CROWN-DIAMETER PREDICTION MODELS FOR TEAK (TECTONA GRANDIS, LINN F.) STANDS IN OGWASHI-UKWU FOREST RESERVE, DELTA STATE, NIGERIA.

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ABSTRACT

This study was conducted to develop crown diameter prediction model for *Tectona grandis* in Ogwashi – Ukwu Forest Reserve, Delta State, Nigeria. The ability to predict crown diameter from diameter at breast height provides an effective technique of finding its estimate. The objective of the study was to develop a crown diameter prediction models for teak (*Tectona grandis*) stands in Ogwashi – Ukwu Forest Reserve. Sampling design employed was Systematic (systemic line transect) for plots laying. Two transects with a distance of 500 m between them were laid at the centre of *Tectona grandis* stands. Temporary sample plots of size, 20 m x 20 m (0.04 ha) were laid in different direction along each transect at 250 m interval and thus adding up to four sample plots per transect and a total of eight temporary sample plots. In each plot, the outside bark diameter at breast height (Dbh) (taken at 1.3 m from ground), crown length and crown diameter were all measured. Correlation analysis was used to aid models development. This was done to give an insight of the association between crown diameter and other tree growth variables. It was observed that crown diameter was highly correlated with crown projection area (r = 0.9665) but had a weak correlation with diameter at breast height (r = 0.2039) and basal area (r = 0.2043). Several models were tested to predict crown diameter using diameter at breast height and basal area. Models 5, 7, 15 and 16 were adjudged the best out of the several models tried. The regression models chosen were statistically significant ($P < 0.05$). Logarithmic and quadratic model were suitable in predicting crown diameter in the study area using diameter at breast height and basal area separately and combined as predictor variable(s).

Keywords: Crown diameter, Crown Projection Area, Diameter at breast height, Basal area *Tectona grandis*, Forest Reserve.

INTRODUCTION

Teak (*Tectona grandis*) is one of the most recognized valuables timbers with aesthetic qualities in the globe (Tewari 1992; Keogh 2009). Its timber qualities include lightness with strength, ease of seasoning without splitting and cracking, durability, resistance to termite, fungus, and weathering, attractiveness in colour and grain, ease of working and carving, etc. The species is indigenous to the region of Indian-Burmese floristic and is naturally found in India, Myanmar, Thailand and Lao (Kaosa-ard, 1981). It is extensively established in the tropics due to its demand for the extravagance market and hefty duty applications (Kollert and Cherubini, 2012).

Teak plantations had solved a few global problems (ITTO, 2001). They have improved local livelihood, ameliorated climate change, bolstered national economies, restored degraded land, reduced deforestation, created employment and returned good profits. As a result, there is need for sustained forest practice. One of the methods for sustained forest practice is to obtained tree crown information of *Tectona grandis.* Tree crown information is one of the factor that provides data to the investigation of several key forest ecosystem characteristics such as forest environment and wildlife, aesthetics, sustainability, productivity and biodiversity (Laar and Akca, 1997; Avery and Burkhart, 2002). Diameter at breast height (Dbh) and Crown Diameter (CD) are important tree attributes that can provide tree crown information. Some variables such as Dbh are easy determined with simple instruments and it is commonly used in forest inventories. However, studies have shown that crown diameters are not so easily obtained (Bechtold *et al.*, 2002). These variables can enhance the reliability of tools like growth and yield models and they are good predictors of forest dynamics (Bragg, 2001). The CD – Dbh relationship is useful in remote sensing technology. This is possible by remotely sensed crown widths from high resolution aerial (Huang *et al.,* 2009) and satellite imagery (Deng and Jiang, 2007), then using the modelled Dbh to estimate individual tree volume, stand volume, tree biomass and carbon. The CD – Dbh models are used to develop tree stocking guides (Smith and Gibbs, 1970); determine stand density and stocking relationships (Goelz, 1996); estimate tree crown surface area and volume (Zarnoch *et al.*, 2004); develop tree – crown profile and canopy architecture (Marshall *et al.*, 2003); develop potential crown – size (Smith and Gibbs, 1970); determine crown competition indices (Vezina, 1962; 1963; Strub *et al.*, 1975); develop canopy cover (Gill *et al.*, 2000); and develop wildlife habitat indices (Hay *et al.*, 1981). Hence, the objective of this study was to develop crown – diameter prediction model for

Tectona grandis in Ogwashi – Ukwu Forest Reserve in Delta state, Nigeria.

