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TREE HEIGHT-DIAMETER AND YIELD FUNCTIONS FOR *Gmelina arborea* (ROXB.) STAND IN EDONDON *GMELINA* PLANTATION, CROSS RIVER STATE, NIGERIA

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ABSTRACT

This study involved developments of models for predicting tree heights and stem volumes for Gmelina arborea stand at Edondon plantation in Obubra Local Government Area (LGA) of Cross Rivers State in southern Nigeria. Simple random sampling technique was adopted for plot location. Forty (40) 25 m × 25 m (0.16ha) temporary plots were used. The tree growth variables measured on all trees with diameter at breast height (Dbh) ≥10 cm included Dbh; diameters at the base, middle and top as well the tree total height. Data were analyzed using descriptive statistics and regression analysis. Linear, logarithmic, polynomial, power and exponential height-diameter and stem volume models were fitted to the dataset. The predictor was tree Dbh (cm). The developed models were assessed using coefficient of determination (R^2) and root mean square error (RMSE). The significance of each of the models was evaluated using one-way analysis of variance. Model validations were done using t-test and mean bias. The results for the individual tree growth variables revealed that the mean Dbh, height, stem volume and basal area were 36.31±14.36 cm, 20.99±6.46 m, 0.12±0.09 m^2 and 0.96±0.61 m^3, respectively. On stand basis, the mean basal area and stem volume were 1.99 m^2/ha and 15.41m^3/ha, respectively. All the height-diameter models presented in this study had very high R^2 low RMSE values. Moreover, the selected models were significant ($P <0.05$). Among the models, logarithmic model was the best with R^2; RMSE values of 0.91; 0.1293, and the least -suitable model was the exponential with R^2; RMSE values of 0.75; 2.2683. All the yield models tried in this study consistently gave poor results with very low R^2 values. The best among the stem volume models was power model with R^2; RMSE values of 0.40; 0.3787, and the least-suitable was the polynomial with R^2; RMSE values of 0.19; 0.8399. The result of model validation for the height-diameter functions revealed that there were no significant differences in mean observed and the predicted height values under liner, logarithmic, polynomial and power functions ($P>0.05$). However, mean observed and predicted tree height values significantly differed under exponential function ($P< 0.05$). Results of model validations for yield models showed that there were no significant difference between the observed and the predicted stem volumes under the linear and the logarithmic models ($P>0.0$). Nevertheless, mean observed and the predicted stem volumes significantly differed under the polynomial, power and exponential functions ($P<0.05$). The result revealed that the mean basal area per hectare in the stand were below the recommended values for a well-stocked forest or planted stand in Nigeria.

Keywords: Tree height, stem volume, stand density, prediction models

INTRODUCTION

Gmelina arborea belongs to the family *Verbenaceae*, and it is a fast growing tree species that is frequently planted to produce wood for light construction, crafts, decorative veneers, pulp production and fuel (Oyamakin *et al*., 2013). The species is also utilized in agro-forestry systems (taungya systems).

According to Jensen (1995), *Gmelina arborea* grows best in climates with mean annual temperature of 21-28°C, and it is a medium-sized deciduous tree that grows up to 40 m tall and 140 cm in diameter, but can usually be smaller than this. The tree form is fair to good, with a trunk up to 6-9 m, usually branchless, often crooked and has a large, low-branched crown (Oyamakin *et al*., 2013). Sustainable forest and forest resources management requires reliable estimates of growing stock. This is because such information guides forest managers in timber evaluation as well as in the allocation of forest areas for harvest (Adeyemi and Adesoye, 2010; Adesoye, 2014). For timber production as well as other purposes, an estimate of growing stock is often expressed in terms of timber volume, which can be estimated from easily measurable tree dimensions such as stem diameter at breast height and tree height.

Generally, measuring breast height diameter is simpler, more accurate, less time-consuming and cheaper than measuring tree height. Consequently, in forest inventories, diameter is measured for all the sampled trees, but height is measured only for a subsample of trees. From these measurements, statistical models are fitted to define the relation between these two variables (Young *et al.,* 2009). The most common procedure is to use an established height-diameter model to predict tree heights from field measurements of tree diameters (Peng, 2001; Rafael and Gregorio, 2004; Peng *et al.,* 2004; Mackie and Mathews, 2006; Turan, 2009; Matthias *et al*., 2010). Based on relationships between stem volume and tree growth variables (height and diameter), such can be utilized for tree volume estimations. The reliability of volume estimates depends on the range and extent of the available sample data, as most of these already existing models are applicable only to the localized area for which it was developed.

