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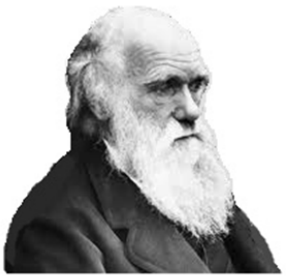

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Prognostic Crown Diameter equations for a Mixed Species Plantation in Southern Nigeria

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ABSTRACT

The dimension of a tree crown has an apparent effect on and is strongly linked with the growth of the tree and its diverse parts. Crown information is an important part of numerous growth and yield models. Hence, empirical predictive equations for the crown diameter of a mixed species plantation in Southern Nigeria were developed and evaluated in this study. In studying this phenomenon, total enumeration of the selected species in the mixed species plantation was carried out. Moreover, major growth attributes of 185 trees of six species, namely: *Khaya ivorensis*, *Entandrophragma angolense*, *Terminalia ivorensis*, *Tectona grandis*, *Treculia Africana*, and *Mansonia altissima* were measured and estimated using mesurational methods. Descriptive, correlation, regression, and residual analyses were then applied to the quantitative data obtained from the mixed species plantation. For all the species, the best adjudged model, with the best fit indices, was $Ln(cd) = Ln(b_0) + b_1 \cdot CPA \cdot dbh$, $R^2 = 0.936$, SEE = 0.037; an indication of parsimonious potential of a predictive exponential model. This paper, therefore, revealed the possibilities of predicting the crown diameter for a mixed species plantation in Nigeria with ample prospects for sustainable planning and management decisions that are relevant for any mixed species plantation.

***Keywords*:** crown, crown diameter, model, mixed species plantation

1. INTRODUCTION

As the total area of forests is declining globally, the extent of plantations is increasing (FAO, 2009). Many different types of plantation are established for different purposes and the majorities are planted as monocultures with the aim of producing timber for the products, such as paper, solid wood, and firewood (Evans, 2009). Mixed species plantations are frequently

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being recommended and used to meet these functions (Paquette and Messier, 2010). A number of reviews have analyzed the productivity of mixed-species plantations compared to monocultures (Piotto, 2008). The size of a tree crown has a marked effect on, and is strongly correlated with the growth of the tree and its various parts (Temesgen *et al*., 2005). An obvious advantage of using crown characteristics in the growth and yield models stems from the fact that growth relationships exist between tree crowns and stem (Adesoye *et al*., 2006). As an important tree variable, the crown diameter of the individual trees is a fundamental component of the forest growth and yield prediction frameworks (Tahvanainen and Forss, 2008), and it is also crucial for assessing the competitive level, tree vigor, microclimate, biological diversity, mechanical stability, fire susceptibility, and behaviour under wind stress, amongst other features (Crecente-Campo *et al*., 2013). No single type of a model can be expected to provide information efficiently for all levels of decision making (Temesgen and Gadow, 2004). Therefore, the objectives of this study was to: (1) measure and estimate tree growth attributes within the mixed species plantation in the study area, (2) develop crown diameter models for the mixed species plantation in the study area, and (3) assess the best diameter crown model with a good fit for the crown attribute prediction.