MATERIALS AND METHOD

Study Area

The study was conducted in Ogwashi-Ukwu Forest Reserve in Aniocha South Local Government Area of Delta State, Nigeria. Ogwashi-Ukwu Forest Reserve lies between latitude 6°00º - 6º 25ºN and longitude 6º 5º- 6º 25º E and occupies a total area of 258 ha, with less than 27 ha (10.5%) occupied by natural lowland rainforest while the deforested areas have been regenerated with exotic tree species (FORMECU, 2000). Some of the area lies below sea level with only few places of 20 mm height above sea level (Odemerho and Ejemeyovwi, 2008). The surface geology of the study area is made up of coarse grained sands containing peaty clay seams and lignite. It is richly endowed with kaolinites also contains lignite seams (Ejemeyovwi 2008). According to Perekeme (2000), the study area is overlaid by various degrees of granites, genesis, shits and isolated deposition of amphibolite. The rainfall pattern is bimodal, with peak periods in July and September, and an annual average between 1600 – 2000 mm. Mean annual temperatures are between 25 - 29°C and a relative humidity of 75% (Meteorological Service Station, 2013).

Methods of Data Collection

Sampling Techniques

Systematic sampling design (systemic line transect) was employed for laying of plots. Two transects with a distance of 500m between them were laid at the centre of *Tectona grandis* stands. Temporary sample plots of size, 20 m x 20 m (0.04 ha) were laid in different direction along each transect at 250 m interval and thus adding up to 4 sample plots per transect and a total of 8 sample plots. In each plot, the outside bark diameter at breast height (Dbh) (taken at 1.3m from ground), crown length and crown diameter were all measured. Crown diameters were measured by projecting the diameter of the crown with ranging poles on the ground at four different directions and taking the distance between the ranging poles using distance tape. The crown diameters were then obtained by taking the average of the readings recorded from the four directions for each tree.

DATA ANALYSIS

Model Variables

Crown Projection Area

CPA (Crown Projection Area) was computed by the formula below:

$CPA = \pi CD^2/4$ ………..equation 1

Where; CD = crown diameter, according to LeMay and Marshall (1990)

$CD = D_1+D_2+D_3 + D_4 /4$ ....equation 2

D_1 = diameter 1, D_2 = diameter 2, D_3 = diameter 3, D_4 = diameter 4, and π = pi (3.142)

Basal Area

Basal area of individual trees in each sample plot was calculated using the formula:

$BA = (\pi D^2)/4$…………..equation 3

Where BA = basal area (m^2), D= diameter at breast height (cm) and π = pi (3.142).

Pairs of continuous variables (CD and Dbh), (CPA and Dbh) and (CPA and BA) were examined in scatter plot for the form, direction and strength of relationship between them. Scatter plot reveal non – linearity, suspected outlier and unequal variance.

Fitting of Data for Regression Equations

Regression and correlation were used to establish the relationship between the Pairs of continuous variables (CPA and Dbh), (CPA and BA) and (CD and Dbh). Simple linear ($y = a + bx$), Quadratic ($y = a + bx + cx^2$), logarithmic ($\ln y = a + \ln bx$) and power function ($y = ab^x$) were used to fit the data in order to developed regression models.

Where, y = dependent variable; x = independent variable; b = regression coefficient; a = regression constant

Model Evaluation

The models formulated were evaluated with a view of selecting the best estimator for tree regression equations. The evaluations were based on Coefficient of determination (R^2), Standard error of estimate (SEE), Variance ratio. In addition, the significance of regression coefficients (β) were observed. Only equations having all the parameters to be significant were selected. A model with high R^2, low SEE and high variance ratio were adjudged to have good fit. Residuals values were plotted against the predicted regression equation values to check the constant error assumption.

Model Validations

The validation data set (i.e. the one tenth of the data observed value) set aside for model validation and that will not be used for model calibration were used for this purpose. The validation was done by testing for significant difference between the predicted value and the actual (observed) value using paired t- test. If there is no significant difference ($P < 0.05$) between the observed and predicted values, then it means the model is acceptable.

RESULTS AND DISCUSSION

Summary Statistics

The summary of tree growth attributes are presented in Table 1. The mean number of trees per hectare as shown in Table 1 was 539. This is an indication of well stocked forest reserve when compared to report of Ajayi and Odey (2012) who reported 425 trees per hectare in *Tectona grandis* plantation of CRUTECH, Obubra Local Government Area of Cross River State. The distribution of diameter at breast height (Dbh) and crown diameter ranged from 17.80 to

54.60 cm and 3.40 to 23.60 m respectively. The mean basal area and crown projection area were 47.23±5.33 and 4,006.94±342 respectively (Table 1). The mean basal and crown projection area are important parameters in understanding tree stocking. According to Palmer and Synnott (1992) that in order to achieve sustainability in forest management, the forest manager should have adequate information about the forest stock. The value of the basal area in this study shows that the plantation is well stocked when compared proportionally with report of Alder and Abayomi (1994), which stated that for a well-stocked tropical rainforest in Nigeria, the average basal area is 15 m^2. The value of the CPA indicate wide spreading canopy. The CPA in this study area is quite high when compared to the value of CPA reported by Adesoye and Ezenwenyi (2014) for *Tectona grandis* plantation in Omo Forest Reserve.

