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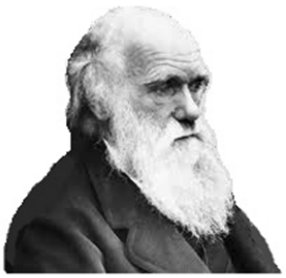

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# Prognostic Crown Diameter equations for a Mixed Species Plantation in Southern Nigeria

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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 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 mensurational 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 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 products such as

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paper, solid wood and firewood (Evans, 2009). Mixed species plantations are frequently 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 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 individual trees is a fundamental component of 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 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: measure and estimate tree growth attributes within the mixed species plantation in the study area, develop crown diameter models for the mixed species plantation in the study area and assess the best diameter crown model with good fit for crown attribute prediction.

## 2. MATERIALS AND METHODS

### 2. 1. Study Area

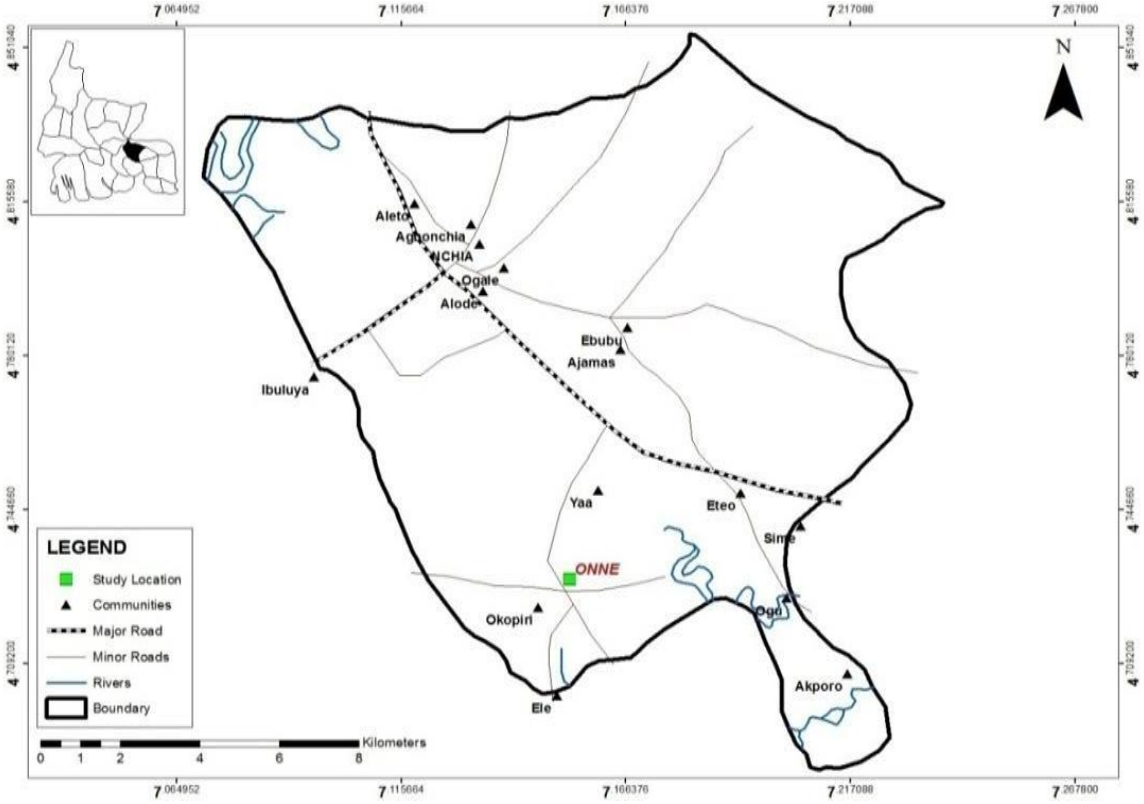


**Fig. 1.** Map of Eleme Local Government in Rivers State, Southern Nigeria showing the study location (FRIN, Onne)

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 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 4km 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 trees: crown diameter (m), diameter at breast height (cm) and diameter at the base (cm), while other pertinent variables were estimated using mensurational 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, $\beta_0$ and $\beta_1$ 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, $\pi$ = 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 $R^2$, 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 crown diameter and tree growth variables.

## 3. RESULTS AND DISCUSSION

The results of the growth variables (Table I) shows that variations exist between 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 tree crown size is a key parameter of tree structure that has a variety of uses, including assessment of stand density, tree growth and amount of timber volume assessment.

