IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 12, Issue 6 Ser. I (June 2019), PP 47-52
www.iosrjournals.org

Development and Evaluation of Linear and Non-Linear Models for Diameter at Breast Height and Crown Diameter of *Triplochiton Scleroxylon* (K. Schum) Plantations in Oyo State, Nigeria

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Abstract: *This study develop and evaluate empirical models for predicting crown diameter using diameter at breast height of Triplochiton scleroxylon (K. Schum) in Gambari forest reserve and Forestry Research Institute of Nigeria arboretum, Nigeria. One linear and four non-linear models (quadratic, cubic, power and exponential) were examined as functions to model diameters at breast height–crown diameter relationships. Stratified random sampling were used for this study and data collected from a total of 40 sample plots obtained from four age series (1972, 1973, 1974 and 1975) of stands of Triplochiton scleroxylon of size 20m x 20m located within the study sites. Analysis showed that the Linear, Quadratic and the Cubic models performed better with higher* R^2_{adj} *values of 0.750, 0.790 and 0.790 respectively, Coefficient of variation (CV) =* $-5.39x10^{-12}$*. Based on the CV,* R^2_{adj} *and SEE values, the cubic model described the best model for the relationship, (CD = 3.354 - 0.166DBH + 0.004*DBH^2 *+ 0.0000165*DBH^3*) hence, it was selected to model the relationship. This indicates that diameter at breast height is a predictor of crown diameter for Triplochiton scleroxylon. However, it is suggested that more variables like height and age should also be tested to determine the strongest predictor of crown diameter for this tree species. In addition, more research is still needed to be done to test applicability of these models across similar agro-ecological zones and to relate the growth rates/patterns in both stem and crown diameters of this tree species to the fitted models.*

***Keywords**: Diameter at breast height, crown diameter models, Triplochiton scleroxylon, Nigeria*

Date of Submission: 25-05-2019 Date of acceptance: 10-06-2019

I. Introduction

It is increasingly recognized that the disappearance of forest will create a number of serious environmental problem namely soil erosion, sedimentation, flood, loss of valuable material which help ensure the people's life (Onilude *et al*, 2013). It is matter of concern that our forests are continuously disappearing at an alarming rate. Forest is a true indicator of ecological setup prevailing in any area. For sustained yield from forest, it is essential to manage them scientifically which would require up-to-date statistics on the dimension of the trees, their extent and type**.**

However, apart from tree height and diameter at breast height that are consider most important variables in tree growth models, diameter at breast height (dbh) and crown diameter are also important tree characteristics as its accurate prediction of tree dimensions has become prominent as analysis techniques, models, and other statistical tools to allow for the rapid evaluation of extensive volumes of data. Some parameters (e.g., diameter or age) are easy to measure with simple instruments and it is widely used by forest inventories. However, a number of studies have shown that other variables which are not so easily obtained are also good predictors of forest dynamics and they can improve the reliability of tools like growth and yield models. One of these parameters is crown size, which has received increasing attention as a means to estimate tree growth (Bragg, 2001). Crown size cannot be measured easily in the field. Usually, compared to dbh, the measurement tends to be affected by observer error and is hindered by visual obstructions (Colbert et al, 2002; Lei, et al, 2009). Measurement of tree crown diameter is more difficult and more time consuming than that of dbh (Avsar, 2004). Crown diameter is used in tree and crown level growth-modeling systems, where simple competition indices are not available to adequately predict recovery from competition when a competitor is removed (Vanclay, 1994). Crown diameter bears a definite relation with its bole diameter irrespective of site and age and, in some cases, irrespective of silvicultural treatments (Dawkins, 1963; Kigomo, 1998).

If relationships between bole diameter and tree crown diameter are known, Basal Area (BA) or volume of trees can be estimated from bole diameters derived from crown diameters. Just as a tree's Diameter at Breast

Height (DBH) is often used as a surrogate for a tree's crown dimensions (Kigomo, 1980, 1991, 1998; Lockhart *et al*., 2005), a tree's crown diameter can equally be used as the surrogate for DBH.