TABLE 1: SUMMARY OF TREE GROWTH ATTRIBUTES

	MINIMUM	MEAN	MAXIMUM
Number of trees/ha	425	539 ± 29	650
Dbh/cm	17.80	33.28 ± 0.66	54.60
CD/m	3.40	13.61 ± 36	23.60
$BA/ha(m^2/ha)$	30.96	47.23 ± 5.33	68.79
$CPA/ha(m^2/ha)$	2,254.25	4,006.94 ± 342	5,409.00

Source: Field data 2017

CD = crown diameter, Dbh = diameter at breast height, BA= basal area, CPA= Crown Projection Area

Development of Prediction Models

Correlation matrix

Correlation analysis was carried out before models development. This was done to give an insight of the association between crown diameter and other tree growth variables. It was observed from the correlation matrix (Table 2) that crown diameter was highly correlated with crown projection area (r = 0.9665) but had a weak correlation with diameter at breast height (r = 0.2039) and basal area (r = 0.2043). This observation was at variance with some findings in previous studies (Francis, 1986; Adesoye and Ezenwenyi, 2014). The result in this study is an indication that the degree of agreement between measures of crown diameter and diameter at breast height depends on the type of tree species.

TABL 2: Correlation Matrix **for the Tree Growth Attributes**

	Dbh(cm)	CD (m)	CPA (m²)	Dbh(cm)	BA/m²	lnDbh	lnCPA	lnCD	lnBA	1/Dbh	1/CD	1/CPA	1/BA	Dbh2/m²	BA2	Dbh3	BA3
Dbh(cm)	1																
CD (m)	0.2039	1															
CPA (m²)	0.29186	0.96654	1														
BA/m²	0.98221	0.20427	0.306375	0.98221	1												
lnDbh	0.98311	0.20531	0.277259	0.98311	0.93234	1											
lnCPA	0.08451	0.96677	0.874842	0.08451	0.07526	0.09833	1										
lnCD	0.08451	0.96677	0.874842	0.08451	0.07526	0.09833	1	1									
lnBA	0.98311	0.20531	0.277259	0.98311	0.93234	1	0.0983	0.09833	1								
1/Dbh	-0.9381	-0.20866	-0.26478	-0.93812	-0.8608	-0.98519	-0.115	-0.115	-0.9852	1							
1/CD	0.04518	-0.86772	-0.73672	0.04518	0.05839	0.02431	-0.9627	-0.9627	0.02431	0.001	1						
1/CPA	0.15083	-0.72048	-0.57591	0.15083	0.16368	0.12796	-0.8572	-0.8572	0.12796	-0.099	0.96199	1					
1/BA	-0.8762	-0.21303	-0.25504	-0.87617	-0.7802	-0.94717	-0.1319	-0.1319	-0.9472	0.9878	0.02674	-0.0694	1				
Dbh2/m²	0.98221	0.20427	0.306375	0.98221	1	0.93234	0.0753	0.07526	0.93234	-0.861	0.05839	0.16368	-0.7802	1			
BA2	0.85944	0.20523	0.323631	0.85944	0.93745	0.76203	0.0699	0.06987	0.76203	-0.66	0.06002	0.1568	-0.5636	0.9375	1		
Dbh3	0.93187	0.20518	0.317712	0.93187	0.98291	0.85427	0.0708	0.07076	0.85427	-0.763	0.06287	0.16508	-0.6713	0.9829	0.98512	1	
BA3	0.70053	0.20108	0.319827	0.70053	0.80979	0.5859	0.0732	0.07321	0.5859	-0.48	0.04294	0.12593	-0.3896	0.8098	0.95973	0.8992	1

Where, Dbh= diameter at breast height (cm), BA= basal area (m²), CPA= crown projection area (m²), CD= crown diameter (m).
Source: Field work 2017.

Model for Crown Projection Area using Diameter at breast height and Basal Area as predictor variable
The scatter plot of the relationships between crown projection area and diameter at breast height/ basal area for the *Tectona grandis* stands is presented in Figures 1 and 2. Figures indicated that the relationship between the variables could not be defined by linear function.

