Comparison of Linear and Nonlinear Regression Models for Crown Diameter Prediction in *Gmelina arborea* Roxb. and Tectona *grandis* Linn. f Stands

Popoola, O. D., * Alih, G. A., Jatto, S. O. S., Alfa, J. I. and Eyinade, M. A.
Department of Forestry and Wildlife, Prince Abubakar Audu University, Anyigba, Kogi State
Corresponding Author: danielpopoola@yahoo.com

ABSTRACT

The crown is the centre of physiological activity, crucial for assessing the tree's vigour. Accurately predicting the crown diameter is crucial in forest management, as it influences tree growth and yield. Diameter at breast height (Dbh) has a strong positive correlation with crown diameter (CD) and forest productivity. This study aimed to develop CD models using linear and nonlinear regression methods for the Department of Forestry and Wildlife, specifically for the Teak and Gmelina plantations at PAAU, Anyigba, Kogi State. Seventeen (17) Temporary Sample Plots of 0.625 ha were randomly laid across two strata identified (Tectona grandis and Gmelina arborea) using simple random sampling techniques at 10% sampling intensity. All tree-related variables were measured using standard procedures. The overall best linear crown prediction equation for the two species is a Multiple Linear-Polynomial model, with standard error of estimate (SEE) and root mean square error (RMSE) values of 1.2049 and 1.1962 for Tectona grandis and Gmelina arborea, respectively. The SEE and RMSE values for these models are 0.433 and 0.4303, respectively. The overall best prediction nonlinear crown prediction equation for Tectona grandis is the Power model, with SEE and RMSE values of 1.2467 and 1.2422, respectively. For Gmelina arborea, the Monomolecular model is the best, with SEE and RMSE values of 0.4385 and 0.4360, respectively. It can be concluded that all the developed models are biologically logical and can be applied to predict the current and future crown diameters of the stand for effective sustainable management, silvicultural treatment, and efficient timber production.

Keywords: Crown diameter, *Gmelina arborea,* Regression models, Growth and Yield

INTRODUCTION

Accurate prediction of crown diameter is crucial in forest management, as it influences tree growth, yield and ecological functions such as photosynthesis and carbon sequestration. The tree crown serves as habitat for a variety of animals. According to Buba (2012), the tree crown is the centre of physiological activity, crucial for assessing the tree's vigour, mechanical stability, biological diversity, competitive level, microclimate, fire susceptibility, and behaviour under wind stress, among other features. The size of a tree crown has a marked effect on and is strongly correlated with the tree growth variables (Buochuama and Oyebade, 2018). For a precise forest inventory and effective management techniques, it is crucial to understand the crown architecture in conjunction with other stem growth variables for growth and yield prediction. Traditionally, field measurements of crown diameter can be complex and tedious due to irregular crown shapes, as well as accessibility and visibility issues in dense areas.

Tectona grandis (Teak) and *Gmelina arborea* plantations have been extensively established and managed commercially in Nigeria due to their fast growth rate (Popoola *et al.,* 2025). The species belongs to the Lamiaceae family. Although teak was formerly under Verbanaceae. Several forest biometricians have made numerous attempts to model crown diameter as a function of Diameter at Breast Height (DBH), height, and tree slenderness coefficient (Buochuama and Oyebade, 2018; Ezenwenyi *et al.,* 2018) for decades using regression techniques. Both Linear and nonlinear regression models have been applied to predict crown diameter, but their performance can vary depending on the geographical location, species and growth variable.

Despite the applicability of these models across various regions, the crown diameter model based on easily measurable tree variables, such as Dbh, is lacking for the Department of Forestry and Wildlife Teak and Gmelina Plantation at Prince Abubakar Audu University (PAAU), Anyigba, Kogi State, Nigeria. This necessitates the development of robust regression equations tailored to the unique environmental and silvicultural conditions of our study area. Therefore, our study aimed at (1) developing species-specific linear and nonlinear regression models for predicting crown diameter for *Tectona grandis* and *Gmelina arborea* stands, (2) comparing the performance and reliability of the developed models for sustainable management of the plantation.

MATERIALS AND METHODS

Study Site Area

The Department of Forestry and Wildlife Teak and Gmelina Plantation, PAAU Anyigba is located between Latitudes 7° 27' to 7° 30 'N and Longitudes 7° 10' to 7° 13' E in Dekina Local Government Area of Kogi State, Northcentral Nigeria (Figure 1). The general climate is a humid tropical one, with a mean annual rainfall of 1260 mm and a temperature of 27 °C (Amhakhian *et al.,* 2016). The rainy season lasts from April to October each year, while the dry season last from November to March. The Forest plantation covers an approximate area of about 11 hectares, forming boundaries with the Forestry and Wildlife Departmental Nursery. The relative humidity is moderately high, varying from an average of 65% to 85% throughout the year (Amhakhian and Isaac*,* 2016).