Furthermore, many ecological and economic problems in forestry today (e.g. continuous cover forestry, wood production and quality) are approached using crown dimensional measures. For example, individual tree competition indices are derived from crown area estimates (Grote, 2002) because crown dimension is a result of past competition as well as an indicator of the current growth potential. Thus, crown dimensional measures are also used in more sophisticated single-tree models – particularly when forest growth in uneven-aged or mixed species stands is addressed (Pretzsch *et al*, 2002). Furthermore, crown size and canopy cover determine the probability of successful natural regeneration by its influence on the pattern of shade, light, and rainfall on the ground (Utschig, 1995). Possibly, considering a more realistic crown dimension will become increasingly important also for stem quality simulation, because branch dimension is one of the most important determinants. Despite its importance crown extension remains difficult to determine. It can only be measured by optical methods from either below (ground inventory) or from above (Satellite/overhead inventory).

Crown diameter models can be formulated from open-grown trees or from stand-grown trees (González et al., 2007). Equations for predicting the dimensions of crowns in open locations consider maximum biological potential, and so are known as "maximum crown width" (MCW) equations, while those for stand-grown trees which generally have a smaller crown due to competition, are called "largest crown width" (LCW) equations (Hann, 1997). LCW models predict the actual size of tree crowns in forest stands, and have many applications including estimations of crown surface area and volume in order to asses forest health (Zarnoch *et al*., 2004), tree-crown profiles and canopy architecture (Hann, 1999; Marshall *et al*., 2003), forest canopy cover (Gill *et al*., 2000) and the aboveground biomass. Modeling crown diameter as a simple linear model between crown width and diameter at breast height is often adequate (Cañadas, 2000; Paulo *et al*., 2002). Although in some studies Non-linear models have been used, such as power function and monomolecular function (Bragg, 2001; Tomé *et al*., 2001; Avsar, 2004).

The choice of *Triplochiton scleroxylon* (K. Schum) is justified by its unique importance among various indigenous species grown in Nigeria. It has also been ranked among the best five plywood timbers in Nigeria (CIRAD, 2009). According to FAO (2002), *Triplochiton scleroxylon* is a large deciduous forest tree commonly attaining 45m in height and 1.5m in diameter. The boles of mature trees' bark is ashy grey or yellowish brown, usually smooth in young trees but scaly and with fissures in older ones. Slash fibrous, creamy white to pale yellow. Obeche was one of the commonest high forest trees in many of the moist lowlands of West Africa accounting for up to 13% of the trees present (Hall & Bada, 1979). In the 1950's and 1960's Obeche formed 60% of Nigeria's roundwood exports, its good peeling properties being favoured by plywood manufacturers. Obeche is an important timber tree and in the FAO database, 12 countries list it as a priority species (Nigeria inclusive). The wood is economically viable as it is been sort for different purposes such as furniture making, house roofing, etc. (CIRAD, 2009). Therefore, its physiological growth models cannot be overemphasized.

The objective of this study is to examine diameter at breast height and crown diameter prediction models for *Triplochiton scleroxylon* growing in the study areas using linear and non-linear functions. Thus, it would be easier to determine tree crown diameter by means of regression equations using linear and non-linear functions and it would cost less for the ground-based forest inventory studies. The function selected can further be used to evaluate the bole diameter and estimate the stands volume and basal area (BA) for this tree species.

II. Materials And Methods

Study areas

Gambari forest reserve and Forestry Research Institute of Nigeria arboretum were used for the collection of data on growth parameters of *Triplochiton scleroxylon* for this study. Gambari forest reserve is located in the tropical dry semi-decidous lowland forest. The reserve is situated along Ibadan-Ijebu Ode road in Oluyole Local Government Area of Oyo State on latitude 7^0 25' and 7^0 55'N and longitude 3^0 53' and 3^0 9'E. The reserve is located at about 152m above the sea level and of size 12,565ha (Onilude and Adesoye, 2008). There are two distinct wet seasons occurring in the reserve, May to July and September to November. The average annual rainfall is about 1257mm while the relative humidity ranges from 84.5% in June to September and 78.8% in December to January. The mean annual temperature is about 31.3^{o}C maximum and 21.0^{o}C minimum (Somade, 2000).