2. MATERIALS AND METHODS

2. 1. Study Area

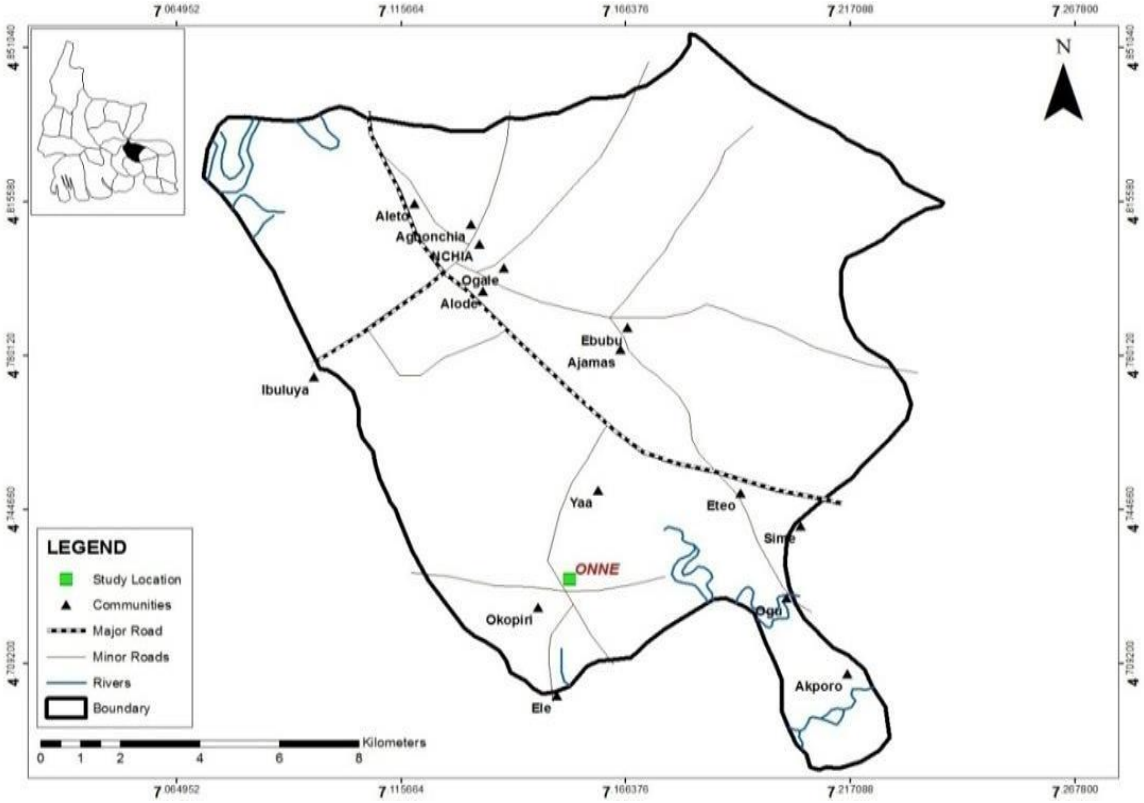

Fig. 1. Map of Eleme Local Government in Rivers State, Southern Nigeria, showing the study location (FRIN, Onne)

The research was carried out at the Forestry Research Institute of Nigeria, Swamp Forest Research Station, Onne. Onne is part of Nchia clan in Eleme Local Government Area of the Rivers State in Nigeria, situated on latitude 4°44' N and longitude 7°15' E of southern Nigeria. The mean minimum temperature is 25 °C, and the mean maximum is 29 °C (ICRAF/IITA, 1994). The site is about 4 km from the Federal Ocean Terminal at Onne.

2. 2. Data

Data used for this study were collected from the different species in the mixed species plantation. Within the mixed species plantation, the following growth variables were measured for all the trees: crown diameter (m), diameter at breast height (cm), and diameter at the base (cm), while other pertinent variables were estimated using mesurational methods.

2. 3. Computation of derived variables

The following variables were obtained from the measured growth variables:

2. 4. Crown Projection Area

$$CPA = (\pi CD^2)/4 \quad \text{(i)}$$

where: CPA = Crown Projection Area, CD = Crown Diameter

2. 5. The Maximum Crown Area

$$MCA = \frac{100 \times \left(\frac{\pi}{4}\right) \times (\beta_0 + \beta_1 D)^2}{10000} \quad \text{(ii)}$$

where: MCA = Maximum Crown Area, β_0 and β_1 are regression coefficients, D = dbh

2. 6. Basal Area

$$BA = \frac{\pi D^2}{4} \quad \text{(iii)}$$

where; BA = Basal Area (m^2), D = dbh, π = 3.142

2. 7. Modeling of Crown Diameter

The following mathematical functions below were developed for this study:

$$cd = b_0 + b_1 \cdot dbh \quad \text{(iv)}$$

$$cd = b_0 + b_1 \cdot dbh + b_2 \cdot dbh^2 \quad \text{(v)}$$

$$cd = b_0 + b_1 \cdot dbh + b_2 \cdot dbh^2 + b_3 \cdot dbh^3 \quad \text{(vi)}$$

$$Ln(cd) = Ln(b_0) + b_1 \cdot Ln(dbh) \quad \text{(vii)}$$

$$Ln(cd) = b_0 + b_1 \cdot dbh \quad \text{(viii)}$$

$$Ln(cd) = Ln(b_0) + b_1 \cdot dbh \quad (ix)$$

$$Ln(cd) = b_0 + b_1 \cdot BA \cdot dbh \quad (x)$$

$$Ln(cd) = Ln(b_0) + b_1 \cdot CPA \cdot dbh \quad (xi)$$

2. 8. Model development and Evaluation

The models were developed with the aim of choosing the best fit for the crown diameter. The evaluation was based on the following conditions: Coefficient of determination (R^2), Standard error of estimate (SEE), Significance of the overall regression equation (F-value), and Probability significance (P-value).