2.2. Data Collection and Analysis

The inventory data used for this study were obtained through stratified random sampling techniques. Proportional sample allocation techniques were used to lay seventeen (17) Temporary Sample Plots (TSP) of 0.625 ha across the two strata identified using simple random sample techniques at 10% sampling intensity. The plantation is a natural regenerated coppice stand, firstly established in 1999. The Diameter at Breast Height (Dbh) was ≥ 10 cm at 1.3 m, and the diameter at the base (D_b, cm) was measured using a diameter tape. Crown diameter (CD, m) measured using distance tape. Diameter at the Middle (cm), Diameter at the Top (cm), Total (THT, m), Merchantable Height (m), and Crown Length (CL, m) using Spiegel relaskop.

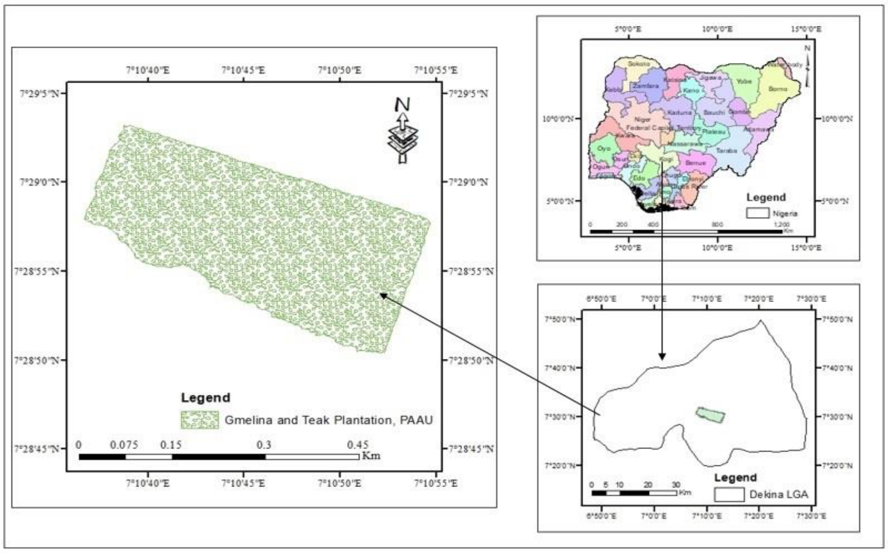

Figure 1: Map of Department of Forestry and Wildlife Teak and Gmelina Plantation, PAAU Source: Field Survey, 2025

The height to base of the live crown was determined by identifying that point along the bole where the lowest live branch or branch whorl is attached to the main bole, as indicated by Jiang *et al.* (2007). Crown diameters were measured by projecting the diameter of the crown with ranging poles on the ground at four different directions and taking the distance between the ranging poles using a distance tape.

Only primarily life-standing trees, free of defects, natural injuries and broken tops due to wind or storm were measured.

2.3. Data Processing and Analysis

The data collected were processed into suitable forms for statistical analysis. Data processing includes basal area estimation, tree slenderness coefficient, volume estimation, Crown ratio, Number of stems per hectare and Crown projection area

2.3.1. Basal Area Computation

The basal area of each tree was computed using:

$$BA = \frac{\pi(Dbh)^2}{4} \quad .... (1)$$

Where: BA = Basal area (m^2) and π= Pi constant (3.142)

2.3.2. Tree Volume Estimation

Individual tree volume was estimated using Newton-Simpson's formula, as extensively used by Akindele (2003), Adesoye and Popoola (2016), and Bueno-Lopez *et al.* (2024):

$$V = \frac{\pi h_m}{24}\left({D_b}^2 + 4{D_m}^2 + {D_t}^2\right) \quad .... (2)$$

Where: V = Merchantable volume (m^3)

2.3.3. Crown Projection Area

For each of the trees in a plot, the crown projection area was estimated using the formula:

$$CPA = \frac{\pi(CD^2)}{4} \quad \text{.... (3)}$$

Where: CPA = Crown projection area (m^2) and CD = Crown diameter (m)

2.3.4. Crown Diameter Prediction Equation

Five (5) different linear and nonlinear models were considered as candidates for modelling the crown diameter prediction equations and are presented in Table 1 below.

