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CROWN DIAMETER MODELS FOR *Tectona grandis* (Linn. F.) IN AGAN FOREST PLANTATION, MAKURDI, NIGERIA

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ABSTRACT

Crown diameters are not easy to measure in a forest stand. Individual tree crown diameter models was developed for Tectona grandis in Agan forest plantation using crown-diameter and bole-diameter at breast height (dbh) over bark as predictor variables. Five sample plots were selected randomly in the plantation and the trees with dbh above 10cm in each plot were measured using diameter tape and crown diameter was also measured. Each plot size was 20m X 20m. The crown diameter range of 10.01 – 11.00m had the highest frequency. Simple and Multiple linear regression analyses were used to relate the dependent and independent variables. The selected models involved an untransformed and transformed single entry crown diameter model with Multiple linear (model 5) and (model 6) as the best fitted models for the relationship between crown diameter and diameter at breast height of the forest plantation of Tectona grandis of Agan forest.

Keywords: Crown diameter models, linear models, *Tectona grandis*, diameter at breast height

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INTRODUCTION

Exotic tree were introduced to Nigeria and other developing countries. Some of these such as *Pinus caribea, Pinus oocarpa, Tectona grandis* and *Gmelina arborea* proved very successful in several tropical countries (Ajayi and Odey, 2012). Teak (*Tectona grandis*) is one of the most widely used tree species for plantation forestry by the government, private sector and individuals in Benue State. Teak is important because it is the preferred wood for electric pole production, telephone poles, timber, naval construction, boat and bridges constructions as well as the ecological importance in the conservation of forest soil moisture regime (Akoto *et al*., 2016).

Within the last four decades, the Federal and State governments in Nigeria in conjunction with the World Bank have heavily invested in plantation establishment of Gmelina and Teak to provide raw materials and products in the form of poles, timber, veneer, wood particles, pit props, pulp, fuelwood and for research, (Ajayi and Odey, 2012). Teak is a valuable timber species that grows fast, it has great anatomical and physical properties (e.g., it is durable, termite resistant, easy to work on, etc.) (Chukwu and Osho, 2018).

Nature has provided natural resources for man, since ages for the sustenance of his socio–economic needs; but these needs are always changing and keep increasing, these resources are in danger of serious depletion. One of the most affected of these resources is the “forest”, that has been continuously under threats of over-exploitation by man, leading to negative changes in its status and productivity. The changes occur

as man attempt to adjust their unending wants and desires for food, shelter, recreation, infrastructural facilities and so on to the forest resources accessible to them (Nwadialor, 2001).
Canopy structure is paramount in shaping forest ecosystems because it provides a significant layer for photosynthesis, respiration, and transpiration (Hernandez-moreno *et al*., 2017). Crown covers is important in reducing soil percolation, issues that usually lead to gulley erosions by playing the role of speed breaks when rainfalls and forest-soil multifunctional regime of improving root pressure by evapo-transpiration that is important in sustainable management of groundwater against degradation (Fu *et al.,* 2017; Ureigho *et al.,* 2018).

Plantations have been able to address a few global problems such as reducing deforestation, restoring degraded land, ameliorating climate change, improving local livelihood, returned good profits, created employment and bolstered national economies. However, despite this fact, teak, attains prices of several thousand US Dollar per m^3 on the world market (Ajayi and Odey, 2012), not all the plantations are in good shape. One of the set back of forest management is collecting reliable forest inventory data faster and accurately (Iizuka *et al*., 2018). Crown diameters are not easy to measure on the field, in forest stand with irregular edges (Kershaw *et al*., 2017). Human influences appear to be major factors constituting serious threats to Agan plantation.

The objective of this study was to develop crown diameter prediction models for *Tectona grandis* in Agan forest plantation. The proper management of Agan *Tectona grandis* plantation requires a reliable crown estimate of the tree species (model). For this purpose and its goal to be achieved, crown model based on the established relationship between some measurable tree parameters such as crown diameter and bole diameter (Dbh) are very paramount. At the moment, no adequate individual tree crown model had been developed for *Tectona grandis* plantation in Agan. Volume of standing trees cannot be measured directly but can be predicted using measured tree attributes such as diameter at breast height (dbh) and crown diameter.

