Journal of Forestry Research and Management. Vol. 17(2).38-47; 2020, ISSN 0189-8418

www.jfrm.org.ng

STUMP-BREAST HEIGHT DIAMETERS RELATIONSHIP FOR TREE SPECIES OF FABACEAE FAMILY IN MAKURDI, NIGERIA

Chukwu, O.* and Ezenwenyi, J. U.

Forestry and Wildlife Department, Nnamdi Azikiwe University, Awka, Nigeria
*corresponding author: onye20042000@yahoo.com; +2348032633835

ABSTRACT

Tree stem diameter has been utilized in forestry as input variable for modelling growth and yield, crown dimensions, biomass and carbon budget, timber volume, tree stability, stand structure to mention but a few; there is paucity of models for estimating tree breast height diameter ($D_{1.3}$) from stump diameter ($D_{0.3}$) for indigenous tree species in Nigeria.$D_{0.3}$and $D_{1.3}$relationship is useful in many situations, such as timber trespass and reconstruction of forest status. This study aimed at establishing the relationship between $D_{0.3}$ and $D_{1.3}$ofthree tree species of Fabaceae family within the Federal University of Agriculture, Makurdi, Nigeria. All standing living *Daniella oliveri*, *Parkia biglobosa* and *Prosopis africana* species trees with stump diameter ≥10.0 cm in twenty temporal sample plots of size50 m x 50 m laid systematically in the study area were enumerated. Out of the models tested, simple linear, cubic and power best explained the relationship between $D_{0.3}$ and $D_{1.3}$ of the three species, respectively. However, the $D_{0.3}$-$D_{1.3}$ relationship for the pooled species was best described by the power model with the lowest values of standard error of estimate (1.869) and Akaike information criterion (336.99). Model validation result showed a non-significant difference (P>0.05) between the predicted and observed values of $D_{1.3}$ from $D_{0.3}$.The models developed can be used to estimate $D_{1.3}$ of the species extracted from the study area for any reason. Local calibration may be performed for the models to be used outside the study area.

Keywords: Fabaceae, regression models, stump diameter; timber trespass

Introduction

In forestry, tree breast height diameter ($D_{1.3}$) is one of the most important tree growth variables for its multipurpose functions. $D_{1.3}$ has been utilized as input variable for estimation of tree growth and yield, crown dimensions, biomass and carbon budget models, site index, timber volume, tree slenderness coefficient, growth spacing, stand structure and so on(Akindele and LeMay, 2006; Adesoye and Ezenwenyi, 2014; Dau and Chenge, 2016; Ezenwenyi and Chukwu, 2017). $D_{1.3}$ has also been used for forest policy and sustainable management decisions (Akindele and LeMay, 2006; Adesoye and Ezenwenyi, 2014; Dau and Chenge, 2016; Ezenwenyi and Chukwu, 2017). Several reasons could warrant the estimation of the breast height diameter of a removed tree; these could be creating historical records of past management activities, reviewing harvesting practices, assessing damage due to catastrophic events, establishing loss due to timber trespass, prediction as part of a forest inventory and providing an empirical quantity of removed tree's $D_{1.3}$ for conviction of illegal loggers (Westfall, 2010; Chukwu and Osho, 2018).

A review of the literature indicated that prediction of tree growth variables from stump dimensions is common (Osho, 1983; Özçelík *et al.*, 2010; Shamaki and Akindele, 2013, Chukwu and Osho, 2017). Most early works on predicting breast height diameter from stump diameter were on exotic species (Osho, 1983; Westfall, 2010; Shamaki and Akindele, 2013), thus, there is paucity of models for estimating $D_{1.3}$ from $D_{0.3}$ for indigenous tree species in Nigeria. *Daniella oliveri* (African copaiba balsam), *Parkia biglobosa* (African locust bean) and *Prosopis africana* (African Mesquite) are indigenous tree species in Fabaceae family (Alabi *et al.*, 2005; Dau and Chenge, 2016).They are common around rural communities in the Savannah areas of West Africa; where they are mostly left standing during land clearing and sometimes planted (Hutchinson and Dalziel, 1963; Laouali *et al.*, 2016). These species are very important economically and ecologically (timber and non-timber benefits). Some of these benefits include: medicine from their leaves, roots and bark, fodder from their leaves and pods and food seasoning from their seeds (Elly and Joseph, 2012; Laouali *et al.*, 2016). They are deciduous perennial plants that grow up to between 7 and 20 m height, in some cases up to 30 m (Ntui *et al.*, 2012; Buba, 2013).

