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Individual tree basal area equation for a young *Tectona Grandis* (Teak) plantation in Choba, Port Harcourt, Rivers State, Nigeria

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ABSTRACT

An individual Tree Basal Area Equation was developed for a Young *Tectona grandis* plantation of the Department of Forestry and Wildlife Management, Faculty of Agriculture, University of Port Harcourt (UNIPORT) Choba, Rivers State, Nigeria, using diameter at breast height (dbh), diameter at the base (d_b), crown diameter (CD), and crown projection area (CPA) as predictor variables. The individual basal area estimates were obtained from data collected from 437 trees in the five-year-old plantation of dimensional area of 2,737.5 m^2. The individual trees were measured for dbh, CD, and d_b using traditional measuring techniques, while the individual Basal Area (BA) and CPA were estimated from the data sets. The data collected were further subjected to descriptive, correlation, and regression analyses with different empirical models, using STATISTICA statistical package. The results of the descriptive analyses produced the mean values of DBH of 7.89±0.0097 cm, BA with the mean value of 0.0052±0.0001 m^2, DB with 32.64±0.397 cm, CD of 3.1004±0.041 m, and CPA with a mean value of 8.1268±0.215 m^2. The results of regression analyses and modelling with empirical non-linear basal area equations fitted with Quadratic models, Exponential models, Linear Fit models, and Polynomial models on STATISTICA, producing the best fits estimates in accordance with residual analyses and fit indices, such as the Mean Prediction Residual (MPR), Standard Error of Estimate (SEE), Residual Coefficient Variation (RCV), and the Prediction Sum of Squares (PRESS). The Quadratic equation (BA = b_o + b_iCPA + DB^2; R^2 –0.8959; SEE - 0.0004) after the evaluation procedures gave the most robust fit indices for the individual basal area, and was thus adjudged the best individual basal area equation for *Tectona grandis* plantations in the study area. This study has shown that the selected model can be effectively used for predicting individual tree basal area of *Tectona grandis* both, within the study area and in any other *Tectona grandis* plantations and, hence, for management and for making timber harvest decisions.

***Keywords*:** individual tree, basal area, equation and management decision

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1. INTRODUCTION

Basal area (BA) is the area in square metres (or square feet) of the cross-section of the trunk of a tree at breast height (1.3 m or 4.5 ft). It is most commonly used as an indicator of stand density and is expressed as square metres per hectare (or square feet per acre). As the individual tree basal area it is related to the tree volume, biomass, and crown parameters. BA is also correlated with competition or the density of a stand (ANU, 1999).

Forest plays important roles in maintaining and providing important ecosystem services and functions. However these important roles are under threat due to the combined effect of deforestation, degradation, and forest fragmentation. Alarms about these threats have been mainly focused on their impact on habitat quality, climate change, and particularly biological diversity. Tree diversity of forested ecosystem has important consequences on carbon storage, decomposition or mineral cycling, nutrient acquisition, communities of biota, and growth and productivity (Nadrowski, 2010).

A plantation is a large piece of land (or water) usually in the tropical or semi-tropical area where one crop is specifically planted for widespread commercial sale or research purpose, and usually tended by resident labourers. Species such as *Tectona grandis* (Teak) plantations is among the most economically import hardwood species in tropical Africa, particularly Nigeria. Forest plantations are the forest stands established by planting in the process of afforestation or reforestation. They are either of introduced species or intensively managed indigenous species that are of even aged class and regular spacing (FAO, 2004). It is a forest stand in which trees are predominantly established by planting, deliberate seeding or coppicing, where the coppicing is of previously planted trees. The direct benefits of forest plantations on the value of the land are forest products, such as sawn timber, fuelwood, charcoal, poles, food products, fodder for livestock, medicinal products, and a shade for agricultural crops (Roland, 2002). According to the International Tropical Timber Organization (ITTO) (2001), these plantations had addressed a few global problems. They have reduced deforestation, restored degraded land, ameliorated climate change, improved local livelihood, returned good profits, created employment and bolstered national economies. Woollens and Hayward (1985) reported that stand basal area growth system remains a key component of the whole stand-level models as the stand area is directly related to other significant, yet economic variables, such as stand volume and quadratic mean diameter. It has also been reported variously that individual tree radial growth models offer a good possibility of exploring articulated management alternatives, as such models relevantly describe the forest growth dynamics (Martins and Ek 1984, Uzoh and Oliver, 2008, Wagles and Sharma, 2012). Thus, the need for the development of individual tree basal area equations of *Tectona grandis* plantation would proffer solutions to management opportunity of any mono culture plantation. Therefore, the objective of this study is to determine the individual tree basal area equation for a Young *Tectona grandis* (Teak) Plantation in the University of Port Harcourt Choba, in Obio Akpo LGA of Rivers State, Nigeria.