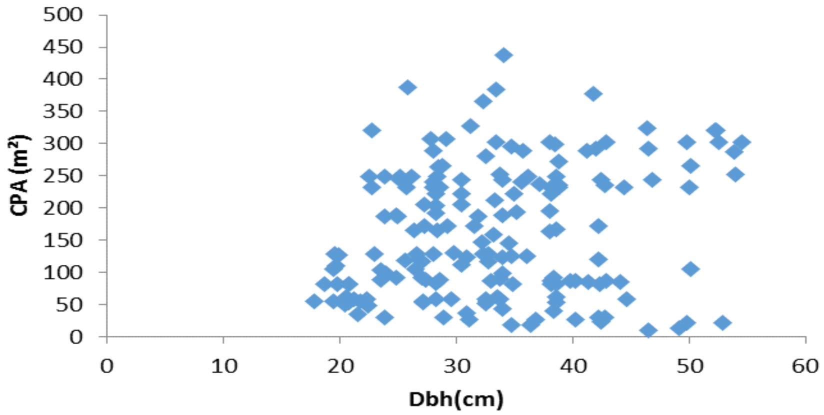

Figure 1: Graphical relationship between Crown Projection Area (CPA) and Diameter at breast height (Dbh).

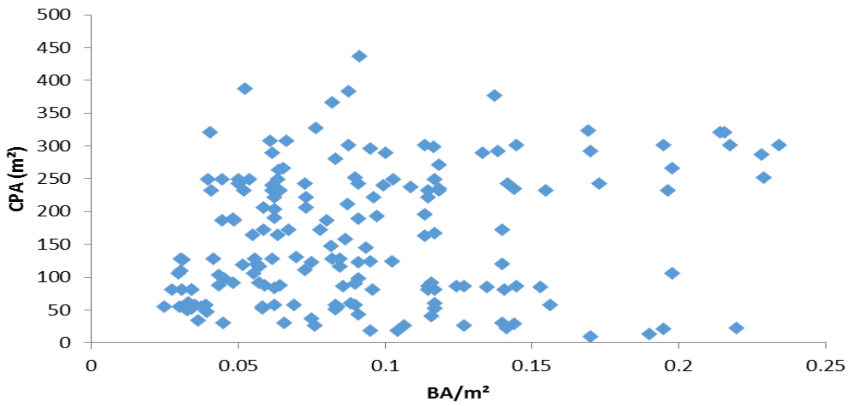

Figure 2: Graphical relationship between Crown Projection Area (CPA) and Basal Area (BA)

Out of several model tried for predicting crown projection area, models 2, 11, and 12 (Table 3) were adjudged the best using diameter at breast height while model 4 and 9 (Table 4) were adjudged the best using basal area. The regression models chosen were statistically significant ($P < 0.05$). The models adjudged the best showed that the predictor variable had non-linear relationship with crown projection area in the study area as also shown in the scatter plot (Figures 1 and 3). Logarithmic and quadratic models are therefore suitable model for predicting crown projection area using diameter at breast height and basal area as independent variable in Ogwashi – Ukwu Forest Reserve, Delta State, Nigeria. The residual plots shown in Figures 3a – c and Figures 4a and b, indicated that the residuals are homogeneously distributed, which suggested that the experimental error is normally distributed. Thus, the assumption of regression does not appear to have been violated by the models.