2.4. Model Evaluation and Selection

The evaluation of the models was based on numerical and graphical analyses of the residuals. Three statistical criteria were used to examine the models' performance based on relative ranking. These criteria include the Root Mean Square Error (RMSE), which analyzes the precision of the estimates; the Regression Sum of Squares (R^2); and the Standard Error of the Estimates (SEE). They are mathematically expressed as follows:

$$RMSE = \sqrt{\sum_{i=1}^{T}\sum_{j=1}^{T_i}\sum_{k=1}^{T_{ij}}\left(Y_{ijk} - \hat{Y}_{ijk}\right)^2 \Bigg/ \left(\sum_{i=1}^{T}\sum_{j=1}^{T_i} n_{ij} - p\right)} \quad \text{.... (14)}$$

$$R^2 = 1 - \sum_{i=1}^{T}\sum_{j=1}^{T_i}\sum_{k=1}^{T_{ij}}\left(Y_{ijk} - \hat{Y}_{ijk}\right)^2 \Bigg/ \sum_{i=1}^{T}\sum_{j=1}^{T_i}\sum_{k=1}^{T_{ij}}\left(Y_{ijk} - \bar{Y}\right)^2 \quad \text{.... (15)}$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}{n - p}} \quad \text{.... (16)}$$

Where: $\bar{Y}_i$ = Arithmetic mean; Y_{ijk} = Actual observation for the ith observations on sample plot; $\hat{Y}_{ijk}$ = Predicted values for the ith observations; n_i = Numbers of observation; p = Numbers of estimated parameters; and R^2 = Regression sum of Square.

Table 1: Linear and Nonlinear Crown Diameter Models

S/N	Function form	Model Forms	Equation
	Linear Model Forms		
1.	$Cd = b_0 + b_1 Dbh$	Simple Linear	(4)
2.	$Cd = b_0 + b_1 Dbh + b_2 THT$	Multiple Linear-Binomial	(5)
3.	$Cd = b_0 + b_1 Dbh + b_2 Dbh^2$	Square	(6)
4.	$Cd = b_0 + b_1 Dbh + b_2 THT + b_2 TSC$	Multiple Linear-Polynomial	(7)
5.	$Cd = b_0 + b_1 \ln(Dbh)$	Logarithmic	(8)
	Nonlinear Model Forms		
6.	$Cd = b_0 \times Dbh^{b_1}$	Power	(9)
7.	$Cd = b_0 \times (1 - e^{-b_1 Dbh})$	Monomolecular	(10)
8.	$Cd = b_0 b_1^{Dbh}$	Compound	(11)
9.	$Cd = b_0 e^{b_1 + b_1 Dbh}$	Growth	(12)
10.	$Cd = b_0 e^{b_1 Dbh}$	Exponential	(13)

Where: Cd = Crown Diameter; Dbh = Diameter at breast height (m); b_0 and b_1 are regression coefficients; THT = Total tree height; and TSC= Tree Slenderness Coefficient

2.5. Model Validation

One third of the whole data set aside was used for data validation purposes, and this was in accordance with Adesoye and Popoola (2016). The Z-score procedure and the mean bias were used to compare predicted values with observed values. The computation of the Z-score is mathematically represented as:

$$Z - score = \frac{x-\mu}{\sigma} \quad \text{.... (17)}$$

Where: x = Individual observation; μ = Mean observation; σ = Standard deviation of observation

3. Results

The summary descriptive statistics for the *Tectona grandis* and *Gmelina arborea* stands are presented in Table 2. The DBH value ranges from 10.00 cm to 28.20 cm and from 10.00 cm to 24.96 cm, with mean values of 15.55 cm and 12.81 cm for *Tectona grandis* and *Gmelina arborea* stands, respectively. The Crown diameter (CD) also ranges from 2.41 m to 9.35 m with mean and standard deviation values of 4.47 m ±1.42 for *Tectona grandis,* while for *Gmelina arborea,* the CD ranges from 2.50 m to 5.25 m with mean and standard deviation values of 3.59 m ± 0.48 (Table 2). The mean values for MHT, TV, TSC, CPA and BA are 7.78 m, 0.14 m^3, 35.20, 17.27 m^2 and 0.02 m^2 for *Tectona grandis* and 7.93 m, 0.09 m^3, 89.20, 38.82 m^2 and 0.01 m^2 for *Gmelina arborea,* respectively. The descriptive statistics for other measured tree growth variables are also presented in Table 2.

Pearson's product-moment correlation analysis was employed to examine the linear relationships between CD and selected measured tree growth variables, as presented in Table 3. From the results presented in Table 3, it was revealed that a strong positive relationship exists between CD and Dbh for both species under consideration. The implication for this is that as the Dbh increases, the CD also increases in the positive direction. Similar trends were also observed for THT, MHT and TV for both *Tectona grandis* and *Gmelina arborea*. Although no significant relationship exists between CD and CL for both species. However, TSC was seen to have a weak negative relationship with CD (Table 3).