2. METHODOLOGY

2. 1. Study Area

This study was carried out in the department of Forestry and Wildlife Arboretum located in Abuja Campus University of Port Harcourt Choba in Obio Akpo Local Government Areas of Rivers State, Nigeria (**Figure 1**).

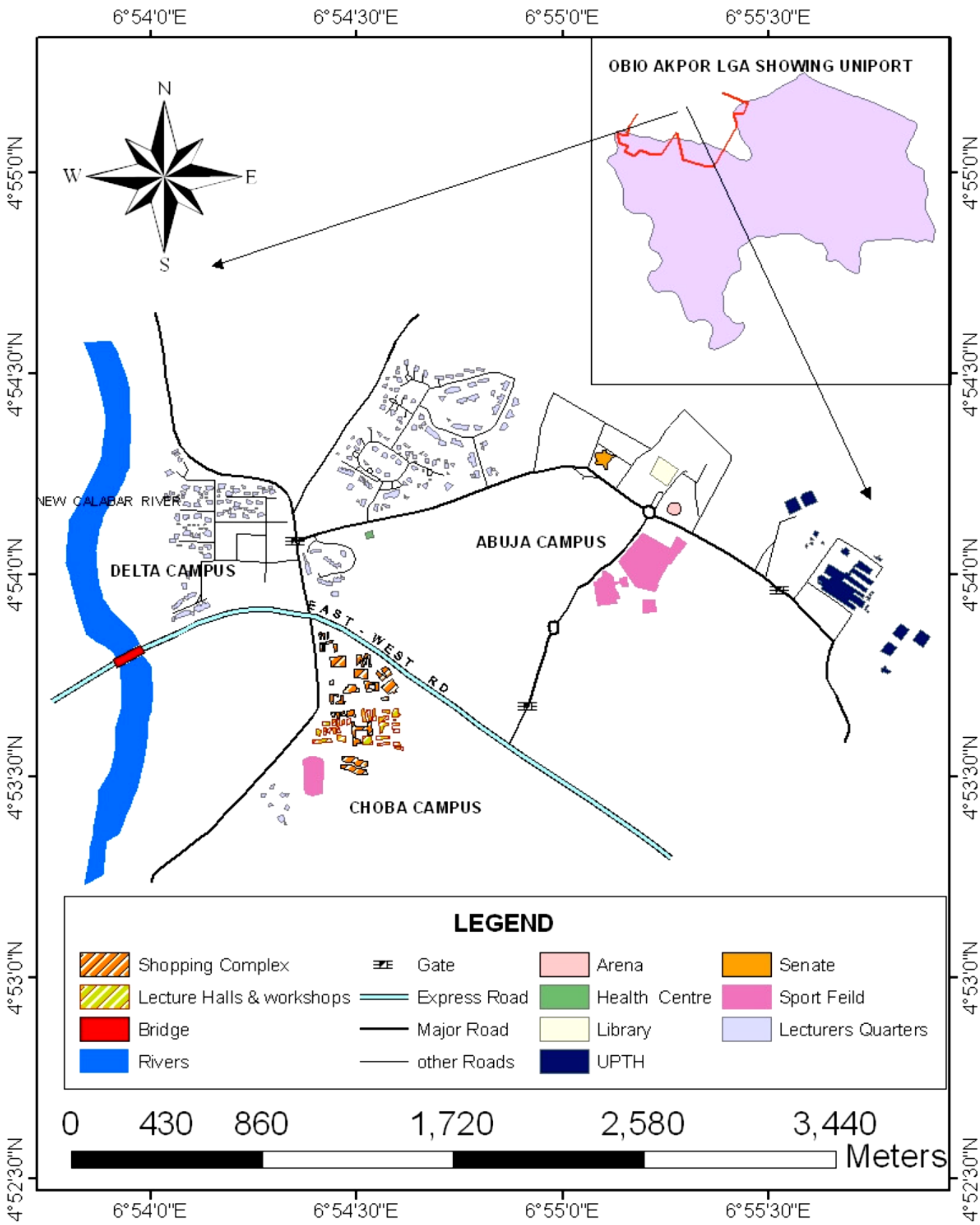

Figure 1. Map of the University of Port Harcourt indicating the study area within Abuja Campus
Source: Google Earth, 2014.