TABLE 3: RELATIONSHIP BETWEEN CROWN PROJECTION AREA AND DIAMETER AT BREAST HEIGHT

Model No	MODEL FORM	R	R^2	Adjusted R^2	S.E	F	α	β_1	β_2	$\beta 3$	Sig
1	$CPA = \alpha + \beta\ (Dbh)$	0.203	0.041	0.036	97.828	7.329	84.047	2.331			0.007*
2	$CPA = \alpha + \beta(LnDbh)$	0.213	0.045	0.040	97.632	8.042	-118.329	80.649			0.005*
3	$CPA = \alpha + \beta(Dbh^{-1})$	0.223	0.050	0.044	97.409	8.857	244.882	-26588.433			0.003*
4	$CPA^{-1} = \alpha + \beta(Dbh^{-1})$	0.078	0.006	0.000	0.013	1.035	0.006	-0.122			0.311
5	$CPA^{-1} = \alpha + \beta(LnDbh)$	0.101	0.010	0.004	0.013	1.756	0.006	0.005			0.187
6	$CPA = \alpha + \beta_1(Dbh) + \beta_2(Dbh^2)$	0.206	0.043	0.031	98.0524	3.759	38.004	5.119	-0.040		0.025*
7	$CPA = \alpha + \beta_1(LnDbh) + \beta_2(Dbh^{-1})$	0.228	0.052	0.041	97.5704	4.633	800.975	-125.079	-6378.692		0.011*
8	$CPA^{-1} = \alpha + \beta_1(LnDbh) + \beta_2(Dbh^{-1})$	0.179	0.032	0.020	0.0133	2.788	-0.229	0.055	1.541		0.064
9	$LnCPA = \alpha + \beta_1(LnDbh) + \beta_2(Dbh^{-1})$	0.159	0.025	0.014	0.7913	2.184	15.519	-2.331	-80.749		0.116
10	$CPA = \alpha + \beta_1(Dbh) + \beta_2(Dbh^2) + \beta_3(Dbh^3)$	0.306	0.094	0.07	95.6769	5.797	-1032.690	104.244	-2.941	0.027	0.001*
11	$CPA = \alpha + \beta_1(LnDbh) + \beta_2(Dbh^{-1}) + \beta_3(Dbh^3)$	0.302	0.091	0.075	95.8095	5.626	7979.590	-1872.520	-46210.480	0.004	0.001*
12	$LnCPA = \alpha + \beta_1(LnDbh) + \beta_2(Dbh^{-1}) + \beta_3(Dbh^3)$	0.237	0.056	0.039	0.7809	3.342	66.608	-14.767	-364.227	2.682	0.021*

TABLE 4: RELATIONSHIP BETWEEN CROWN PROJECTION AREA (CPA) AND BASAL AREA (BA)