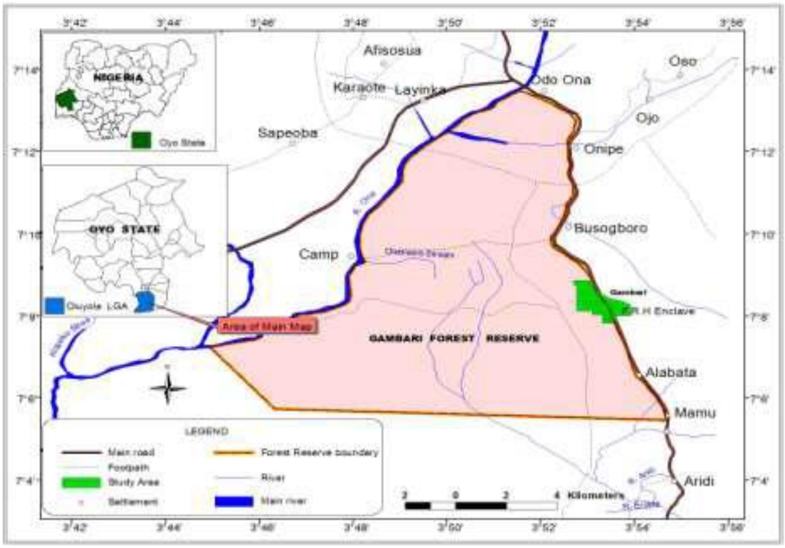

Figure 1: Map of Gambari forest reserve showing the study area

Data Collection

Data used for this study were obtained from a total of 40 sample plots of obtained from four age series (1972, 1973, 1974 and 1975) of *Triplochiton scleroxylon* of size 20m X 20m located within the study sites. At every sample plot, measurement taken and recorded included Diameter at breast height (overbark) of trees ≥ 5cm, diameter at the base, middle and top of all sampled trees, crown diameter and diameter of all sampled trees, total and merchantable heights of all sampled trees with a Spiegel relascope. Two crown diameters were measured per tree, one being the horizontal diameter of the axis of the crown which passes through the centre of the plot and the second being perpendicular to the first. The arithmetic mean crown diameter is calculated from these two field measurements. Table 1 shows the descriptive statistics of the measured tree parameters.

However, to investigate relationship between dbh and crown diameter, arithmetic means of dbh and crown diameter were carried out using R statistical software package program. Arithmetic mean diameter over bark at breast height is the dbh considered as an independent variable and arithmetic mean crown diameter is the crown diameter considered as dependent variable.

Table 1. Descriptive statistics of the measured tree parameters.

Variables		**A. Mean**	**SD**
Diameter at Breast Height	*(34.40 –160.10)*	*75.89*	*23.51*
Crown Diameter	*(9.37 – 96.00)*	*4.42*	*6.27*

SD= Standard Deviation, A. Mean = arithmetic mean, Values in parentheses are the minimum and maximum of the variables

III. Model Development And Evaluation

Paine and Hann (1982) applied curvilinear equations and Ek (1974) used non-linear least squares regression techniques to model the relationships between tree growth variables. The simple linear approach has been the most commonly used in Europe (e.g. Krajicek et al., 1961; Lassig, 1991; Smith et al., 1992). Leech (1984) compared nonlinear with linear models for predicting crown width-Dbh relationships and concluded that the results were not significantly different. For this study, one linear and six non-linear models (Quadratic, Cubic, Growth, Exponential, Power and Compound equations) were used. These equations was selected as candidate functions to model the relationships between crown diameter (Cd) and diameter at breast height (Dbh) as shown in Table 2. Comparison of the model estimates was based on values of three statistics: Standard error of estimate (SEE), which analyses the precision of estimates and also provides information about the dispersion of prediction errors in the regression analysis; Coefficient of variation (CV) and the adjusted coefficient of determination (R^2_{adj}), which reflects the part of the total variance that is explained by the model. In all the statistical analyses, a confidence level P = 0.05 was used for statistical significance.

Table 2: Crown diameter models analyzed

Equation name	Model form	Model code
Linear	$Cd = b_0 + b_1 . dbh$	1
Quadratic	$Cd = b_0 + b_1.dbh + b_2.dbh^2$	2
Cubic	$Cd = b_0 + b_1.dbh + b_2.dbh^2 + b_3.dbh^3$	3
Power	$Cd = b_0.dbh^{b1}$	4
Exponential	$Cd = b_0. e^{(b1.dbh)}$	5

Cd=crown diameter, b_0, b_1, b_2 and b_3 = model parameters, dbh= diameter at breast height

IV. Results And Discussion

The results obtained by fitting the candidate models are shown in Table 3. There was a strong positive, non-linear relationship between crown diameter and dbh (Table 3). All parameters were found to be significant at the 5% level of probability. Some of the models fitted for the data performed well as shown in the results.