A model with higher R^2, the least SEE, and significant overall regression, as well as low probability of significance, was selected as the suitable model for each species.

2. 9. Statistical Analysis

Descriptive statistics was used in estimating growth attributes, correlation and regression analyses were used to evaluate the association and relationship between the crown diameter and tree growth variables.

3. RESULTS AND DISCUSSION

The results of the growth variables (**Table 1**) shows that variations exist between the crown diameter of the mixed species plantation in the study area with *Treculia africana* stand having the highest mean value of CD (12.924 ±0.136), followed by *Mansonia altissima* stand, having a mean value of CD (7.244 ±0.415), *Terminalia ivorensis* stand, having a mean value of CD (6.784 ±0.405), *Tectona grandis* stand, having a mean value of CD (5.510 ±0.398), *Entandrophragma angolense* stand, having a mean value of CD (4.322 ±0.246), and *Khaya ivorensis* stand, having the lowest mean value of CD (3.588 ±0.936). Brovkina *et al*. (2015) reported that the tree crown size is a key parameter of tree structure that has a variety of uses, including assessment of the stand density, the tree growth, and amount of timber volume assessment.

Table 1. Summary Statistics of the Growth Variables by Species in the Study Area

Species	Variable	Mean ±SE
Khaya ivorensis	CD	3.588 ± 0.936
	CPA	10.312 ± 0.534
	MCA	1031.202 ± 53.417
	THT	20.099± 0.116
	DBH	9.114 ± 0.238
	BA	0.030 ± 0.001

Entandrophragma angolense	CD	4.322 ± 0.246
	CPA	16.106 ± 2.024
	MCA	1610.451 ± 202.356
	THT	19.380 ± 0.156
	DBH	17.274 ± 0.624
	BA	0.024 ± 0.002
Terminalia ivorensis	CD	6.784 ± 0.405
	CPA	38.598 ± 5.410
	MCA	3859.768 ± 541.031
	THT	18.580 ± 0.096
	DBH	21.091 ± 0.406
	BA	0.352 ± 0.001
Tectona grandis	CD	5.510 ± 0.398
	CPA	28.364 ± 3.445
	MCA	2836.369 ± 344.452
	THT	11.988 ± 0.791
	DBH	20.531 ± 1.581
	BA	0.039 ± 0.005
Treculia africana	CD	12.924 ± 0.136
	CPA	131.512 ± 2.755
	MCA	13151.090 ± 275.492
	THT	10.486 ± 0.307
	DBH	30.804 ± 2.031
	BA	0.081 ± 0.009
Mansonia altissima	CD	7.244 ± 0.415
	CPA	44.202 ± 4.812
	MCA	4420.172 ± 481.077

	THT	18.653 ± 0.544
	DBH	18.048 ± 1.858
	BA	0.032 ± 0.007

N - number of trees, CD - crown diameter, THT - total height, DBH - diameter at breast height, BA - basal area, CPA - crown projection area, and MCA - maximum crown area

3. 1. Result of the correlation analyses

The results, as shown in **Table 2** below revealed elements of similarity among association that exist between crown diameter and diameter at breast height, basal area, crown projection area and maximum crown area with high values of coefficient of correlation (r).

Table 2. Correlation matrix between the crown diameter (CD) and other growth attributes for *Khaya ivorensis*

	CD(m)	THT(m)	DBH(cm)	BA(m^2)	CPA(m^2)	MCA(m^2)
CD(m)	1.000					
THT(m)	0.410	1.000				
DBH(cm)	0.619	0.537	1.000			
BA(m^2)	0.606	0.483	0.996	1.000		
CPA(m^2)	0.997	0.381	0.587	0.575	1.000	
MCA(m^2)	0.997	0.381	0.587	0.575	1.000	1.000

CD - crown diameter, THT - total height, DBH - diameter at breast height, BA - basal area, CPA - crown projection area and MCA - maximum crown area

In **Table 3** below, Association of the crown diameter and crown projection area revealed high values of coefficient of correlation (r).