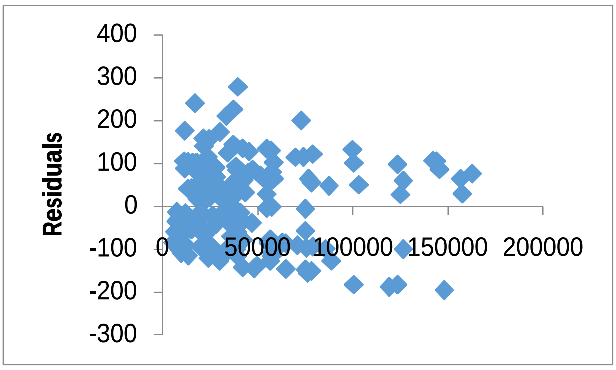

Figure 3a: Residual plot using CPA function based on LnDbh

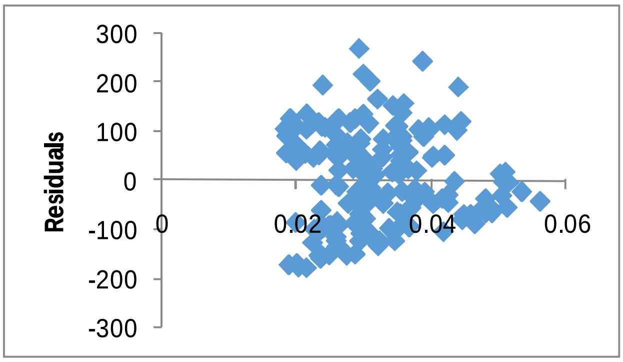

Figure 3b: Residual plot using CPA function based on LnDbh, 1/Dbh and Dbh3

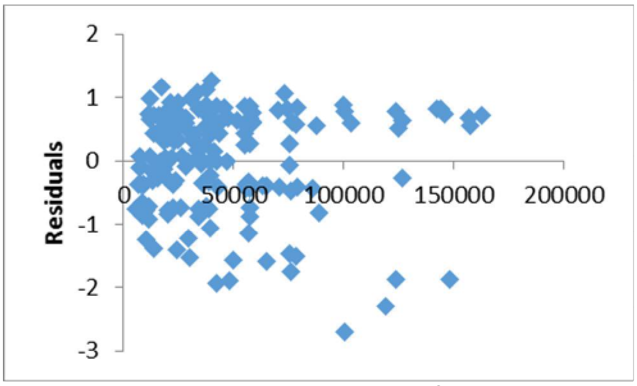

Figure 3c: Residual plot using LnCPA function based on LnDbh, 1/Dbh and Dbh3

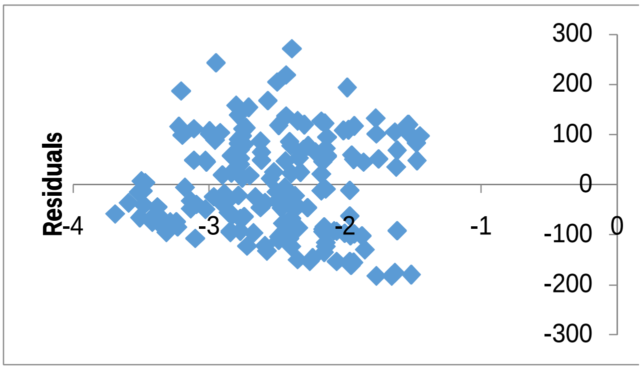

Figure 4a: Residual plot using CPA function based on LnBA

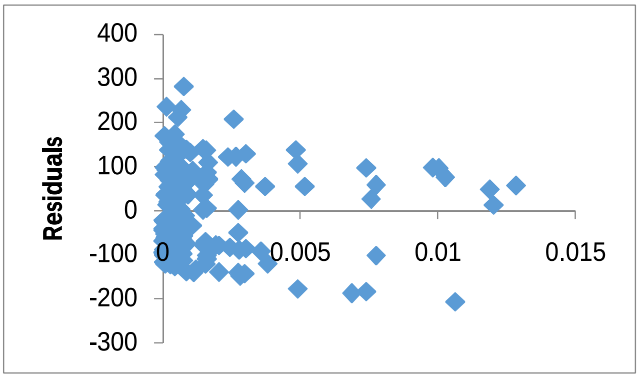

Figure 4b: Residual plot using CPA function based on BA, BA^2 and BA^3

Model for Crown Diameter using Diameter at Breast Height and Basal Area as predictor variables

The scatter plot of the relationships between crown diameter, diameter at breast height and basal area for the study area are presented in Figures 5 and 6. The graph indicated that there is no evidence of linearity in their relationship.

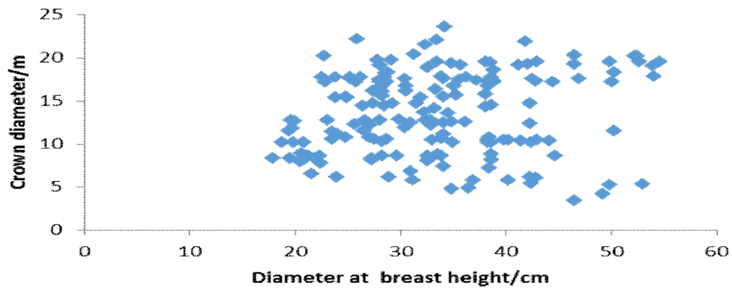

Figure 5: Graphical relationship between crown diameter (CD) and diameter at breast height (Dbh)

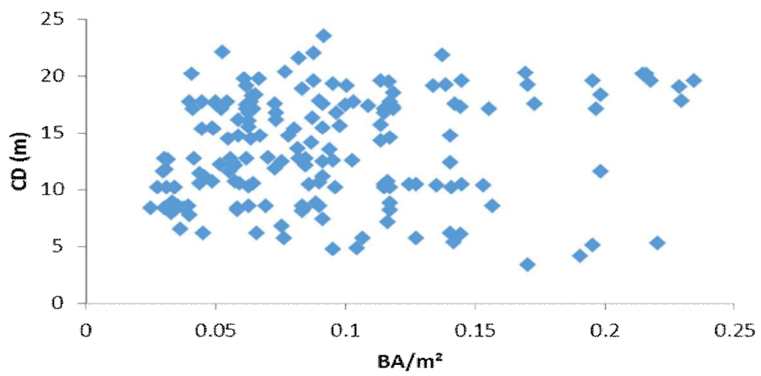

Figure 6: Graphical relationship between crown diameter (CD) and basal area (BA)

The model to predict crown diameter using diameter at breast height and basal area is shown in Table 5. Out of several models tested, model number 5, 7, 15 and 16 were adjudged the best. The graphs of residual analyses for the equations are presented in Figures 5a - d. The residual plots shown that the residuals are homogeneously distributed, which suggested that the experimental error is normally distributed. Thus, the assumption of regression does not appear to have been violated by the models. Logarithmic and quadratic model were suitable in predicting crown diameter in the study area using diameter at breast height and basal area separately and combined as predictor variable(s). Similar studies were also carried out using different tree species (for example, Bechtold, 2003; Ige, and Erhabor, 2013; Akinyemi and Smith 2012; Adesoye and Ezenwenyi 2014). According to Paine and Hann (1992), quadratic expression of stem diameter are known to improve crown – width models for some species and stated further that diameter at breast height is by far the most common variable used in crown – width prediction variable.