Relevant and adequate information regarding the growth characteristics of the forest plantation is not available; information about the crown-diameter relationship model will give an insight into the best management approaches to be adopted. The crown leaves serves as a capture for radiant energy for photosynthesis; therefore measurement of the tree crown is carried out to assist in quantification and understanding of the tree growth (Ureigho *et al.,* 2018). Tree crown diameter relationship is important for tree and stand volumes from aerial photographs (Gering and May, 1995). Crown characteristics and growth variables have been used for forest growth and yield models (Gonzalez-Benecke *et al.,* 2014; Fu *et al.,* 2016).

MATERIALS AND METHODS

Study Area

Agan forest is located in Makurdi local government area of Benue state as shown in Figure 1. The plantation is located in Daudu, along Makurdi-Lafia road. The purpose of the plantation was to supply electric poles and fuel wood for domestic purposes. The plantation is made up of *Tectona grandis* (Teak) and *Gmelina arborea* (Gmelina). The occupation of the nearby people is farming and hunting and the inhabitants found are Tivs.

Figure 1: Map of the study area

Data Collection

Simple random sampling (SRS) was used in order to ensure that each plot in the plantation has equal chance of being selected. A sampling frame consisting of sampling units of size 20m by 20m (0.04ha) was established. The total area of the plantation was divided into sample plots of equal size (0.04ha) and five sample plots were randomly selected using random table. Complete enumeration of trees larger than 10cm was carried out in the sample plots. Within each plot the following tree growth variables were measured.

1. Diameter at breast height (DBH)
2. Crown diameter

Crown Diameter

Crown measurement was based on the assumption that the vertical projection of a tree crown is circular (Krajicek *et al.,* 1961). Four radii were measured as in (Ayhan, 1973) along four axes at right angle. Along the widest part of the tree crown the tape was held horizontally and extended until each person was vertically under the tip of the longest branch on their side. Measurement was recorded as maximum width. The tape was then turned by 90^o and measurement repeated along the thinnest part of the tree crown and recorded as minimum width. Average crown diameter (Cd) was calculated by summing up the four radii and dividing by 2, thus:

$$Cd = \frac{\sum r_i}{2} \quad \text{............ [1]}$$

Where:

Cd = average crown diameter

r_i = projected crown radii measured on four axes

Bole Diameter

Diameter at breast height (dbh) was measured for all tree individuals by means of diameter tape. For trees with deformations at 1.3m, the measurement was made at the sound point on the stem above the abnormality. For buttressed trees, a point of measurement was selected approximately 0.5m above the convergence of the buttress (Husch *et al.,* 2003).

Data Analysis

The data collected from tree measurement was processed into suitable form for statistical analysis. Data processing included basal area estimation and crown projection area estimation.

Basal Area Estimation

The diameter at breast height (dbh) was used to compute basal area using the formula:

$$BA = \frac{\pi D^2}{4} \quad \text{......... [2]}$$

Where
BA = Basal area (m^2)
D = Diameter at breast height (m) and
π = 3.142

Crown Projection Area Estimation

The crown projection area for each tree was estimated using the formula:

$$CPA = \frac{(\pi CD^2)}{4} \quad \ldots\ldots [3]$$

Where
CPA = crown projection area (m^2)
CD = crown diameter (m)

Crown Diameter Prediction Models

The simple and multiple linear regression analysis were used to develop equation relationship between crown diameter and dbh. The models were patterned after the one presented by Ajayi *et al.* (2006).

The following models for predicting crown diameter were used for this study;

- Linear $Cd = b_o + b_1D$ ……………… (4)
- Quadratic $Cd = b_o + b_1D + b_2D^2$ ….. (5)
- Cubic $Cd = b_o + b_1D + b_2D^2 + b_3D^3$ … (6)

Where
Cd = crown diameter
D = dbh and
$b_{0 \ldots b3}$= regression constants

Assessment of the Models

The crown diameter models were assessed with the view of recommending those with good fit for further uses. The following statistical criteria were used:

1. Coefficient of Determination (R^2)

This is the measure of the proportion of variation in the dependent variable that is explained by the behaviour of the independent variable (Thomas, 1977). For the model to be accepted, the R^2 value must be high.

$$R^2 = 1 - \frac{SSE}{SST} \quad \ldots.. [7]$$

Where R^2 = Coefficient of determination, SSE = Error sum of squares or Residual sum of squares, SST = Total sum of squares and 1= regression line.