The study therefore aimed at evaluating the relationships between stump diameters and breast height diameter for *D. oliveri*, *P. biglobosa* and *P. africana* in Makurdi, Nigeria using regression models, with a view to estimating breast height diameters from stump diameter required as input variable for crown, height, volume and yield predictions.

Materials and Methods

Study Area

The study was carried out at an unprotected forest, situated behind College of Engineering, Federal University of Agriculture Makurdi, Benue State, Nigeria. The University lies from Latitude 7° 39ʹ10″ Nto 7° 47ʹ0″ N and Longitudes 8° 44ʹ40″E to 8° 49ʹ46″ E within the southern guinea savannah ecological zone of Nigeria and covers a total land area of 80.48 km^2 (Msugh-Ter *et al.*, 2017; Onuwa, 2017). The topography of the study area is characterized by gentle hills. The soil is mainly sandy-loamy; the climate is characterized by distinct rainy and dry seasons. The annual rainfall ranges between 1016 mm to 1524 mm spreading over May to October. The climate of the area is tropical sub-humid with high temperatures and high humidity; the average maximum and minimum daily temperature of 35°C and 21°C in wet season, and 38°C and 16°C in dry season." (Dau and Chenge, 2016).

Data collection

Systematic sampling technique was adopted for plots' location in this study. Five (5) 1 km-transect each were cut in the forest at an interval of 500 m from each other. Twenty (20) temporary sample plots (TSPs) of size 50 m x 50 m (0.25 ha) were alternately laid at 250 m interval along each transect. In each TSP, total enumeration of standing living *Daniella oliveri*, *Parkia biglobosa* and *Prosopis africana* trees with breast height diameter ≥10.0 cm were made. Stump diameter ($D_{0.3}$)and diameter at breast height ($D_{1.3}$) outside bark were measured using diameter tape calibrated in cm.

Data Analysis

Data from the *D. oliveri*, *P. biglobosa* and *P. africana* trees for the study were subjected to descriptive statistics (mean and standard deviation) and bivariate correlation (Pearson's product-moment).Seven different functions (simple linear, semi logarithmic, square, inverse, quadratic, cubic and power) were examined to model the relationship between stem breast height diameter and stump diameter outside bark. Ordinary least square (OLS) was used to fit data available for this study. The expressions of the candidate functions were presented in Table 1.

Table 1: Candidate functions used for modeling the $D_{1.3}$ and $D_{0.3}$ relationships

Equation No.	Function form	Function
1	$D_{1.3} = \alpha + \beta D_{0.3}$	Simple Linear
2	$D_{1.3} = \alpha + \beta \ ln \ D_{0.3}$	Semi Logarithmic
3	$D_{1.3} = \alpha + \beta \left(\frac{1}{D_{0.3}}\right)^2$	Square
4	$D_{1.3} = \alpha + \beta {D_{0.3}}^{-1}$	Inverse
5	$D_{1.3} = \alpha + \beta D_{0.3} + \gamma {D_{0.3}}^2$	Quadratic
6	$D_{1.3} = \alpha + \beta D_{0.3} + \gamma {D_{0.3}}^2 + \delta {D_{0.3}}^3$	Cubic
7	$D_{1.3} = \alpha \ {D_{0.3}}^{\beta}$	Power

Where: α, β, γ and δ = regression parameters, $D_{0.3}$ = stump diameter, $D_{1.3}$= breast height diameter and *ln* = natural logarithm.