TABLE 5: RELATIONSHIP BETWEEN CROWN DIAMETER (CD), CROWN PROJECTION AREA (CPA) AND DIAMETER AT BREAST HEIGHT (Dbh)

Model No	MODEL FORM	R	R^2	Adjusted R^2	S.E	F	α	β_1	β_2	β_3	Sig
1	$CD = \alpha + \beta(BA)$	0.144	0.021	0.015	4.661	3.605	12.266	13.906			0.059
2	$CD = \alpha + \beta(Dbh)$	0.153	0.024	0.018	4.654	4.095	10.799	0.083			0.045*
3	$LnCD = \alpha + \beta(Dbh)$	0.074	0.006	0.000	0.398	0.947	2.422	0.003			0.332
4	$CD^{-1} = \alpha + \beta(Dbh)$	0.026	0.001	-0.005	0.041	0.117	0.082	0.000			0.733
5	$CD = \alpha + \beta(LnDbh)$	0.166	0.008	0.022	4.645	4.811	3.257	2.968			0.030*
6	$CD = \alpha + \beta(Dbh^2)$	0.144	0.021	0.015	4.661	3.605	12.66	0.001			0.059
7	$CD = \alpha + \beta(LnBA)$	0.162	0.028	0.022	4.645	4.811	17.282	1.484			0.030*
8	$LnCD = \alpha + \beta(LnDbh)$	0.090	0.008	0.002	0.398	1.392	2.061	0.137			0.040*
9	$CD^{-1} = \alpha + \beta(Dbh^{-1})$	0.014	0.000	-0.006	0.041	0.023	0.084	0.366			0.859
10	$CD^{-1} = \alpha + \beta(LnBA)$	0.008	0.000	-0.006	0.041	0.012	0.088	0.001			0.913
11	$CD^{-1} = \alpha + \beta(BA^{-1})$	0.037	0.001	-0.005	0.041	0.230	0.084	0.000			0.632
12	$LnCD = \alpha + \beta(LnBA)$	0.090	0.008	0.002	0.398	1.392	2.708	0.068			0.240
13	$CD = \alpha + \beta_1(BA) + \beta_2(BA^2)$	0.145	0.021	0.009	4.674	1.807	12.043	18.772	·20.840		0.167
14	$CD = \alpha + \beta_1(Dbh) + \beta_2(Dbh^2)$	0.162	0.026	0.015	4.661	2.285	7.568	0.279	-0.003		0.105
15	$CD = \alpha + \beta_1(Dbh) + \beta_2(Dbh^2) + \beta_3(BA^3)$	0.281	0.079	0.063	4.547	4.805	-20.016	2.355	-0.041	2623.806	0.003*
16	$CD = \alpha + \beta_1(Dbh) + \beta_2(Dbh^2) + \beta_3(Dbh^3)$	0.284	0.080	0.064	4.543	4.899	-44.309	5.081	-0.143	0.001	0.003*
17	$CD = \alpha + \beta_1(BA^3) + \beta_2(Dbh) + \beta_3(Dbh^3)$	0.278	0.078	0.061	4.550	4.706	-9.808	3626.230	1.229	-0.001	0.004*
18	$CD^{-1} = \alpha + \beta_1(Dbh) + \beta_2(Dbh^2) + \beta_3(Dbh^3)$	0.222	0.049	0.032	0.040	2.897	0.523	-0.039	0.001	-9.986	0.037*

CD= crown diameter (m)
Source: field work 2017.