It falls between 04°54’30.4” N and 006°55’1” E. It is located at the North-Eastern area of Abuja Campus, University of Port Harcourt. Port Harcourt is situated within latitude of 4°51’N and longitude 7°01’E of the equator (NDES, 2001).

University of Port Harcourt lies in the humid tropical zone with rainfall that ranges from 2000-2470 mm, with an annual temperature ranging from 23 °C minimum, to 32 °C maximum and a high relative humidity amounting to 70-90% (NDES, 2001).

2. 2. Method of Data Collection

The diameter at breast height (DBH) of all the trees in the sample plots were determined with the use of diameter tape at the measurement (1.3 m, or 4.5 ft) above the ground on the uphill side of the tree. Crown diameters (CD) of all the trees in the plantation were measured using a conventional method.

2. 3. Basal Area Calculation

Basal area of individual trees in the sample plots were calculated using the formula:

$$BA= (\pi D^2)/4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where: BA = basal area (m^2), D = diameter at breast height (cm), and π = pi (3.14259).

2. 4. Crown Projection Area Calculation

Crown diameters were measured using two ranging poles and 30-m linen tape using crown projection technique. This was done through measuring the distance between edges of the crown in a north-south and east-west directions. The two values obtained were averaged and the result was taken as a crown diameter:

$$CD = D_1 + D_2/2$$

where CPA (crown projection area) was computed by the relation:

$$CPA = \pi CD^2/4$$

where: CD = crown diameter, D_1 = 93.1 a diameter 1, D_2 = diameter 2, π = pi (3.14259), and CPA = crown projection area.

2. 5. Statistical Data Analysis

The statistical analysis under this study would include descriptive, correlation, and regression analyses, linear and polynomial regression. The descriptive analysis will involve: tables, graphs, and charts, while regression procedures would follow simple and multiple regression orders as given below:

a) Simple regression model which is expressed as:

$$Y = \beta_0 + \beta_1 X \ldots\ldots\ldots\ldots (2)$$

where: Y is the dependent variable, and β_0 is regression constant, β_1 is the regression slop, and X is the independent variable.

b) Multiple linear regression model which is expressed as:

$$Y = b_0 + b_1X_1 + b_2X_2 \ldots\ldots, b_nX_n \ldots\ldots\ldots\ldots (3)$$

where: Y is the dependent predictor variable, X_1, X_2, ……,X_n are the independent variables, b_0, b_1, b_2……, b_n are the regression parameters.

2. 6. Evaluation of Regression Models

The developed models will be evaluated to know how well their model fit the data. This would be done using the following:

(a) Fit indices or criteria:

$$\text{FI or } R^2 = 1 - \frac{SSE}{SST} \text{ or } \frac{SSR}{SST} \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where: SSR = Regression sum of square, SSE = Error sum of squares, or Residual sum of squares, SST = Total sum of squares

(b) Standard error of estimate is given as

$$SSE = \sqrt{\frac{SSE}{n - p}} \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

(c) The prediction sum of squares statistic (PRESS) is given as

$$PRESS = (Y_i - Y^*_{ip})^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where: Y_i = observed value of Y for observation i

Y^*_{ip} = Predicted value of Y or observation i, as calculated from a regression equation.

(d) The adjusted square multiple correlation coefficient is give as

$$R^2_a = 1 - \left(\frac{SSE}{n - p}\right)\left(\frac{n - 1}{SST}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

3. RESULTS

3. 1. Summary statistics

The dataset from the field inventory were carefully organised and analysed so as to detect and display the underlying patterns. The dataset comprises the tree growth variables measured from individual trees of *Tectona grandis* plantation, established in 2011. A total of 437 trees were measured and summary statistics of the dataset used in this study, represented in **Table 1**. The distribution of diameter at the breast height (DBH) ranged from 2.7400 – 15.4700 cm; diameter at the base (DB) ranged from 12.9000 – 63.0900 cm; crown diameter ranged from 0.6000 – 6.5500 m; and the crown projection area (CPA) ranged from 0.2830 – 44.7750 m^2. Table 1 shows that diameter at the base (DB) has the mean value of 2.6451 cm, crown projection of area (CPA) 8.1268 m^2, and basal area with the mean value of 0.0052 m^2. The standard deviation values of the variables (DBH, DB, CD, CPA and BA) are: 0.0974, 0.3968, 0.0410, 0.2153, and 0.0001, respectively.

Table 1. Descriptive Statistics for Tree Variables of *Tectona grandis* in the Study Area.