3.1. Linear and Nonlinear Regression Models for Crown Diameter Prediction

The linear species-specific crown diameter prediction models for *Tectona grandis* and *Gmelina arborea* are presented in Table 4, along with their associated parameter estimates and fit indices. The overall best prediction model for *Tectona grandis* is Equation 18, with SEE, RMSE, and R^2 values of 1.2049, 1.1962, and 0.2859, respectively. For *Gmelina arborea,* the overall best prediction model is Equation 23, with SEE, RMSE, and R^2 values of 0.433, 0.4303, and 0.1249, respectively. Equations 18 and 23 are adjudged overall best linear models for *Tectona grandis* and *Gmelina arborea,* respectively, based on their fit index and relative ranking as presented in Table 4. Both species' overall best prediction models incorporate Dbh, TSC and THT in their model forms. Next to these models are multiple linear-binomial model forms that only incorporate Dbh and THT, represented as Equation 19 with RMSE, SEE, and R^2 values of 1.1966, 1.2031, and 0.2855 for *Tectona grandis,* and Equation 24 with RMSE, SEE, and R^2 values of 0.4324, 0.4361, and 0.1164 for *Gmelina arborea,* respectively. The least performed linear model is the simple linear equation, represented as Equations 22 and 27 for *Tectona grandis* and *Gmelina arborea,* respectively (Table 4).

Table 2: Summary Descriptive Statistics for *Tectona grandis* and *Gmelina arborea* Stands

	Tectona grandis (N = 412)				*Gmelina arborea* (N = 262)			
Variables	Mean	Mini.	Max.	Std. Dev.	Mean	Mini.	Max.	Std. Dev.
D_b (cm)	19.13	11.10	35.20	4.91	15.69	11.20	28.80	3.28
Dbh (cm)	15.55	10.00	28.20	3.85	12.81	10.00	24.96	2.73
D_m (cm)	11.11	5.00	22.00	3.017	9.31	6.00	18.00	2.16
D_t (cm)	7.24	3.00	15.00	2.25	6.32	4.00	12.00	1.51
THT (m)	11.69	7.60	18.20	1.97	11.11	8.30	13.50	0.93
MHT (m)	7.78	5.10	13.20	1.43	7.93	5.90	10.50	0.85
CD (m)	4.47	2.41	9.35	1.42	3.59	2.50	5.25	0.48
BA (m^2)	0.02	0.01	0.06	0.01	0.01	0.01	0.05	0.01
MV (m^3)	0.09	0.02	0.35	0.06	0.06	0.02	0.21	0.03
TV (m^3)	0.14	0.02	0.52	0.09	0.09	0.03	0.34	0.05
CPA (m^2)	17.27	4.57	68.66	11.51	38.82	15.29	151.90	21.99
CL (m)	3.12	1.90	4.12	0.76	3.34	2.10	7.50	0.88
Crown Ratio	4.14	2.20	9.30	1.14	30.01	16.15	62.50	6.72
TSC	35.20	21.67	72.73	6.53	89.20	50.08	117.65	13.38

Where: D_b = Diameter at the base (cm); Dbh = Diameter at breast Height (cm); D_m = Diameter at the middle (cm); D_t = Diameter at the top (cm); THT = Total Height (m); MHT = Merchantable Height (m); BA = Basal Area (m^2); MV = Newton's Merchantable Volume (m^3); TV = Newton's Total Volume (m^3); Std. Dev = Standard Deviation; TSC = Tree Slenderness Coefficient; Mini = Minimum Value; Max. = Maximum value.

Table 3: Rectangle Pearson Correlation Matrix for the Growth Variables

Variables	Dbh (cm)	THT (m)	MHT (m)	BA (m^2)	MV (m^3)	TV (m^3)	CPA (m^2)	CL (m)	CR	TSC
***Tectona grandis* (N = 412)**										
CD (m)	0.50*	0.53*	0.51*	0.49*	0.50*	0.50*	0.99*	0.35*	0.04	-0.19*
***Gmelina arborea* (N = 262)**										
CD (m)	0.29*	0.33*	0.30*	0.28*	0.31*	0.29*	1.00*	0.08	-0.03	-0.18*

***Correlation Values marked are significant at $p< 0.05$**

Where: Dbh = Diameter at breast Height (cm); THT = Total Height (m); MHT = Merchantable Height (m) BA = Basal Area (m^2); MV = Newton's Merchantable Volume (m^3); CPA = Crown projection area (m); CL = Crown Length (m); TV = Newton's Total Volume (m^3); TSC = Tree Slenderness Coefficient