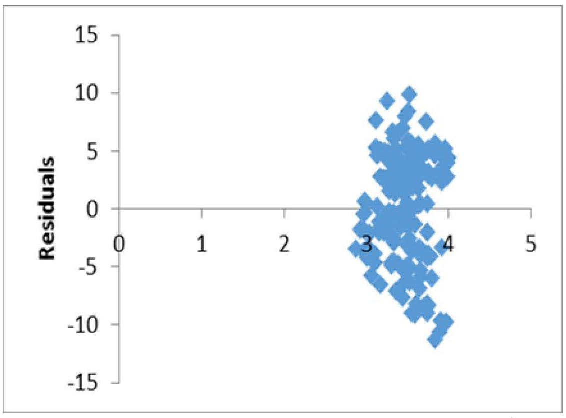

Figure 7a: Residual plot using crown diameter function based on LnDbh alone

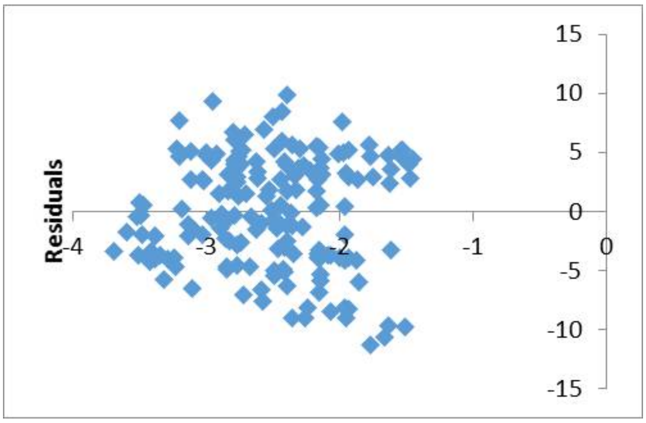

Figure 7b: Residual plot using crown diameter function based on LnBA alone

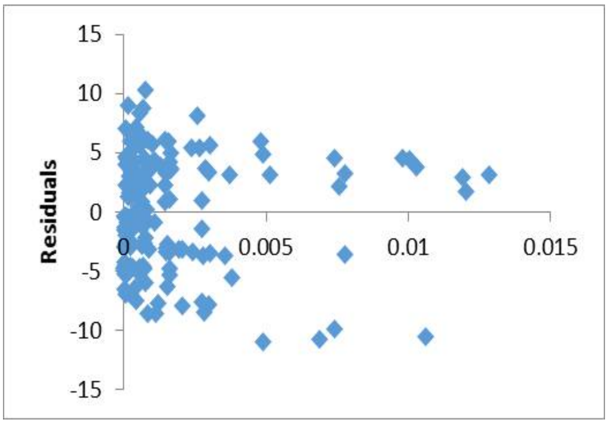

Figure 5c: Residual plot using crown diameter function based on Dbh, Dbh^2 and BA^3

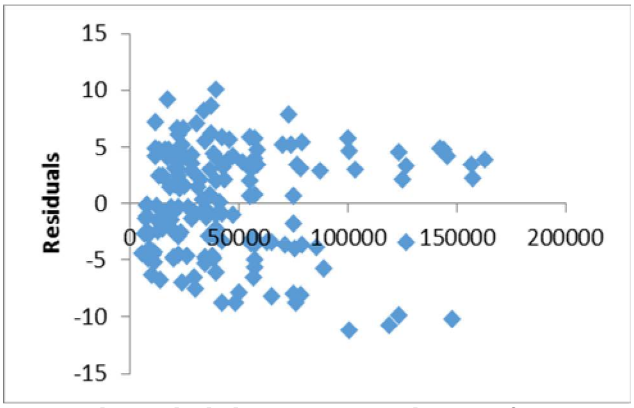

Figure 7d: Residual plot using crown diameter function based on Dbh, Dbh^2 and Dbh^3

Model Validation

A model each was selected from the various set of best adjudged models for validation. The results of the t-test carried out to validate each of the equation at 95% probability level, shows that there was no significant difference ($p > 0.05$) between predicted and observed values for all the models (Table 6). The coefficient of determination (R^2) for the models, ranged between 0.981 and 0.999. This suggests that a substantial proportion of the variation in tree volume is explained by Dbh, stump diameter, merchantable height and total tree height.

Table 6: Results of model validation for tree growth models in Ogwshi – Ukwu Forest Reserve

Model Form	t_{cal}	$t_{critical}$	M_o	M_p	Remark
$CPA = \alpha + \beta(LnDbh)$	0.000224	1.974	161.602	161.601	ns
$CPA = \alpha + \beta(LnBA)$	0.00155	1.974	161.602	161.614	ns
$CD = \alpha + \beta(LnDbh)$	0.00356	1.974	13.558	13.559	ns
$CD = \alpha + \beta(LnBA)$	0.000506	1.974	13.558	13.557	ns

t_{cal}- t calculated, $t_{critical}$- critical t, M_o- mean of observed values, M_p- mean of predicted values, ns – not significant at $p \geq 0.05$

CONCLUSION

Tree crown model is useful in key forest ecosystem characteristics which includes biodiversity, forest environment and wildlife. It is an important aspect of evaluating and managing trees in the forest stand. Findings from this study confirmed that crown diameter was highly correlated with crown projection area (r = 0.9665) but had a weak correlation with diameter at breast height (r = 0.2039) and basal area (r = 0.2043). Therefore, data transformation is needed to give good estimates of crown diameter. In conclusion, the crown diameter can be more accurately and suitably predicted by diameter at breast height and basal area separately and combined as predictor variable(s) using logarithmic and quadratic model.

This model is useful in the study area in remote sensing technology, competition indices, tree stocking guideline and wildlife habitat indices.

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