Variables	Valid N	Mean	Minimum	Maximum	Standard Dev.
DBH	437	7.89581	2.74000	15.47000	0.097421
BA	437	0.00524	0.00100	0.019000	0.000133
DB	437	32.64513	12.9000	63.09000	0.396797
CD	437	3.10039	0.60000	7.55000	0.041021
CPA	437	8.12681	0.28300	44.77500	0.215324

DBH - diameter at breast height, BA - basal area, DB - diameter at the base, CD - crown diameter, CPA - crown projection area.

3. 2. Correlation matrix of growth variables of *Tectona grandis* in the study area

Table 2 below presents the correlation association between the basal area and the growth variables of the study area.

Table 2 shows that the association between DBH and BA has a high value of 0.9824; and DB and BA have 0.9381. It can be seen that BA is extremely and absolutely correlated with DBH and DB; this shows that basal area increases with the increase in DBH and DB. There is also a solid undesirable association between the basal area (BA) and linear crown index (LCI) which implies that BA decreases with the increase in LCI. The Table also shows that when a variable correlates with itself it gives 1. These remarks are naturally sensible and ideally comprehensive.

Table 2. Correlation Matrix Growth Variables of *Tectona grandis* in the Study Area.

	BA (m)	DBH (cm)	DB (cm)	CD (m)	CPA	LCI
BA (m)	1					

DBH (cm)	0.982425	1				
DB (cm)	0.938132	0.951032	1			
CD (m)	0.659019	0.675786	0.694664	1		
CPA	0.677184	0.674512	0.692133	0.981236	1	
LCI	–0.23821	–0.24894	–0.27444	0.468757	0.425796	1

BA - basal area; DBH - diameter at breast height; CD - crown diameter; CPA - crown projection area; LCI - linear crown index.

3. 3. Models for Predicting Basal Area

Table 3 shows the four (4) functions (Quadratic, Exponential, Linear fit, and Polynomial models) that were used in estimation of individual tree basal area. All the models or functions used for prediction individual basal area fitted to the data with corresponding parameter estimates; fit and prediction statistics are presented in Table 3. The different functions/models were based on CPA, CD, and DB, as predictor variables.

Table 3 also presents the parameters (a, b, c, and d) used in the estimation, the estimates, the standard error (SE), degree of freedom (t/df), the p value or the level of significance, standard error of estimate (SEE), and the coefficient of determination (R^2).

From the results in Table 3 is visible that quadratic and linear fit model gave the highest coefficient of determination (R^2), that is 0.8959 and 0.8685, and the lowest standard error of estimates (SEE) of 0.0004 and 0.0004. Thus the exponential and polynomial models show low R^2 values of 0.4009 and 0.4040, with high SEE values of 0.0020 and 0.0020.

The Table shows that quadratic and linear fit models gave the best basal area equation with the quadratic model being the best. Table 3 also shows that exponential and polynomial models were as well fit but not the best for the basal area estimation in the study area.

Table 3. Individual tree basal area equations, parameters, estimates, standard error (SE), and fit statistics for *Tectona grandis* in the study area.

Function	Parameter	Estimate	SE	t(df = 434)	P-value
Quadratic model					
$Ba = b_o+b_1CPA + b_2DB^2$	b_0	0.00016	0.00099	1.580125	0.1148
$R^2 = 0.8959$; SEE = 0.0004	b_1	0.00002	0.00001	1.874272	0.0616
	b_2	0.00000	0.00000	46.25375	0.0000
Exponential model					
$Ba=b_0+b_1e^{(1-b_2CPA)}$	b_0	–2.72	0.00	–3221.86	0.00

R^2= 0.4009; SEE= 0.0020	b_1	–0.00001	0.00004	–0.38125	0.7032
	b_2	0.00683	–0.0002	3.63258	0.0003
Linear fit model					
$Ba = b_0 + b_1CPA + b_2CD$	b_0	–0.0049	0.0002	–24.1437	0.0000
R^2 = 0.8685; SEE = 0.00044	b_1	0.00003	0.00001	2.017860	0.0442
	b_2	0.00030	0.00001	40.02794	0.0000
Polynomial model					
$Ba= b_0 + b_1CD + b_2CPA^2 + b_3DB^3$	b_0	–0.0186	0.0007	–26.0031	0.0000
R^2 = 0.4040; SEE = 0.0020	b_1	0.00228	0.0002	12.10215	0.0000
	b_2	–0.0000	0.0000	–1.54030	0.1242
	b_3	0.2569	0.0025	103.2148	0.0000

SE - level of significance; SEE - standard error of estimate; t - degree of freedom; R^2 - coefficient of determination.