The developed models were evaluated for goodness of fit using two (2) statistical criteria. These criteria were: standard error of estimate (SEE) and Akaike information criterion (AIC). They are mathematically expressed as:

$$SEE = \sqrt{\frac{\sum_i^n (y_i - \hat{y}_i)^2}{n-P}} \quad (8)$$

$$AIC = 2p + n\ln(RSS/n) \quad (9)$$

Where: SEE= standard error of estimate, AIC= Akaike information criterion Y_i = Observed value of Y for observation *i*; $\hat{Y}_i$= predicted value *i*, *n*= the total number of observations Y_i (trees) used to fit the model, p= the number of model fixed parameter, *ln* = natural logarithm and RSS = residual sum of square

Graphical analyses were performed for the residuals and assessments of the appearance of the fitted curves overlaid on the data set. The t-test for paired samples was adopted as model validation method for the observed $D_{1.3}$and the $D_{1.3}$estimated from stump diameter of the pooled species data at 5% level of significance. The validation data set was one-third of the total data collected for the study which was not used for model calibration.

Results

Table 2 showed the results of the descriptive statistics and correlation analysis for the three (3) tree species of Fabaceae family investigated. The result revealed that *Daniella oliveri* had mean $D_{0.3}$ of 35.3 cm and mean $D_{1.3}$ of 28.7 cm with correlation coefficient (r) of 0.93. Similarly, *Parkia biglobosa* and *Prosopis africana* had 45.3 and 35.8 cm mean $D_{0.3}$, and 38.9 and 30.8 cm mean $D_{1.3}$ with r= 0.95 and 0.94, respectively (Table 2).

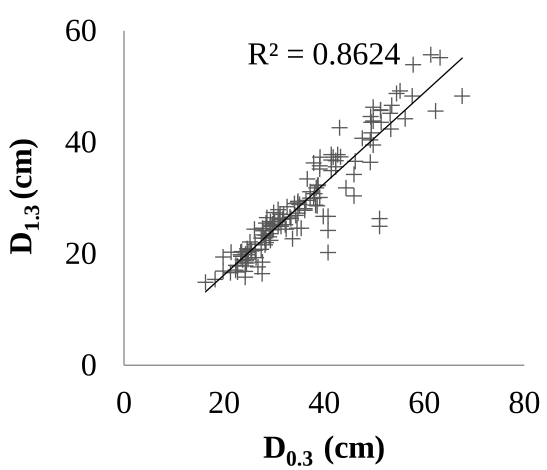
Table 2: Results of descriptive and correlation `statistics

Species	Variable (cm)	n	Min.	Max.	Mean	SD	r $D_{0.3}$
Daniella oliveri	$D_{0.3}$	146	16.3	67.6	35.3	10.802	
	$D_{1.3}$	146	14.9	55.7	28.7	9.504	0.93
Parkia biglobosa	$D_{0.3}$	265	27.5	100.4	45.3	13.754	
	$D_{1.3}$	265	25.0	86.8	38.9	12.299	0.95
Prosopis africana	$D_{0.3}$	227	20.4	74.2	35.8	9.764	
	$D_{1.3}$	227	16.9	62.6	30.8	8.771	0.94

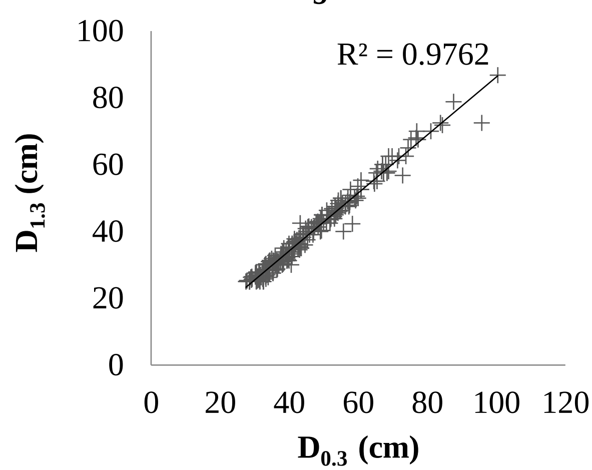
Where: $D_{0.3}$= stump diameter, $D_{1.3}$= breast height diameter, n= number of trees, SD= standard deviation and r= correlation coefficient

The graphical relationships between the explanatory variable ($D_{0.3}$) and the response variable ($D_{1.3}$) for the three species and pooled species data were displayed in Figure 1. The scatter plot (graph) showed a linear relationship between stump diameter and breast height diameter of the *D. oliveri*, *P. biglobosa* and *P. africana* trees in the study area.