**Table I.** 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 result as shown in Table II 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 II.** Correlation matrix between 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 III below, Association of crown diameter and crown projection area revealed high values of coefficient of correlation (r)

**Table III.** 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 result as shown in Table IV below revealed general associations between crown diameter (CD) and the growth attributes for *Terminalia ivorensis* in the study area.

**Table IV.** Correlation matrix between 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 V below, the association of crown diameter and crown projection area and that of crown diameter and maximum crown area both gave a high coefficient of correlation (r) of 0.978.

**Table V.** Correlation matrix between 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 VI shows that the association of 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 VI.** 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 result as shown in Table VII below revealed general associations between crown diameter (CD) and the growth attributes for *Mansonia altissima* in the study area.

**Table VII.** 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 VIII below:

**Table VIII.** Estimated Linear Model Parameters for the Six Species

| Equation/Species | $b_0$ | $b_1$ | | | $R^2$ | SEE | F-Value | P-value |
|---|---|---|---|---|---|---|---|---|
| **$Cd = b_0 + b_1 dbh$** | | | | | | | | |
| *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 |
| **$Cd = b_0 + b_1 dbh + b_2 dbh^2$** | $b_0$ | $b_1$ | $b_2$ | | $R^2$ | 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 |
| **$Cd = b_0 + b_1 dbh + b_2 dbh^2 + b_3 dbh^3$** | $b_0$ | $b_1$ | $b_2$ | $b_3$ | $R^2$ | 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($b_0$) + $b_1$Ln(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) = $b_0$ + $b_1$BAdbh** | $b_0$ | $b_1$ | | | $R^2$ | 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($b_0$) + $b_1$CPAdbh** | $b_0$ | $b_1$ | | | $R^2$ | 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, residual plot was generated from residual numbers and the product of crown projection area and diameter at breast height (Fig. 2).

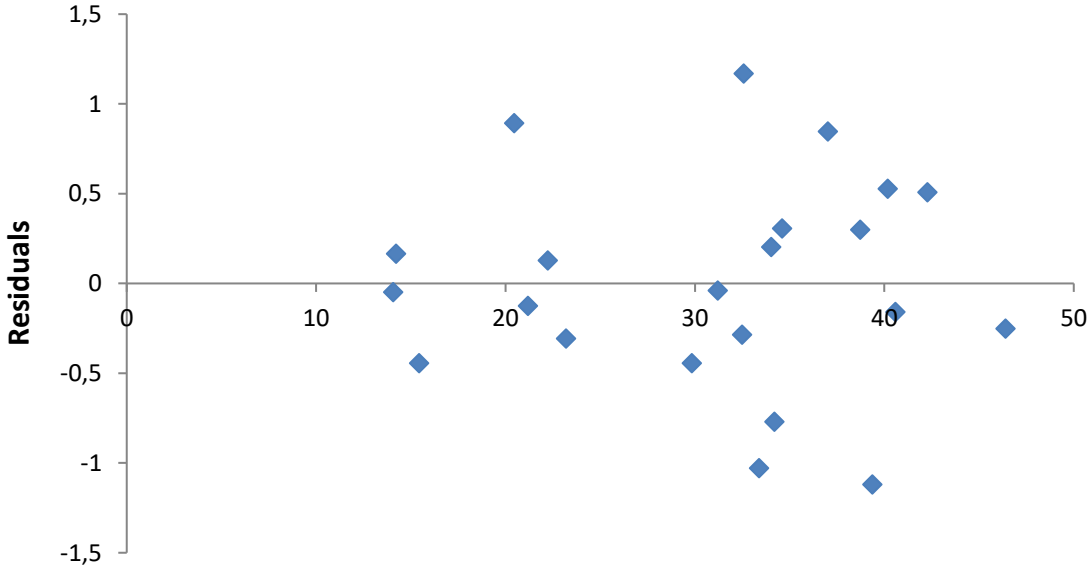


**Fig. 2.** Residual plot for best adjudged crown diameter model for *Khaya ivorensis* in the study area.

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; 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 being described as the best adjudged model by many authors. For example, Avsar and Ayyildiz, 2005 settled on the power model to describe 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 showed in this study has considerable relationship with CPA and dbh and these findings can be employed for crown diameter studies on any mixed species plantation in Southern Nigeria.

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