Table 4: Model fit Statistics for the Linear Crown Diameter models

Function form	RMSE	SEE	R^2 Value	Rank	Equation
Tectona Grandis					
$Cd = -0.4222 + 0.1311Dbh + 0.1932THT + 0.0075TSC$	1.1962	1.2049	0.2859	1st	(18)
$Cd = 0.1585 + 0.0962Dbh + 0.2396THT$	1.1966	1.2031	0.2855	2nd	(19)
$Cd = -2.9839 + 2.7375\ln(Dbh)$	1.2419	1.2464	0.2303	3rd	(20)
$Cd = 1.4795 + 0.2076Dbh - 0.0010Dbh^2$	1.2430	1.2497	0.2290	4th	(21)
$Cd = 1.7467 + 0.1734Dbh$	1.2431	1.2476	0.2288	5th	(22)
Gmelina arborea					
$Cd = 2.9505 - 0.0515Dbh + 0.2205THT - 0.0134TSC$	0.4303	0.4353	0.1249	1st	(23)
$Cd = 1.8649 + 0.0286Dbh + 0.1180THT$	0.4324	0.4361	0.1164	2nd	(24)
$Cd = 1.5507 + 0.2446Dbh - 0.0066Dbh^2$	0.4339	0.4376	0.1104	3rd	(25)
$Cd = 1.6524 + 0.7478\ln(Dbh)$	0.4378	0.4403	0.0941	4th	(26)
$Cd = 2.8906 + 0.0510Dbh$	0.4402	0.4427	0.0842	5th	(27)

Where: Cd = Crown Diameter; Dbh = Diameter at breast height (m); THT = Total tree height; and TSC= Tree Slenderness Coefficient; ln = Natural Logarithm; R^2 value = Coefficient of Determination

Table 5: Model fit Statistics for the Nonlinear Crown Diameter models examined

Function form	RMSE	SEE	R^2 Value	Rank	Equation
Tectona Grandis					
$Cd = 0.8398 \times Dbh^{0.6098}$	1.2422	1.2467	0.2300	1st	(28)
$Cd = 7.6934 \times (1 - e^{-0.0569Dbh})$	1.2433	1.2478	0.2286	2nd	(29)
$Cd = 2.4755 * 1.0376^{Dbh}$	1.2449	1.2494	0.2266	3rd	(30)
$Cd = 2.4755e^{0.0369Dbh}$	1.2449	1.2494	0.2266	3rd	(31)
$Cd = 1.1090e^{0.8029 + 0.0369Dbh}$	1.2449	1.2517	0.2266	5th	(32)
Gmelina arborea					
$Cd = 3.9180 \times (1 - e^{-0.1921Dbh})$	0.4360	0.4385	0.1017	1st	(33)
$Cd = 2.1127 \times Dbh^{0.2042}$	0.4382	0.4407	0.0925	2nd	(34)
$Cd = 2.9767 * 1.0136^{Dbh}$	0.4409	0.4434	0.0813	3rd	(35)
$Cd = 2.9767e^{0.0136Dbh}$	0.4409	0.4434	0.0813	3rd	(36)
$Cd = 2.5649e^{0.1489 + 0.0136Dbh}$	0.4409	0.4447	0.0813	5th	(37)

Where: Cd = Crown Diameter; Dbh = Diameter at breast height (m); *e* = Exponential function; R^2 value = Coefficient of Determination

For the nonlinear species-specific crown diameter prediction models examined, the Power model, represented as Equation 28, was the overall best prediction equation for the *Tectona grandis* stand, with SEE, RMSE, and R^2 values of 1.2467, 1.2422, and 0.2300, respectively (Table 5). Next to the Power model for *Tectona Grandis* stands the Monomolecular model, represented as Equation 29, with SEE, RMSE, and R^2 values of 1.2478, 1.2433, and 0.2286, respectively.

For *Gmelina arborea,* the nonlinear Monomolecular model form, represented as Equation 33, was adjudged by the fit indices to be the overall best prediction equation, with SEE, RMSE, and R^2 values of 0.4385, 0.4360, and 0.1017, respectively. Next to the Monomolecular model for *Gmelina arborea* stands is the Power model, represented as Equation 34, with SEE, RMSE, and R^2 values of 0.4407, 0.4382, and 0.0925, respectively. For both *Gmelina arborea* and *Tectona grandis*, there is no significant difference between the Compound model and Growth model forms developed for crown diameter prediction, as shown in the relative ranking (Table 5). The least well-performing model form, as revealed by the fit indices, is the Exponential model, represented by Equations 32 and 37 for *Tectona grandis* and *Gmelina arborea,* respectively.