Daniella oliveri



Parkia biglobosa



Journal of Forestry Research and Management. Vol. 17(2).38-47; 2020, ISSN 0189-8418
www.jfrm.org.ng

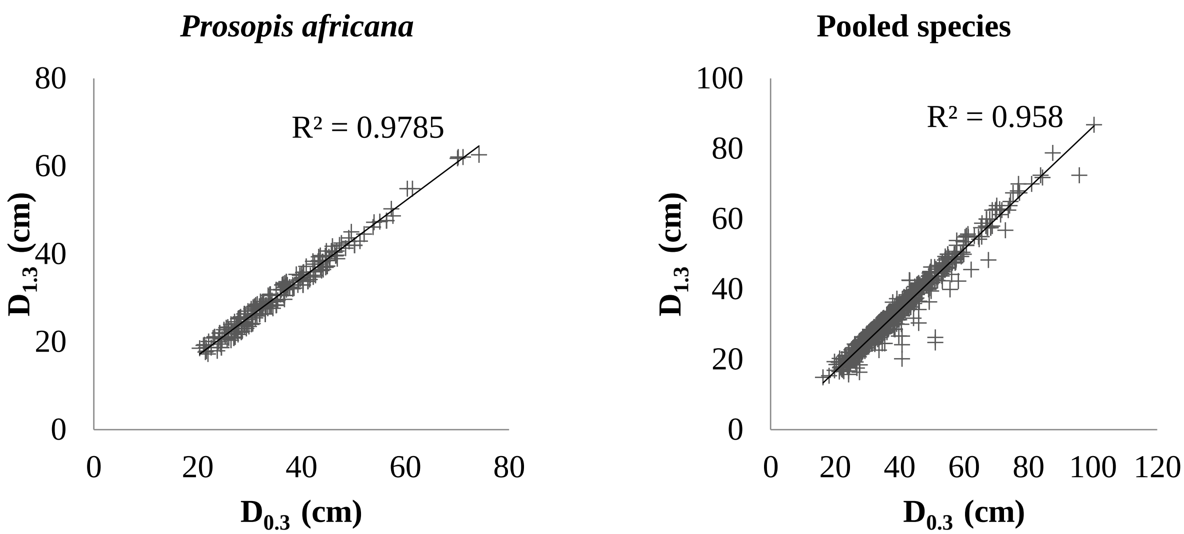


Figure 1: Relationship between breast height diameter and stump diameter

All parameters of the models used in establishing the relationship between breast height diameter and stump diameter for individual tree species studied were found to be significant at the 5% level of probability. For *Daniella oliveri*, out of the seven models fitted using $D_{0.3}$ as independent variable; the simple linear model gave the lowest values of SEE (3.537) and AIC (370.89).In the case of *Parkia biglobosa*, the cubic model had the lowest SEE and AIC values of 1.485 and 214.24 (Table 3a), respectively. Furthermore, in modelling the relationship between $D_{1.3}$ and $D_{0.3}$ for *Prosopis africana*, the power model gave the best performance with the lowest values of SEE (1.187) and AIC (92.98). The results for the fit indices for all the models examined were presented in Table 3a.

Table 3a: Examined stump-breast height diameter models, fit statistics and model ranks

Species	Model name	Model	Fit indices		Rank
			AIC	SEE	
Daniella oliveri	Simple Linear	$D_{1.3} = -0.139 + 0.817D_{0.3}$	370.89	3.537	1
	Semi Log	$D_{1.3} = -74.523 + 29.329 \ln D_{0.3}$	397.06	3.869	5
	Square	$D_{1.3} = 42.008 - 12862.289 \left(\frac{1}{D_{0.3}}\right)^2$	507.86	5.654	7
	Inverse	$D_{1.3} = 57.386 - 928.289{D_{0.3}}^{-1}$	451.35	4.660	6
	Quadratic	$D_{1.3} = 0.645 + 0.774D_{0.3} + 0.001{D_{0.3}}^2$	372.81	3.549	3
	Cubic	$D_{1.3} = 9.864 + 0.006D_{0.3} + 0.021{D_{0.3}}^2 + 0\ {D_{0.3}}^3$	373.73	3.548	4
	Power	$D_{1.3} = 0.794\ {D_{0.3}}^{1.006}$	370.92	3.538	2

