using Newton's formula. Statistical Package for Social Scientists (SPSS) was used to conduct multiple regression analysis to generate linear models relating tree merchantable volume as a function of diameter at breast height (DBH); and merchantable height. Four (4) linear and non linear equations were generated with merchantable volume as the dependent and diameter at breast height and total height. The models are as follows

$v = \beta_\circ + \beta_1 D$ ------------------------------------------ 1

$v = \beta_\circ + \beta_1 D^2H$ ---------------------------------------- 2

$lnv = \beta_\circ + ln\beta_1 D$ ------------------------------------- 3

$lnv = \beta_\circ + ln\beta_1 D^2H$ ---------------------------------- 4

Where:
V = Tree volume ($m^3$)
$D^2H$ = D.B.H square and height
Ln = Natural log
$\beta_\circ, \beta_1 and\ \beta_2$ Are regression parameters

### 2.4 Model Assessment

Statistics such as the coefficient of determination ($R^2$), standard error of estimate (S.E.E.) and Root mean square root (RMSE) were used in order to test goodness of fit of the models. Residual analysis was also used to check whether the models are appropriate or not.

## 3. Result and Discussions

The table 1 shows that a total of one hundred and eighty one (181) species was recorded from eight families (8) in the study area. *Fabaceae* family had six (6) species which had the highest number of species followed by the family *aracaceae* with two species (2). The death trees were excluded from the study. This was because the volume equations developed 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.

**Table 1:** Data distribution according to family

| Family | Species | No of observation |
|---|---|---|
| *Fabaceae* | 6 | 93 |
| *Capparaceae* | 1 | 4 |
| *Balanitaceae* | 1 | 15 |
| *Rhamaceae* | 1 | 1 |
| *Arecaceae* | 2 | 2 |
| *Combrataceae* | 1 | 2 |
| *Malvaceae* | 1 | 4 |
| *Meliaceae* | 1 | 60 |
| Total | 8 | 181 |

The diameter at breast height (D.B.H) ranged from 0.10m to 1.05m with a mean of 0.2914, merchantable height ranged from 14.30m to 3.20m respectively. The merchantable volume ranged from $0.05m^3$ to $1.55\ m^3$ in the study area as shown in the table 2 below.

**Table 2:** Tree variables name of trees

| Tree variables | No of trees | Minimum | Maximum | Mean | Std. Dev |
|---|---|---|---|---|---|
| DBH | 181 | 0.10 | 1.05 | 0.2914 | 0.16748 |
| Height | 181 | 3.20 | 14.30 | 7.1964 | 3.08667 |
| Volume | 181 | 0.05 | 1.55 | 0.3106 | 0.27704 |

Four (4) linear and non-linear equations were generated in this study with the merchantable volume as the dependent variable; height and DBH are the independent variables for prediction and estimation. The data were subjected to SPSS in computer for regression analysis to validate and test of good fit of the models. The statistical analysis showed that the models are appropriate and concise for volume evaluation. The model were assessed and validated to ensure their adequacy for the prediction of merchantable volume of trees.

**Table 3:** Volume equations using D.B.H and height

| Equation | Coefficient of determinations ($R^2$) | $R^2$ adjusted | RMSE |
|---|---|---|---|
| V= -0.140 +0.934D | 0.93 | 0.87 | 0.011 |
| V= 0.160 + 0.147D² H | 0.93 | 0.86 | 0.010 |
| Lnv =0.295+0.918lnD | 0.92 | 0.84 | 0.130 |
| Lnv =-0.423+0.988lnD² H | 0.98 | 0.98 | 0.010 |

The results of the generated models shows that all the models generated have very good fit as they all have $R^2$ above the recommended value for goodness of fit. According to Thomas, 1977, In order for the model to be accepted, the $R^2$ value must be high i.e. >50%. Model four (4) was rated the best for the estimation of merchantable volume of the trees species in the study area. A good measure of the overall predictive value of the regression equation is the standard error of estimate (S.E.E.) (Akindele and LeMay, 2006). It is a common measure of goodness of fit in nonlinear regression (Glantz and Slinker, 2001) [5] with low values indicating better fit. From this study, the S.E.E ranged from 0.004 to 0.09927. The calculated standard errors of the present study were very low which suggest good fit as indicated by Akindele and LeMay, 2006. Root mean square error (RMSE) was calculated to further ascertain the validity of the model and it was discovered that the values were very small and this confirm that the models are valid for use.

**Validation of the model**

The generated Models were validated with 30% of the data collected from different locations which was used for model generation. The coefficient of the determination ($R^2$) for all the four (4) models was found to be around 89 to 97 percentage. This means that large proportion of the variation in the tree volume was explained by D.B.H and merchantable height. Residual analysis indicated that the models were appropriate for volume estimation.

**Table 4:** Validation Result

| Models | R | $R^2$ (%) | SEE | RMSE |
|---|---|---|---|---|
| 1 | 0.89 | 89 | 0.06 | 0.09407 |
| 2 | 0.92 | 91 | 0.01 | 0.08401 |
| 3 | 0.83 | 82 | 0.09 | 0.14339 |
| 4 | 0.97 | 97 | 0.01 | 0.05924 |

## 4. Conclusion

Tree volume equations were developed in the present study to estimate the merchantable volume of tree species in sahelian ecosystem. Findings from the study shows that all the linear and non-linear models generated perform very well; although equation four (4) was the best with highest $R^2$ which is in the logarithmic form. In all the equations generated strong positive correlation was discovered between the dependent and the independents variables. The study combine all the tree species in the study area for the development of the tree volume equation and it appears to be very good and precise this could be because the trees in the study area were all combine together regardless of the family and the species. It should be noted that every tree species has its own biological attribute which can have bias implication in the study. Where there is interest in species-specific volume models, recalibration of the models should be considered.

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