3.2. Model Performance and Validation for Crown Diameter Prediction Model

The performance and validation of the crown diameter prediction were conducted using the Wilcoxon matched-pairs Z-test at a 0.05% probability level for the remaining datasets not used in model development. All the model forms used for predicting crown diameter were found to be suitable for both *Tectonia grandis* and *Gmelina arborea* stands in the study area (Tables 6 and 7). The results, as presented in Table 6 for *Tectonia grandis* stands show no significant difference between the observed and predicted values at $P < 0.05$. The Z-scores are between 0.2655 and 0.6967 for the linear model forms and between 0.6584 and 0.7466 for the nonlinear model forms.

Similar trends were also observed for *Gmelina arborea* stands, which show no significant difference between the observed and predicted values at $P < 0.05$ (Table 7). Although the Z-sore values are between 0.9934 to 1.2708 for linear model forms, 0 and 1.1672 and 1.2993 for nonlinear model forms, respectively (Table 7). The model validations for the overall best linear and nonlinear forms for the species are also presented in Figures 2 and 3.

Table 6: Validation Performance Statistics for *Tectona grandis* Crown Diameter models

Models form	Paired Differences			Z-Value	P-Value	Remarks
	Mean	Std. Dev.	Std. Err. Mean			
Linear Model						
$Cd = b_0 + b_1Dbh$	0.0971	1.2071	0.1043	0.6967	0.4860	Suitable
$Cd = b_0 + b_1Dbh + b_2THT$	0.0609	1.1316	0.0978	0.4199	0.6745	Suitable
$Cd = b_0 + b_1Dbh + b_2Dbh^2$	0.0882	1.2063	0.1042	0.6322	0.5272	Suitable
$Cd = b_0 + b_1Dbh + b_2THT + b_3TSC$	0.0618	1.1335	0.0979	0.2655	0.7906	Suitable
$Cd = b_0 + b_1 ln (Dbh)$	0.0893	1.2064	0.1042	0.6400	0.5222	Suitable
Nonlinear Model						
$Cd = b_0 \times Dbh^{b_1}$	0.0940	1.2061	0.1042	0.6747	0.4999	Suitable
$Cd = b_0 \times (1 - e^{-b_1Dbh})$	0.0919	1.2062	0.1042	0.6584	0.5103	Suitable
$Cd = b_0 \times {b_1}^{Dbh}$	0.1027	1.2116	0.1047	0.7386	0.4602	Suitable
$Cd = b_0e^{b_1 + b_2Dbh})$	0.1038	1.2117	0.1047	0.7466	0.4553	Suitable
$Cd = b_0e^{b_1Dbh}$	0.1034	1.2117	0.1047	0.7439	0.4569	Suitable

Valid Number =134 **Aplpha = 0.05**

Where: Std. Err. Mean = Standard Error Mean; Std. Dev. = Standards Deviation

Table 7: Validation Performance Statistics for *Gmelina arborea* Crown Diameter models

Models form	Paired Differences			Z-Value	P-Value	Remarks
	Mean	Std. Dev.	Std. Err. Mean			
Linear Model						
$Cd = b_0 + b_1Dbh$	0.0615	0.4454	0.0480	1.2270	0.2198	Suitable
$Cd = b_0 + b_1Dbh + b_2THT$	0.0658	0.4336	0.0468	1.2708	0.2038	Suitable
$Cd = b_0 + b_1Dbh + b_2Dbh^2$	0.0501	0.4461	0.0481	0.9934	0.3205	Suitable
$Cd = b_0 + b_1Dbh + b_2THT + b_3TSC$	0.0593	0.4362	0.0470	1.1456	0.2520	Suitable
$Cd = b_0 + b_1 ln (Dbh)$	0.0593	0.4459	0.0481	1.1796	0.2381	Suitable
Nonlinear Model						
$Cd = b_0 \times Dbh^{b_1}$	0.0596	0.4456	0.0480	1.1869	0.2353	Suitable
$Cd = b_0 \times (1 - e^{-b_1Dbh})$	0.0586	0.4454	0.0480	1.1672	0.2431	Suitable
$Cd = b_0 \times {b_1}^{Dbh}$	0.0649	0.4446	0.0479	1.2993	0.1939	Suitable
$Cd = b_0e^{b_1 + b_2Dbh})$	0.0606	0.4448	0.0480	1.2109	0.2259	Suitable
$Cd = b_0e^{b_1Dbh}$	0.0606	0.4448	0.0480	1.2112	0.2258	Suitable