3. 4. Model evaluation of individual tree basal area of *Tectona grandis* of the study area

Table 4 shows the different functions that were used to evaluate the *Tectona grandis* of the study area. It also shows the mean prediction residual (MPR) of all the functions (quadratic, exponential, linear fit and polynomial models),the standard error of the estimates (SEE) of each of the function, the residual coefficient variation (RCV) of each function and the prediction sum of square (PRESS) of all the functions with quadratic equation showing the fit indices from models' evaluation.

Table 4. Model Evaluation for *Tectona grandis* in the Study Area

FUNCTION	MPR	RSD	RCV	PRESS
Quadratic	-8.52469^{-12}	0.00035	410572114.6	7.26704^{-23}
Exponential	-2.0651^{-06}	0.002020206	–978.2606169	8.14416^{-07}
Linear fit	1.65447^{-11}	0.0004436	26812211.77	2.73727^{-22}
Polynomial	-3.48314^{-11}	0.002009852	–57419454.86	2.31688^{-16}

MPR - mean prediction residual; RSD/SEE - standard error of estimate; RCV - residual coefficient of variation; PRESS - predicted sum of square.

4. DISCUSSION

This study provided information on the tree growth variables and individual basal area on Teak (*T. grandis*) plantation in the study area. The initial stocking at 2.5 m × 2.5 m amounted to 438 trees while the present stocking of the plantation is 437 trees. The study showed that out of 438 Teak (*T. grandis*) in the plantation, 437 survived, showing a very low mortality rate of 0.2% and a high survival rate of 99.8% which is indicative of intensive management. The indication of low mortality in the plantation can be attributed to the fire outbreak that occurred recently. This was in consonant with Monserud and Sterba (1996) which specified the importance of growth modifiers as a function of the stand basal area or other variables signifying stocking density of the stand. Palmer and Synnott (1992) also opined the fact that to achieve sustainability in the forest management, the forest manager should have a suitable knowledge of the forest stock. Correlation analysis was carried out to give an understanding of association among the basal area and other tree growth variables before models development.

The results observed from the correlation matrix (Table 2) indicate that the basal area was highly correlated with diameter at the breast height and diameter at the base. This trend agreed with the work of Avery and Burkhart (2002) while correlating growth variables that peculiarly useful for forest management decision of which, according to him, they are predicted on the information about the present and future resource conditions (Avery and Burkhart, 2002). Among the four models used, quadratic ranked best followed by the linear fit model. The quadratic best fit individual basal area model affirmed the assertion of Gyawali *et al*. (2015) who submitted that individual basal area models to be relevant in many silvi-cultural and management considerations, such as thinning intensities and could judiciously be applied in updating inventories, prediction of future yield, and exploring management alternatives. Other authors also supported its choice and preference to the diameter growth models as they relate to the high correlation between the basal area estimates and the volume growth (Schroder *et al.* 2002, Andreasen and Tomter, 2003, Anta *et al.* 2006).

The critical evaluation with MPR, RSD, RCV, and PRESS helped in determining the best fit models of all the models evaluated; the information on these estimated favourably enhanced the quadratic equation as the best fit model for this study (Table 4). The estimate of the best fit model in quadratic equation was at variance to the studies by Colbert *et al*., (2004) who reported that Chapman-Richards is the best model for basal area estimation, and Smith, *et al*., (1992) who revealed that Chapman-Richards growth rate function was fit to predict the inside-bark basal area growth. The study showed that the crown projection area (CPA), diameter at the base (DB), and crown diameter (CD) were appropriate for the tree basal area estimation especially when the basal area and the crown projection area are estimated with quadratic model; and this is in agreement with the work of Chen *et al*., (2007) who reported that the crown projection area is a better predictor for a basal area.

5. CONCLUSION

Quantifying tree growth characteristics is an important aspect of valuing and managing trees in forest stands. Objective and reliable methods for obtaining these managements are needed. The findings from this study confirmed that there is a strong positive correlation between the basal area as a dependent variable and diameter at the breast height (DBH), diameter at the base (DB), crown projection area (CPA), and the crown diameter (CD) as independent variables. However, using CPA, DB, and CD can give a good estimate of basal area. This study concluded that, basal area can be more accurately and precisely predicted by the crown projection area, diameter at the base, and the crown diameter using quadratic and linear fit model. This model can be used in predicting basal area from the forest inventories for stocking guideline development, growth and yield models that use diameter characteristics.

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