Parkia biglobosa	Simple Linear	$D_{1.3} = -1.259 + 0.887D_{0.3}$	218.57	1.505	4
	Semi Log	$D_{1.3} = -122.487 + 42.792\ln\ D_{0.3}$	519.02	2.648	5
	Square	$D_{1.3} = 61.202 - 36589.241\left(\frac{1}{D_{0.3}}\right)^2$	921.42	5.631	7
	Inverse	$D_{1.3} = 83.090 - 1849.713{D_{0.3}}^{-1}$	769.12	4.229	6
	Quadratic	$D_{1.3} = -0.093 + 0.839D_{0.3} + 0.0{D_{0.3}}^2$	219.04	1.501	3
	Cubic	$D_{1.3} = 1.0 - 0.993D_{0.3} + 0.974{D_{0.3}}^2 - 0.945\ {D_{0.3}}^3$	214.24	1.485	1
	Power	$D_{1.3} = 1.0\ {D_{0.3}}^{-0.997}$	216.75	1.497	2
Prosopis africana	Simple Linear	$D_{1.3} = -1.035 + 0.889D_{0.3}$	94.55	1.190	3
	Semi Log	$D_{1.3} = -87.254 + 33.305\ \ln\ D_{0.3}$	353.26	1.935	5
	Square	$D_{1.3} = 46.607 + -16780.007\left(\frac{1}{D_{0.3}}\right)^2$	738.73	3.994	7
	Inverse	$D_{1.3} = 63.881 - 1109.978{D_{0.3}}^{-1}$	589.37	3.017	6
	Quadratic	$D_{1.3} = 0.328 + 0.818D_{0.3} + 0.001{D_{0.3}}^2$	93.78	1.186	2
	Cubic	$D_{1.3} = 1.0 - 0.993D_{0.3} + 0.976{D_{0.3}}^2 - 0.951\ {D_{0.3}}^3$	95.80	1.188	4
	Power	$D_{1.3} = 0.764{D_{0.3}}^{1.033}$	92.98	1.187	1

Where: $D_{0.3}$= stump diameter, $D_{1.3}$= breast height diameter, AIC= Akaike information criterion and SEE= standard error of estimate.

Modelling the relationship between $D_{1.3}$ and $D_{0.3}$ for the pooled species data, the power model gave the best performance with the lowest values of SEE (1.869) and AIC (336.99). Square model had the highest values of SEE (5.472) and AIC (908.17). The results for the fit indices for all the models examined for the pooled species data were presented in Table 3b.

Table 3b: Examined stump-breast height diameter models, fit statistics and model ranks for pooled data

Species	Model name	Model	Fit indices		Rank
			AIC	SEE	
Pooled Data	Simple Linear	$D_{1.3} = -0.906 + 0.872D_{0.3}$	542.43	1.873	4
	Semi Log	$D_{1.3} = -97.327 + 35.975\ \ln\ D_{0.3}$	888.27	2.803	5
	Square	$D_{1.3} = 49.85 - 20634.814\left(\frac{1}{D_{0.3}}\right)^2$	908.17	5.472	7
	Inverse	$D_{1.3} = 68.68 - 1289.943{D_{0.3}}^{-1}$	768.34	4.207	6
	Quadratic	$D_{1.3} = 0.498 + 0.807D_{0.3} + 0.001{D_{0.3}}^2$	339.41	1.871	2

Cubic	$D_{1.3} = 1.97 + 0.708D_{0.3} + 0.003{D_{0.3}}^2 + 0\ {D_{0.3}}^3$	340.66	1.870	3
Power	$D_{1.3} = 0.768\ {D_{0.3}}^{1.027}$	336.99	1.869	1

Where: $D_{0.3}$= stump diameter, $D_{1.3}$= breast height diameter, AIC= Akaike information criterion and SEE= standard error of estimate.