Valid Number =86 **Aplpha = 0.05**

Where: Std. Err. Mean = Standard Error Mean; Std. Dev. = Standards Deviation

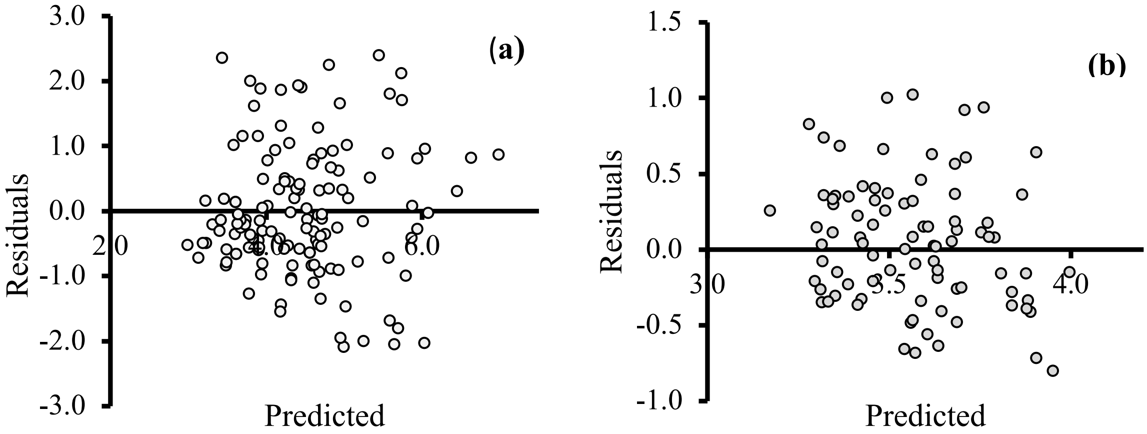

Figure 2: Predicted verses Residual Graph using $Cd = b_0 + b_1 Dbh + b_2 THT + b_3 TSC$ Model **(a)** for *Tectona grandis* **(b)** for *Gmelina arborea*

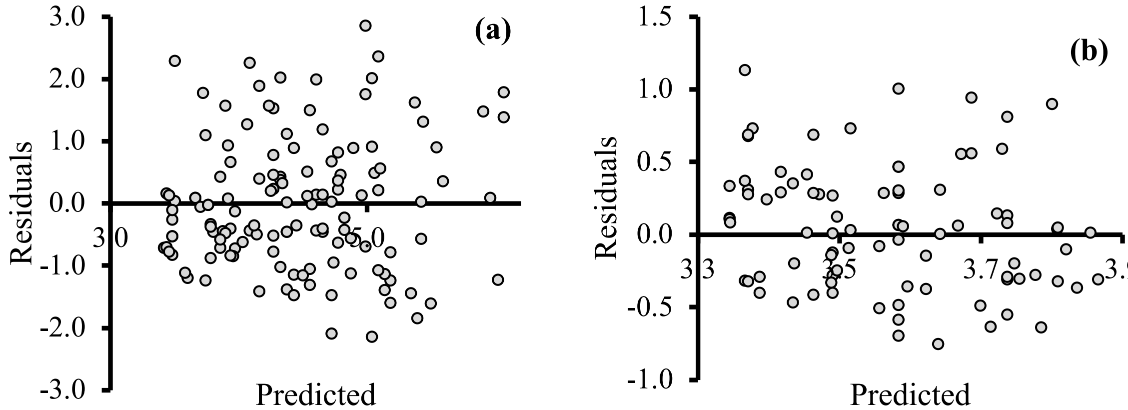

Figure 3: Predicted Versus Residual Crown Diameter **(a)** $Cd = b_0 \times Dbh^{b_1}$ for *Tectona grandis* **(b)** using $Cd = b_0 \times (1 - e^{-b_1 Dbh})$ *Gmelina arborea*

Discussion

A better understanding of crown spread over time is crucial for describing forest productivity, tree competition, and making sound forest management decisions. According to Adesoye and Popoola (2016), accurately accounting for stem volume is crucial for making informed decisions in studies of growth and carbon sequestration potential, as well as for efficient management of the forest estate. All the techniques employed to measure the volume and growth of the wood within our study area provide valuable insights into the site's potential. The results from our studies, which involved a species-specific allometric equation, were consistently accurate and biologically reasonable. Although the statistical techniques to provide an accurate crown diameter prediction equation differ widely in the literature.

Our results reveal that Crown Diameter (CD) has a significant relationship with Diameter at Breast Height (Dbh), total tree height, and tree slenderness coefficient (TSC) when considered as an independent variable in a linear model approach. Therefore, these linear model forms were selected as the overall best prediction model, contradicting those reported by Adesoye and Ezenwenyi (2014 for *Tectonia grandis* stands. The coefficients associated with crown diameter and Dbh were all positive, indicating that larger crowns tend to be larger in all dimensions. This finding aligns with those of Olugbadieye *et al.* (2019) and Ezenwenyi *et al.* (2018).