Table 3. Correlation matrix between crown diameter and other growth variables for *Entandrophragma angolense*

	CD(m)	THT (m)	DBH (cm)	BA (m^2)	CPA (m^2)	MCA (m^2)
CD (m)	1.000					
THT (m)	0.389	1.000				
DBH (cm)	0.691	0.603	1.000			

BA (m^2)	0.736	0.563	0.992	1.000		
CPA (m^2)	0.986	0.370	0.684	0.735	1.000	
MCA (m^2)	0.986	0.370	0.684	0.735	1.000	1.000

CD - crown diameter, THT - total height, DBH - diameter at breast height, BA - basal area, CPA - crown projection area and MCA - maximum crown area

The results, as shown in **Table 4** below, revealed general associations between the crown diameter (CD) and the growth attributes for *Terminalia ivorensis* in the study area.

Table 4. Correlation matrix between the crown diameter and other growth variables for *Terminalia ivorensis*

	CD (m)	THT (m)	DBH (cm)	BA (m^2)	CPA (m^2)	MCA (m^2)
CD (m)	1.000					
THT (m)	0.543	1.000				
DBH (cm)	0.190	–0.117	1.000			
BA (m^2)	0.196	–0.115	0.999	1.000		
CPA (m^2)	0.992	0.546	0.229	0.234	1.000	
MCA (m^2)	0.992	0.546	0.229	0.234	1.000	1.000

CD - crown diameter, THT - total height, DBH - diameter at breast height, BA - basal area, CPA - crown projection area and MCA - maximum crown area

As revealed in **Table 5** below, the association of the crown diameter and crown projection area and that of the crown diameter and maximum crown area, both gave a high coefficient of correlation (r) of 0.978.

Table 5. Correlation matrix between the crown diameter and other growth variables for *Tectona grandis*

	CD (m)	THT (m)	DBH (cm)	BA (m^2)	CPA (m^2)	MCA (m^2)
CD (m)	1.000					
THT (m)	0.498	1.000				
DBH (cm)	0.693	0.524	1.000			
BA (m^2)	0.657	0.418	0.964	1.000		

CPA (m^2)	0.978	0.431	0.646	0.634	1.000	
MCA (m^2)	0.978	0.431	0.646	0.634	1.000	1.000

CD - crown diameter, THT - total height, DBH - diameter at breast height, BA - basal area, CPA - crown projection area and MCA - maximum crown area

Table 6 shows that the association of the crown diameter and crown projection area and that of crown diameter, and maximum crown area, both gave a high positive coefficient of correlation (r) of 0.999.

Table 6. Correlation matrix between crown diameter and other growth variables for *Treculia africana*

	CD (m)	THT (m)	DBH (cm)	BA (m^2)	CPA (m^2)	MCA (m^2)
CD (m)	1.000					
THT (m)	0.026	1.000				
DBH (cm)	–0.151	0.195	1.000			
BA (m^2)	–0.145	0.200	0.988	1.000		
CPA (m^2)	0.999	0.023	–0.149	–0.145	1.000	
MCA (m^2)	0.999	0.023	–0.149	–0.145	1.000	1.000

CD - crown diameter, THT - total height, DBH - diameter at breast height, BA - basal area, CPA - crown projection area and MCA - maximum crown area

The results shown in **Table 7** below revealed general associations between the crown diameter (CD) and the growth attributes for *Mansonia altissima* in the study area.

Table 7. Correlation matrix between crown diameter and other growth variables for *Mansonia altissima*

	CD(m)	THT(m)	DBH(cm)	BA(m^2)	CPA(m^2)	MCA(m^2)
CD(m)	1.000					
THT(m)	0.466	1.000				
DBH(cm)	0.584	0.397	1.000			
BA(m^2)	0.461	0.281	0.980	1.000		

CPA(m^2)	0.988	0.360	0.564	0.448	1.000	
MCA(m^2)	0.988	0.360	0.564	0.448	1.000	1.000

CD - crown diameter, THT - total height, DBH - diameter at breast height, BA - basal area, CPA - crown projection area and MCA - maximum crown area

The estimated linear model parameters by species in the mixed species plantation can be found in **Table 8** below:

Table 8. Estimated Linear Model Parameters for the Six Species

Equation/Species	b_0	b_1			R^2	SEE	F-Value	P-value
$Cd = b_0 + b_1dbh$								
Khaya ivorensis	1.159	0.125			0.384	0.410	17.440	0.000
Entandrophragma angolense	–0.039	0.273			0.478	1.007	26.568	0.000
Terminalia ivorensis	2.786	0.190			0.036	1.829	0.673	0.423
Tectona grandis	1.429	0.190			0.480	1.520	52.676	0.000
Treculia africana	13.236	-0.010			0.023	0.647	0.466	0.502
Mansonia altissima	4.889	0.130			0.341	1.654	10.873	0.003
$Cd = b_0 + b_1dbh + b_2dbh^2$	b_0	b_1	b_2		R^2	SEE	F-Value	P-value
Khaya ivorensis	–1.725	0.440	-0.008		0.402	0.411	9.078	0.001
Entandrophragma angolense	10.375	–0.991	0.036		0.640	0.851	24.927	0.000
Terminalia ivorensis	25.571	–2.010	0.053		0.050	–0.062*	0.449	0.645
Tectona grandis	1.077	0.234	–0.001		0.482	1.531	26.077	0.000
Treculia africana	13.385	–0.022	0.000		0.023	0.664	0.229	0.798
Mansonia altissima	-0.620	0.729	–0.013		0.644	1.246	18.089	0.000
$Cd = b_0 + b_1dbh + b_2dbh^2 + b_3dbh^3$	b_0	b_1	b_2	b_3	R^2	SEE	F-Value	P-value
Khaya ivorensis	–0.755	0.282	–7.481	0.000	0.402	0.411	9.066	0.001
Entandrophragma angolense	26.487	–3.806	0.194	–0.003	0.662	0.840	17.646	0.000
Terminalia ivorensis	17.216	–0.855	0.018	0.001	0.048	1.869	0.433	0.656
Tectona grandis	2.058	0.016	0.012	0.000	0.488	1.536	17.460	0.000

Treculia africana	6.896	0.739	–0.027	0.000	0.153*	0.635	1.086*	0.380*
Mansonia altissima	0.715	0.494	–0.001	0.000	0.650	1.268	11.744	0.000
Ln(cd) = Ln(b_0) + b_1Ln(dbh)	b_0	b_1			R^2	SEE	F-Value	P-value
Khaya ivorensis	–0.763	0.687			0.438	0.110	21.815	0.000
Entandrophragma angolense	–1.102	0.892			0.394	0.230	18.822	0.000
Terminalia ivorensis	0.812	0.353			0.018	0.233	0.335	0.570
Tectona grandis	–0.317	0.647			0.508	0.334	58.767	0.000
Treculia africana	2.625	–0.020			0.020	0.051	0.419	0.525
Mansonia altissima	0.689	0.449			0.509	0.213	21.731	0.000
Ln(cd) = b_0 + $b_1$dbh	b_0	b_1			R^2	SEE	F-Value	P-value
Khaya ivorensis	0.552	0.037			0.422	0.111	20.481	0.000
Entandrophragma angolense	0.441	0.057			0.460	0.217	24.668	0.000
Terminalia ivorensis	1.504	0.018			0.021	0.233	0.381	0.545
Tectona grandis	0.680	0.044			0.510	0.333	59.220	0.000
Treculia africana	2.583	0.000			0.023	0.050*	0.478	0.497
Mansonia altissima	1.587	0.020			0.347	0.245	11.154	0.003
Ln(cd) = Ln(b_0) + $b_1$dbh	b_0	b_1			R^2	SEE	F-Value	P-value
Khaya ivorensis	0.552	0.037			0.422	0.111	20.481	0.000
Entandrophragma angolense	0.441	0.057			0.460	0.217	24.668	0.000
Terminalia ivorensis	1.504	0.018			0.021	0.233	0.381	0.545
Tectona grandis	0.680	0.044			0.510	0.333	59.220	0.000
Treculia africana	2.583	0.000			0.023	0.050*	0.478	0.497
Mansonia altissima	1.587	0.020			0.347	0.245	11.154	0.003
Ln(cd) = b_0 + b_1BAdbh	b_0	b_1			R^2	SEE	F-Value	P-value
Khaya ivorensis	1.020	0.409			0.376	0.116	16.854	0.000
Entandrophragma angolense	1.068	0.780			0.540	0.200	34.038	0.000
Terminalia ivorensis	1.743	0.191			0.025	0.232	0.457	0.508