Figure 2 displayed the residuals distribution against the predicted breast height diameter. The constant error variance assumption seems to be upheld by the selected models for all the species and the pooled data.

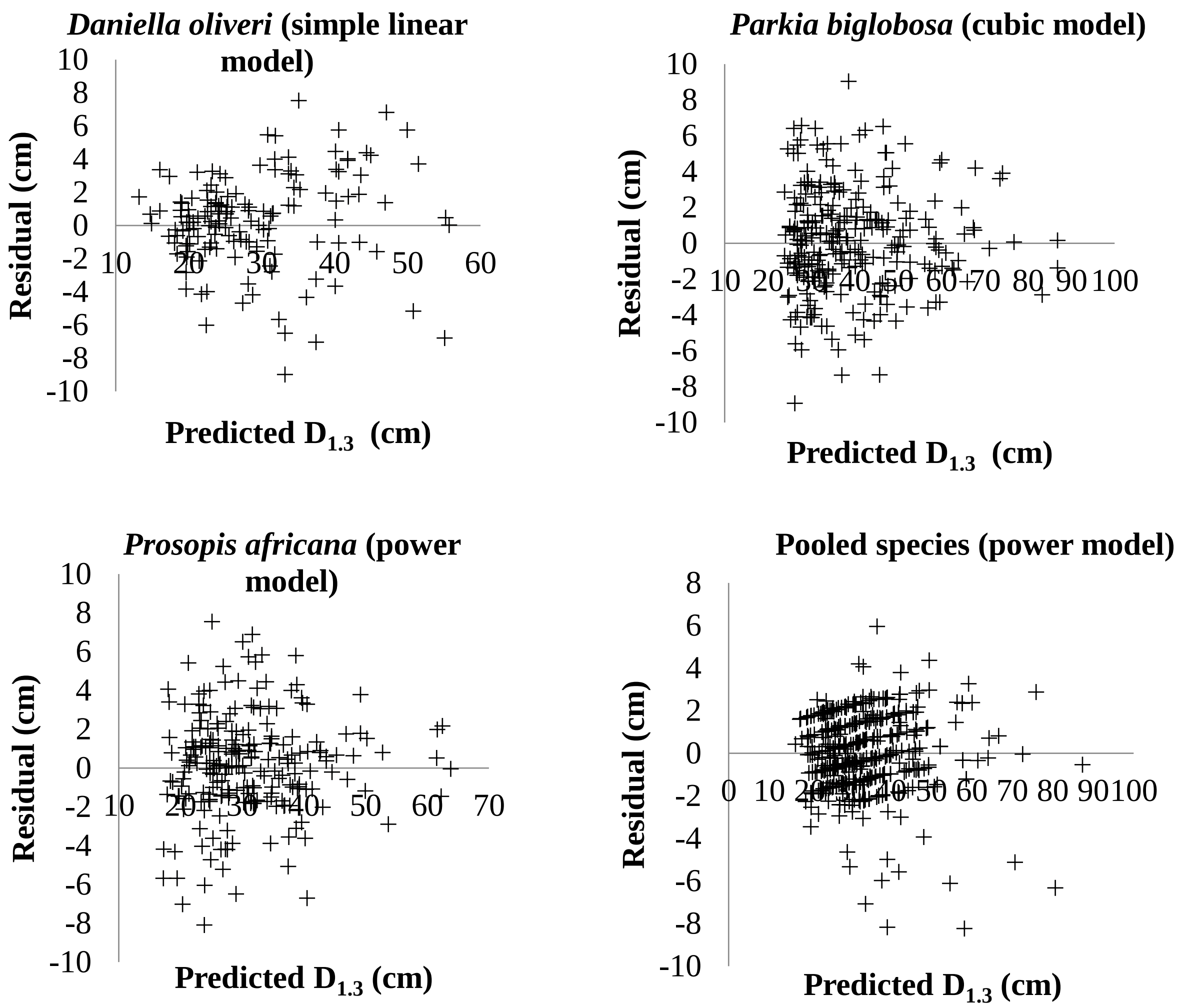


Figure 2: Residual distribution against $D_{1.3}$using models with best performances

Validation result of the selected model with the best performance for the pooled species was presented in Table 4. The validation test result showed that observed value of the pooled data for $D_{1.3}$estimated using power model was not significantly (P>0.05) different from the predicted value of $D_{1.3}$at probability level of 0.05.