2. Regression Mean Square Error (RMSE)

This is also referred to as the standard deviation or residual of the error variance of the estimate. It measures the spread of data and is a good indicator of precision. The value must be small.

$$RMSE = \sqrt{\frac{\sum(Y_i - Y)^2}{n-p}} \quad \ldots\ldots\ldots (8)$$

Note: Yi = observed value of the dependent variable
Y = predicted value of the dependent variable
n = number of observations
p = number of parameters

3. Standard Error

The value should be relatively small for the model to be considered valid. Standard error is given as

$$SE = \sqrt{\frac{\sum_{i=1}^{n}(Cd_i - \widehat{Cd}_i)^2}{n-k}} \quad \ldots\ldots. (9)$$

Cd_i is the observed crown diameter for the ith tree; $\widehat{Cd}_i$ is the crown diameter for the ith tree; k is the number of model parameters; n is the number of observations.

4. Furnival Index

This is the most appropriate factor for comparing the precision of regression equations whose dependent variables are variously defined (Furnival, 1961). It affords the opportunity of comparing the precision of models with either untransformed or transformed dependent variable. This value must be small for the model to be useful. The formula is:

$$F1 = \frac{1}{[f'(Y)]}\sqrt{MSE} \quad \ldots. (10)$$

Where $f'(Y)$ is the derivative of the dependent variable with respect to crown diameter, MSE is the mean square error of the fitted equation, and the square bracket [()] is the geometric mean.

RESULTS

Growth Variables

The result of the descriptive statistics of data collected on growth variables for the species are given in table 1 below. The table shows the mean, standard error, standard deviation, co-efficient of variation, minimum, maximum of each growth variable.

Table 1: Descriptive statistics for the tree species

Variables	Mean	S.E	S.D	C.V	Min.	Max.
DBH	0.98	0.08	0.67	83.8	0.48	1.84
BA	0.84	0.06	0.61	44.8	0.18	2.66
CPA	0.85	0.11	1.25	18.3	0.03	5.56
CD	9.92	0.17	1.93	17.39	5.10	12.79

CD = Crown diameter (m), DBH = Diameter at breast height (m), BA = Basal area (m^2), CPA = Crown projection area (m^2)

Crown diameter has the highest variable mean of (9.92m) with 12.79m as the maximum and 5.10m as minimum crown diameter while basal area has the lowest mean of (0.84cm) with a maximum of 2.66 m^3 and minimum of 0.18m^3. The coefficient of variation of the variables was determined with 83.8% as the highest in Dbh and the lowest was 17.4% for crown diameter.