Comparing the results of our fitted parameters estimates for all the models developed for *Tectona grandis* and *Gmelina arborea* stands, we observed variation and divergence in the crown diameter and Dbh, which can be attributed to the management history of the studied area, stand density and characteristics, as well as various illegal logging activities within the study area. The nonlinear CD models developed for our study area were based solely on Dbh, as supported by Olugbadieye *et al.* (2019) and Buba (2012). Our findings for the nonlinear model suggest that both the Monomolecular model and Power models can be used interchangeable to obtain an accurate crown diameter prediction model for the two species under investigation. This was contrary to Buochuama and Oyebade (2018 who selected the exponential function as their overall best prediction model.

The results from the validation models for the predicted and observed values reveal the suitability of all the developed models, showing no significant difference at a probability level of 0.05. The graphical residual plots for the predicted and observed crown diameter prediction equations are unbiased, as shown by having a random pattern and constant error variance. All the results presented are encouraging and can be applied to a wide range of stand conditions.

Conclusion

This study developed a species-specific model to enhance understanding of the relationship between diameter at breast height (Dbh) and crown diameter. All the models were efficient and biologically logical and can be applied to predict the current and future crown diameter of the stand. Thus, we were able to contribute significantly to the crown diameter prediction model for our study area, as evidence that such an equation has not been developed until now. The results from our study have high practical application value and can serve as a basis for sustainable management decisions, silvicultural treatments, and effective timber production.

References

Adesoye P.O. and Ezenwenyi J.U. (2014). Crown Diameter Prediction Models for *Tectona Grandis* Linn. F in Omo Forest Reserve, Nigeria. *Journal of Forestry Research and Management*. 11: 72-87

Adesoye, P.O. and Popoola, O.D. (2016). Determinants of Stem Form: Application to *Tectona grandis* (Linn. F) Stands. *Journal of Sustainable Forestry* 35(5): 338 - 354

Akindele, S.O. (2003). Volume Prediction from Stump Diameters of *Gmelina arborea* Roxb trees in Akure forest reserve, Nigeria. *Nigerian Journal of Forestry,* 33 (2): 116-123.

Amhakhian, S.O., Aina, O.A., and Anokehi, D.O. (2016). Impact of Land use system on some physical and chemical properties: A case study of Kogi State University, Anyigba. *International Journal of Agriculture and Bioseciences*, 5(5): 316-321

Amhakhian, S. O., and Isaac, I. B. (2016). Effects of Organic Manure on the Growth Parameters and Yield of Okra in Anyigba, Kogi State, North Central Nigeria. *Journal of Agricultural Science and Engineering* 2.4: 24 -30

Buba T. (2012). Prediction equations for estimating tree height, crown diameter, crown height and crown ratio of *Parkia biglobosa* in the Nigerian Guinea Savanna. *African Journal of Agricultural Research*, 7(49): 6541-6543

Bueno-López, S.W., Caraballo-Rojas, L.R., Torres-Herrera, J.G. (2024). Evaluation of Different Modeling Approaches for Estimating Total Bole Volume of Hispaniolan Pine (*Pinus occidentalis* Swartz) in Different Ecological Zones. *Forests*, 15.6: 1052.

Buochuama, A. and Oyebade, B.A. (2018). Prognostic Crown Diameter equations for a Mixed Species Plantation in Southern Nigeria. *World News of Natural Sciences*, 16: 117 -129

Ezenwenyi, J.U., Chukwu, O. and Ezeano, C.I. 2018. Modelling crown diameter and canopy cover estimation for *Tectona grandis* planation in university of Ibadan, Nigeria. Emerging issues in sustainable forest management experiences and lesson for Nigeria, 40th annual conference of forestry Association of Nigeria. Pp 250-251

Jiang L, J.R. Brooks and G.R. Hobbs (2007): Using Crown Ratio in Yellow-poplar Compatible Taper and Volume Equations. *Northern Journal of Applied Forestry* 24 (4): 271 275p.

Olugbadieye, O.G., Adesuyi, F.E., Daramola, J.O., and Bola,T.S. (2019). Crown Width Models for *Gmelina arborea* Roxb. Stands at Obanla, Federal University of Technology, Akure, Nigeria. *International Journal of Forestry and Wood Science*, 6(2):62-66

Popoola, O.D., Ige, P. O. and Chukwu A. U. (2025). Non-Linear Mixed-Effects Bole-Volume and Weibull Diameter Distribution Models for *Tectona grandis* (Linn. F) Plantation in Omo Forest Reserve, Nigeria. In Akinyele, A. O; Omitoyin, S. A; Ige, P. O; Coker, O. M; Fasoro, O. A and Ajiboye, A. O (Eds), Renewable Natural Resources Management and Use: A path to sustainable development: Proceedings of the 1st Faculty of Renewable Natural Resources, University of Ibadan Conference, 16-20 June, 2025, 233-243p