Table 4: Paired sample t-test results of validation of Power model for pooled data

Model	Mean Obs.$D_{1.3}$(cm)	Mean Pred. $D_{1.3}$ (cm)	t-value	δ^2 Obs.	δ^2 Pred.	p-value	df	Remark
Power (Pooled data)	34.6	34.8	0.821	175.5	171.9	0.413	208	ns

Where; δ^2 = variance, df= degree of freedom, CPA=crown projection area (m^2), ns= not significant (P>0.05). Numbers of tree = 209.

Discussion

This study concerted its efforts towards establishing the relationship between breast height diameter and stump diameter of *D. oliveri*, *P. biglobosa* and *P. africana* species within the Federal University of Agriculture Makurdi, Benue State, Nigeria. The descriptive statistics result indicated tapering of the tree species stems from the base towards the breast height. This result confirmed the biological validity of the data set as indicated by Husch *et al.* (2003). The three (3) species investigated revealed positive and high correlation between $D_{1.3}$ and $D_{0.3}$; this implied that $D_{1.3}$ increase with the increase in $D_{0.3}$. This result is in tandem with the work of Adesoye and Ezenwenyi (2014).

The result of the seven models forms examined for each of the 3 tree species of the Fabaceae family showed that the simple linear, cubic and power models gave the best performance for *Daniella oliveri, Parkia biglobosa* and *Prosopis africana*, respectively. The models had the least values of standard error of estimate (SEE) and Akaike information criterion (AIC). The result for *Daniella oliveri* (simple linear model) isin disagreement with the result reported by Osho (1983) who found multiple linear regression model explained the relationship between breast height diameter and stump diameter of Teak (*Tectona grandis* Linn. f.) stands in OnigambariForest Reserve, Oyo State, Nigeria. The result of *Parkia biglobosa* (cubic model) is in disagreement with Osho (1983) and Chukwu and Osho (2018). The disagreement might be as result of difference in species and location. In the case of *Prosopis africana* (power model), similar results were also obtained by Chukwu and Osho (2018) for *Tectona grandis* Linn. f. in Omo Forest Reserve, Ogun State, Nigeria. However, the research of Chukwu and Osho (2018) was on Basal area, which is directly derived from breast height diameter.

However, the model result for the pooled species showed that power model best described the relationship between stump diameter and breast height diameter of *Daniella oliveri, Parkia biglobosa and Prosopis africana* in the study area. The power model gave the least SEE and AIC, this result also corroborate with the result of Chukwu and Osho (2018).

The graphical relationship between the residuals and estimated breast height diameter obtained with simple linear, cubic, power and power models for *Daniella oliveri*, *Parkia biglobosa*, *Prosopis africana* and for the pooled species data (Figure 2) revealed a fairly constant error variance. This trend was similar to the findings of Shamaki and Akindele (2013).

The paired t-test result for model validation showed a non-significant difference. This indicates that the developed $D_{1.3}$-$D_{0.3}$ model (Power) was valid for estimating breast height diameter of *Daniella oliveri, Parkia biglobosa, Prosopis* stands in the Federal University of Agriculture Makurdi, Benue State, Nigeria.

Conclusion

This study developed models that can easily estimate breast height diameter from stump diameter for three tree species in Fabaceae family. These models can be used to produce inputs for reconstruction of past forest status. The developed breast height-stump diameter models are in simple linear, cubic, power and power forms for *Daniella oliveri, Parkia biglobosa, Prosopis africana* and pooled species, respectively. The models developed are applicable to the species occurring in Makurdi, Benue State, Nigeria. The study recommended that local calibration may be performed for the models to be used for these species occurring outside the study area.

References

Adesoye, P. O. and Ezenwenyi, J. U. (2014).Crown diameter prediction models for *Tectona grandis* Linn. f. in Omo Forest Reserve, Nigeria. *Journal of Forestry Research and Management* 11: 1-16.