Tectona grandis	1.262	0.320			0.322	0.392	27.055	0.000
Treculia Africana	2.567	–0.003			0.016	0.051	0.324	0.575
Mansonia altissima	1.871	0.083			0.130	0.283	3.137	0.091
Ln(cd) = Ln(b_0) + b_1CPAdbh	b_0	b_1			R^2	SEE	F-Value	P-value
Khaya ivorensis	0.877	0.002			0.936*	0.037*	409.697*	0.000*
Entandrophragma angolense	1.143	0.001			0.796*	0.133*	113.280*	0.000*
Terminalia ivorensis	1.574	0.000			0.886*	0.079	139.674*	0.000*
Tectona grandis	1.126	0.001			0.655*	0.280*	108.109*	0.000*
Treculia Africana	2.531	-0.000			0.029	0.050	0.601	0.447
Mansonia altissima	1.655	0.000			0.648*	0.180*	38.577*	0.000*

b_0, b_1, b_2, b_3 = regression coefficient, R^2 = coefficient of determination, SEE = standard error of the estimate, F-value = Significance of the overall regression equation and P-value = probability significance

3. 2. Residual analysis for *Khaya ivorensis* stand

For the best adjudged crown diameter model in *Khaya ivorensis* stand, a residual plot was generated from residual numbers and the product of crown projection area, and diameter at breast height (**Fig. 2**).

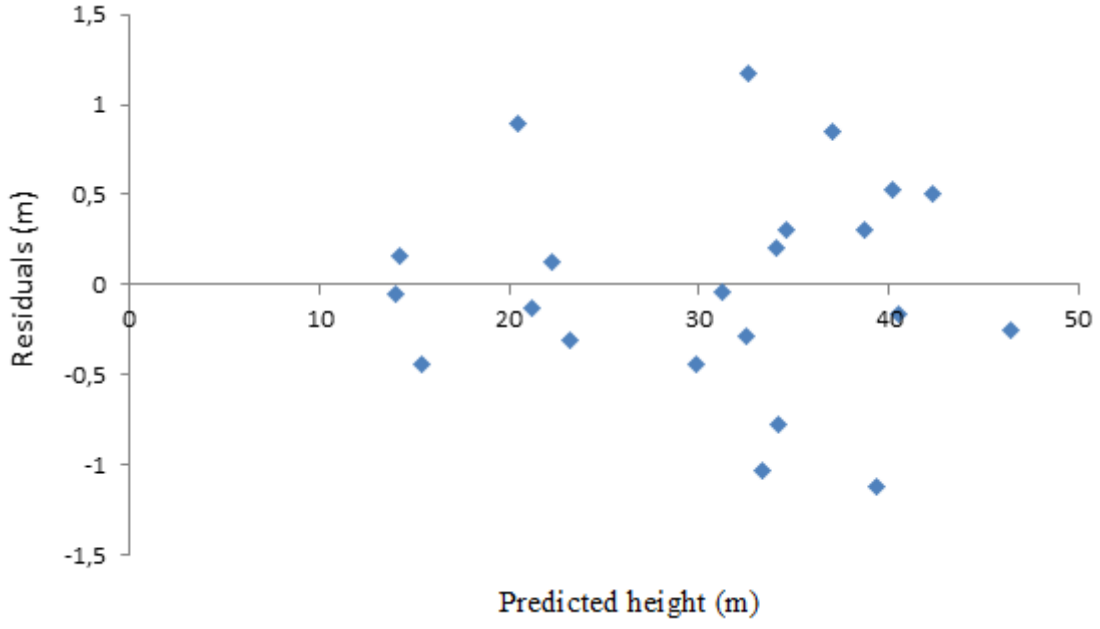

Fig. 2. Residual plot for best adjudged crown diameter model for *Khaya ivorensis* in the study area.

It can be observed that for all the species, CPA and MCA have the greatest correlation with CD; this finding differs from the work done by Warbington and Levitan (1992). They stated that, DBH is an important tree characteristic and the variable that has the greatest correlation with crown width.

The graph shows a residual plot between residuals and crown projection area for *Khaya ivorensis*. It shows a more or less random pattern with an indication that the model is unbiased.

In this study, the exponential function is deemed the best model for all the species, except for *Khaya ivorensis* which has the cubic function as the best adjudged model. Different models have been described as the best adjudged model by many authors. For example, Avsar and Ayyildiz, 2005, settled on the power model to describe the crown diameter-CPAdbh relationships; and this could invariably be germane in application to other growth attributes.

4. CONCLUSION

This work has revealed that crown diameter models shown in this study have a considerable relationship with CPA and dbh, and these findings can be employed for the crown diameter studies on any mixed species plantation in Southern Nigeria.

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