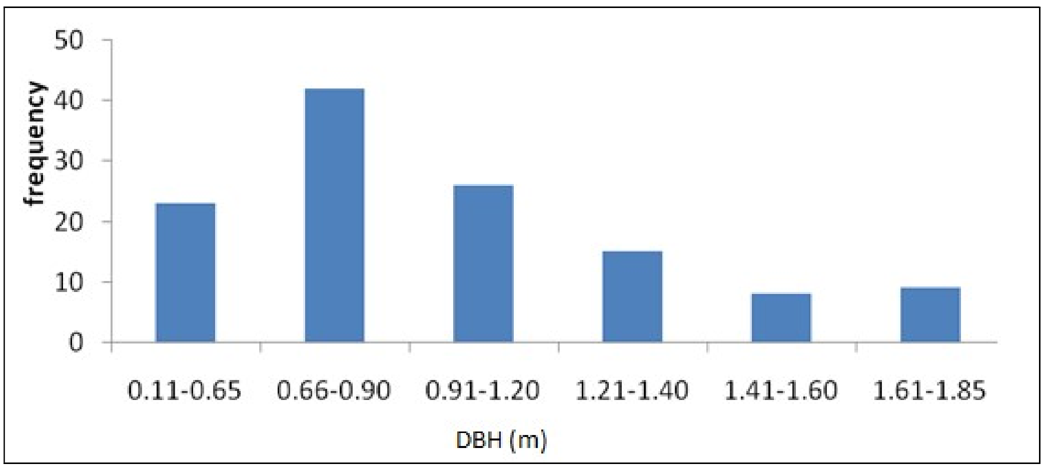


Figure 2: Tree Diameter size class distribution in the Plantation

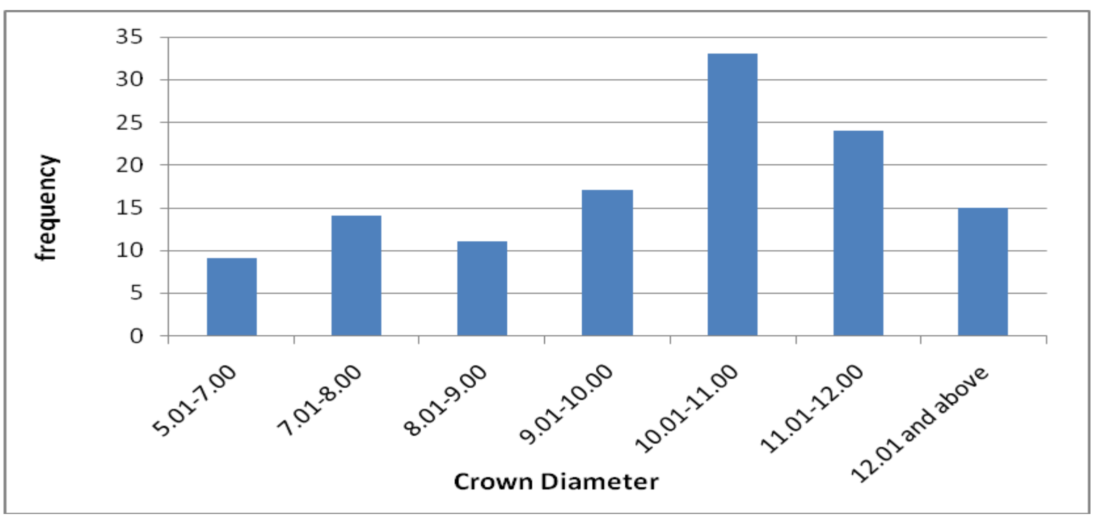


Figure 3: Crown Diameter distribution

Figure 2 shows Dbh class of the plantation, it ranges from 0.66 – 0.90m with the highest frequency. While Figure 3 shows that the crown diameter range of 5.01 – 7.00m had the lowest frequency.

Model Summary and Comparison

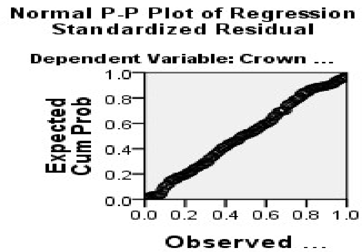
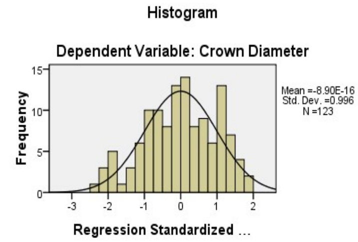
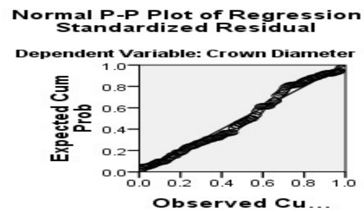
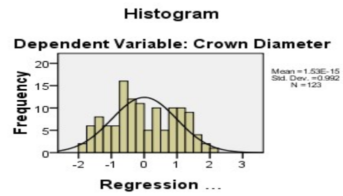
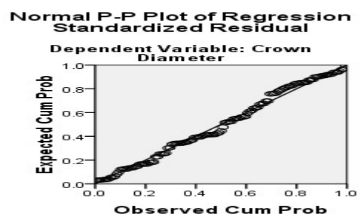
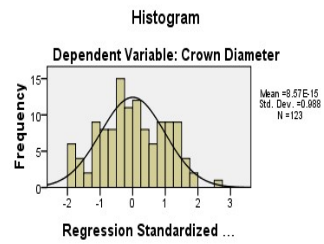
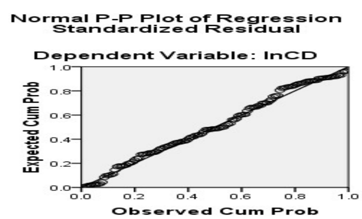
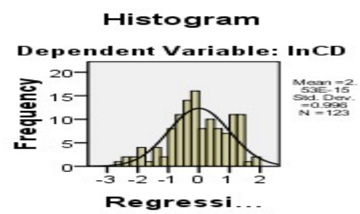
Table 2: Model Summary

No	Model form	Parameters				R	R^2	SEE	RMSE	F.I
		b_0	b_1	b_2	b_3					
4	$Cd = b_o + b_1D$	4.482	2.183	-	-	0.592	0.351	1.041	1.083	0.080
5	$Cd = b_o + b_1D + b_2D^2$	1.204	8.876	-3.033	-	0.671	0.450	0.962	0.925	0.074
6	$Cd = b_o + b_1D + b_2D^2 + b_3D^3$	-3.311	22.872	-16.318	3.893	0.687	0.472	0.946	0.896	0.073
7	$Cd = b_o + b_1 \ln D$	1.901	0.407	-	-	0.642	0.412	0.171	0.029	0.013