Akindele, S. O. and LeMay, V. M. (2006). Development of tree volume equations for common timber species in the tropical rain forest area of Nigeria. *Forest Ecology and Management*, 226: 41-48.

Alabi, D.A., Akinsulire, O.R. and Sanyaolu, M.A.(2005).Qualitative determination of chemical and nutritional composition of *Parkia biglobosa* (Jacq.)Benth.*African Journal of Biotechnology*, 4 (8): 812-815.

Buba, T.(2013).Allometric prediction models of growth variables of *Daniella oliveri* in the Nigerian Guinea Savanna. *African Journal of Plant Science*, 7(6): 213-218.

Chukwu, O and Osho, J.S.A (2017). Nonlinear Height-Stump diameter models for *Tectona grandis* Linn. f. Stands in Omo Forest Reserve, Nigeria. *Journal of Tropical Forestry and Environment* 7 (2): 45-54.

Chukwu, O and Osho, J.S.A(2018). Basal area-stump diameter models for *Tectona grandis* Linn. f. stands in Omo Forest Reserve, Nigeria. *Journal of Forest and Environmental Science*, 34 (2): 119-125.

Dau, J.H and Chenge, B.I (2016). Growth space requirements models for *Prosopis africana* (Guill&Perr) Taub tree species in Makurdi, Nigeria. *European Journal of Biological Research*, 6(3): 209-217.

Elly, N.S and Joseph, C.(2012).*Parkia Biglobosa:* A Potential Multipurpose Fodder Tree Legume in West Africa. *International Tree Crops Journal*; 7: 113-139.

Ezenwenyi, J.U and Chukwu, O (2017).Effects of slenderness coefficient in crown area prediction for *Tectona grandis* Linn.f. in Omo Forest Reserve, Nigeria. *Current Life Science* 3(4): 65-71.

Husch B., Beers, T.W and Kershaw Jr. J.A (2003).Forest Mensuration4th edition. New Jersey: John Wiley and Sons Inc. 443pp.

Hutchinson, J and Dalziel, J.M (1963).Flora of West Tropical Africa. Crown Agents for Overseas Governments and Administrations, London. Vol. 6.

Laouali.A, Boubé, M., Tougiani, A and Ali, M(2016). Analysis of the structure and diversity of *Prosopis africana* (G. et Perr.) Taub.tree stands in the southeastern Niger. *Journal of Plant Studies*, 5(1): 58-67.

Manyi, M.M, Akaangee, L, M and Onah, I.E (2017).Personal protective practices against mosquito bites by undergraduate students of Federal University of Agriculture Makurdi, North Central Nigeria, *American Journal of Entomology*. 1(2): 27-30.

Ntui, V.O, Uyoh, E.A, Urua, I.S., Ogbu, U and Okpako, E.C (2012).Regeneration of*Parkiabiglobosa*Benth. An important tree species of Africa. *Journal of Microbiology and Biotechnology Research*, 2(1), 169-177.

Onuwa, P.O, Eneji, I.S, Itodo, A.U and Sha'Ato, R (2017).Determination of pesticide residues in edible crops and soil from University of Agriculture Makurdi Farm Nigeria, *Asian Journal of Physical and Chemical Sciences.*3(3): 1-17.

Osho, J.S.A (1983). Volume prediction from stump diameter for Teak (*Tectona grandis* L.f.) in Onigambari Forest Reserve. *Nigerian Journal of Forestry*, 13(1-2): 53-56.

Özçelík, R, Brooks, J.R, Diamantopoulou, M.J. and Wiant-Jr, H.V (2010). Estimating breast height diameter and volume from stump diameter for three economically important species in Turkey. *Scandinavian Journal of Forest Research*, 25:32-45.

Shamaki, S.B and Akindele, S.O (2013). Volume estimation models from stump diameter for Teak (*Tectona grandis* Linn f.) Plantation in Nimbia Forest Reserve, Nigeria, *Journal of Environmental Science and Water Resources.* 2(3): 089-094.

Westfall, J.A (2010). New models for predicting diameter at breast height from stump dimensions. *Northern Journal of Applied Forestry*, 27: 21-27.