Table 3: Model statistics and parameter estimates of the fitted models

Model code	Model Statistics			Parameter estimates			
	R^2	R^2 (adj)	SEE	b_o	b_1	b_2	b_3
1	0.780	0.750	0.340	- 1.254	0.075	-	-
2	0.860	0.790	0.403	- 5.999	0.200	0.0001	-
3	0.900	0.790	0.200	3.354	-0.166	0.004	0.0000165
4	0.32	0.310	0.258	-1.875	1.296	-	-
5	0.301	0.298	0.601	-0.036	0.017	-	-

SEE= Standard Error of Estimates, R^2= Coefficient of determination, R^2_{adj} = Adjusted coefficient of determination, b_0 $b_1$$b_2$ b_3 = model parameters

Since higher R^2 values and lower SEE values indicate a better function, for this study, the Linear, Quadratic and the Cubic models performed better with higher R^2_{adj} values 0.750, 0.790 and 0.790 respectively, which were greater than 0.50, with lower SEE-values 0.200 0.340 and 0.430 respectively (Table 3). Cubic model gave the best performance according to the values of the statistics used to compare the models in the fitting phase with coefficient of variation of Therefore, cubic model was selected as the best function to model the relationship between diameter at breast height (dbh) and crown diameter (cd) for *Triplochiton scleroxylon* in the study sites. The cubic regression function selected is:

CD = = 3.354 - 0.166DBH + 0.004DBH^2 + 0.0000165DBH^3, as shown in table 4.

The adjusted coefficient of determination and the standard error of estimate were R^2 adj = 0.790 and SEE = 0.200 respectively. Also, the result of the regression models between dbh and crown diameter variables showed a statistically significant relationship ($P < 0.05$). This indicates that dbh is a predictor of crown diameter for *Triplochiton scleroxylon*. The cubic model is the best to predict the crown diameter for the fitting data.

Table 4: The regression equations of the fitted models

Model Code	Equation name	Regression Equation
1	Linear	CD = - 1.254 + 0.075DBH
2	Quadratic	CD = - 5.999 + 0.200DBH + 0.0001DBH^2
3	Cubic	CD = 3.354 - 0.166DBH + 0.004DBH^2 + 0.0000165DBH^3
4	Power	CD = -1.875(DBH)$^{1.296}$
5	Exponential	CD = -0.036 $e^{(0.017DBH)}$

Many studies have also been carried out to determine the relationship between tree dbh and crown diameter but for different tree species (Bragg 2001; Bechtold 2003). The results revealed a strong relationship between tree dbh and crown diameter (Bragg 2001; Bechtold 2003; Hemery *et al*. (2005). Also, Ige *et al*, (2013), in his study suggested a cubic relationship for this specie. However, for this study a strong relationship between the tree dbh and crown diameter was also noted. It can be revealed that dbh and crown diameter could be estimated by means of dbh, which is easy to measure for the studies in a ground-based forest inventory and stand structure determination for the studied tree species.

V. Conclusion And Recommendation

The best among the equations is the cubic model as explained by the relationship which can further be used to evaluate and estimate the stand volume and basal area for this tree species in the study areas. The best models were selected based on Coefficient of determination (CV), adjusted R^2, standard error, and F statistic. It should be noted that the models developed by this study were based on data collected from Forestry Research Institute of Nigeria arboretum and Onigambari forest reserve and also covered a limited range of stem and crown diameters. The models should therefore be used with caution outside these study sites. More research is still needed to be done to test applicability of these models across similar Agro-ecological zones and to relate the growth rates/patterns in both stem and crown diameters of these tree species to the fitted models.

In conclusion, deforestation and degradation have been major and crucial challenges in tree species growth monitoring and modeling in Nigeria. FAO (2010) reported on the rate of deforestation in Nigeria, that between 1990 and 2010, Nigeria lost an average of 409,650ha or 2.38% per year. In total, between 1990 and 2010, Nigeria lost 47.5% of its forest cover or around 8,193,000ha. Therefore, sustainable use through conservation and protection of this species will go a long way in making this species available on sustainable scale. Hence, the use of cubic equation for modeling dbh-crown diameter is hereby recommended.

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Onilude, Quadri A.. " Development and Evaluation of Linear and Non-Linear Models for Diameter at Breast Height and Crown Diameter of Triplochiton Scleroxylon (K. Schum) Plantations in Oyo State, Nigeria. "IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS) 12.6 (2019): PP- 47-52.