D = Diameter at breast height (m); b_o = regression constant (intercept), b_1, b_2 and b_3 = regression coefficients, R^2 = Coefficient of Determination; SEE= standard error of estimate; RMSE = residual mean square error; FI = furnival index

As shows on Table 2, model 4 had the highest standard error of estimate with the lowest residual and coefficient of determination but turned to be the only model with the best fitted residual plot and normal probability plot among the models. As shown in Table 2 models 5, 6 and 7 R, R^2, RMSE and SEE were slightly better than model 4 which could be as the result of transformation carried out on model 5, 6 and 7. In models 6 and 7, the Furnival indexes were lower than standard errors of the models; model 7 has a fairly fitted residual plot and Normal probability plot that is better than model 6 and 5, which made it to be the best fitted linear model among the three transformed models. The above models significantly explained the variation in crown diameter and correlated well with tree diameter. The data behaved accordingly with increasing crown diameter and tree diameter size. As shown in Table 3 model 7 has the lowest residual with an ideal prediction of unbiased or zero residual. However, the coefficient of the intercept was significantly different.

Table 3: Plots of residuals from crown diameter equations

Model No	Model form	Normal Probability Plot	Histogram
4	$Cd = b_o + b_1D$		
5	$Cd = b_o + b_1D + b_2D^2$		
6	$Cd = b_o + b_1D + b_2D^2 + b_3D^3$		
7	$Cd = b_o + b_1 \ln D$		

DISCUSSION

Coombes *et al*. (2019) stated a reduction in crown area with an increase in DBH. Kotaro *et al*. (2022) noted an increase in crown area as DBH decrease in big trees. Competition has an effect on the rate of increase in crown size; canopies can enlarge if there is less neighbors to hinder growth (Verma *et al*., 2014). Tanmoy *et al*. (2021) trees with large DBH were taller and have wider crown.

The best model is based on the goodness of fit as indicated by R^2, residuals mean of square (the magnitude of the errors associated with regressions) and root mean square error or standard error of fitted regression. A residual analysis is applied to know the lack of fit and bias. However, transformed model can be analyzed based on the value of the Furnival index (Furnival, 1961) as it has different and transformed response variable (Vanclay, 1994). The index adjusts the standard error of the regression in order to facilitate the comparison. The finding of this result agrees with (Ureigho *et al*., 2018) with model 4 having the lowest R^2. Linear regression analysis had the highest R^2 value (R^2=0.55) between DBH and crown diameter (Tanmoy *et al*., 2021).

Linear Crown diameter and bole Dbh relationships with positive y-intercepts behavior described by Dawkins (1963) stated that a possible depression in the relationship could occur at the upper end of the Crown diameter and Dbh relationship due to tree senility (age). Such a depression is possible with tropical wood and was found in this study. However, crown-diameter and bole-diameter regression models exists in Crown diameter and Dbh relationships due to their utility in forest inventory as shows on the table above. The current trend towards production of multiple products from a single tree has created an increased interest in the development of tree function. Measurement of crown diameter is not common in forest inventories, yet this value has wide applicability in forestry. Consequently, quantification of crown diameter attributes is an important component of many forest growth and yield models. For all practical purpose therefore, crown-diameter and bole-diameter at breast height (dbh) were adequate for predicting tree volume in Agan plantation.

CONCLUSION

Linear equations were developed to predict crown-diameter from bole-diameter (Dbh) for *Tectona grandis* in Agan plantation. These equations can be useful in predicting crown diameter from forest inventories for stocking guideline development, growth models, stand volume estimation, and forest products sustainability index models that use crown with other studies of crown radius and Dbh relationships on teak species; although enough differences existed to warrant further study.

The crown diameter and tree diameter relationship models in Agan plantation are highly significant and with a high linear relationship between response and independent variables. Modeling by crown diameter helps in the determination of an appropriate management regime for the tree. The importance of the relationship has been examined since the crown diameter can be predicted from the measurement of tree diameter. This is further illustrated by the possibility of estimating crown area and stand density of the plantation. It must be emphasized that this assumption holds only for selected tree species within the study area.

RECOMMENDATIONS

The height–diameter models can be validated for their prediction along different tree diameters. It will guide forest researchers and managers to adopt and utilise the best models. Model validation is carried out using independent validation data sets.

Future research is needed with a greater variety of site and stand conditions in addition to a greater variety of tree sizes and species stands.

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