Considering the fact that tree stem diameter (i.e. diameter at breast height) can be more accurately measured, and at lower cost than total tree height, foresters often choose to measure only a few trees' heights and estimate the remaining heights with height-diameter allometries (e.g. Turan, 2009; Nuray, 2010; Adeyemi, 2012). Foresters can also use these height-diameter equations to indirectly estimate height growth by applying the equations to a sequence of diameters that were either measured directly in a continuous inventory or predicted indirectly by a diameter-growth equation (Mark *et al.*, 1999). Therefore, the development and use of height-diameter models proves indispensable in the efficient and effective forest design and monitoring by effectively reducing the cost of data acquisition (Adesoye, 2014).

In Nigeria, considerable work has been done on the development of volume equations using models based on the height-diameter relationship of trees for planted forests as reported by many authors (e.g. Osho, 1983; Onyekwelu and Akindele, 1995; Adekunle, 2007; Adeyemi and Adesoye, 2010; Adeyemi, 2011; 2012), but many of these models are usually species and location-specific; therefore, there is need to develop height-diameter and stem volume models for this tree species in the study area.

Yield models are invaluable for providing useful information for effective planning and management of forest resources. According to Calama and Montero (2004), the height-diameter relationship of tree species varies from stand to stand and even within the same stand and is usually not constant over time. Therefore, there is need to develop location and stand specific height-diameter models for *G. arborea* because of its many useful characteristics and uses to which it is put as reported by Levi and Apolinaria (2002).

There are also other factors determining this relationship that are attributes of the specific stand or location (Cimini and Salvati, 2011).

The most obvious among these factors are growing space and stand conditions (Sharma and Zhang, 2004). Accuracy of height-diameter models are highly needed for estimating individual tree volume and site index as well as for describing stand growth dynamics. The estimation of stand development over time relies on accuracy of height-diameter functions (Nuray, 2010). Hence, there is a need to develop, test and validate tree height-diameter models that can be used to predict the "missing" heights from field measurement of tree diameters of *Gmelina arborea* in the study area.

Furthermore, in the past, a lot of activities have been engaged in by the surrounding communities, which may have impacted the structure and composition of stems in the stand. However, these have not been documented, and therefore require attention in order to formulate appropriate management strategies. Similarly, information on stand density is keyed to ensuring perpetual availability of the timber resources. Nevertheless, this is not yet known for the stand. And with the quest for a sustainable forest management, the information on the status of this plantation demands attention for strategic planning.

The objective of this study was to develop height-diameter and stem volume prediction equations for the stand as well as evaluating the stand density per hectare in the area, while ascertaining the most suitable model(s) for *Gmelina arborea* height and volume estimations in the stand.

MATERIALS AND METHODS

The study was carried out at Edondon *Gmelina* plantation. The plantation is a part of major *Gmelina* plantations established in Cross River State (Edondon, Awi and Obom-Itiat). It is situated in Obubra Local Government Area of Cross River State, and surrounded by human settlements such as Okokori-Oferekpe, Edondon (where it is situated), Isabang, Ochon, Ohana, Iyamoyong and Okomerotiet communities. The plantation is located between latitudes 5^o34'N and 5^o56'N, and longitudes 8^o10'E and 8^o32'E with the boundaries of Obubra, Ikom and Akamkpa LGAs of Cross River State, Nigeria. It is bounded in the east by Ukpon River and in the north-west by Calabar-Ikom road (Figure 1). The plantation was established in 1976 (about 39 years ago) and it covers an area of 622 hectares.

The annual rainfall ranges between 350 mm in January to a maximum of 487.7 mm in August. The rain is fairly distributed throughout the months of April to October. The annual temperature ranges from 27.6^{o}C in August to 36.2^{o}C in February. The relative humidity ranges from 62% in February to 92% in August. The plantation lies within the lowland rainforest with fresh water swamp at the fringes. The main rock types are granites, gneisses and quartz schist with gravels and occasional rock outcrops in some areas (Wright *et al.*, 1985). The soil is brownish sandy-loam, overlaid with clay and iron stone gravels. Edondon soils are classified as combisol of acid crystalline rock. They are acid soils, which vary in texture from sandy-loam to gravelly sandy-clay. The soils are well-drained (Ogar, 1994).

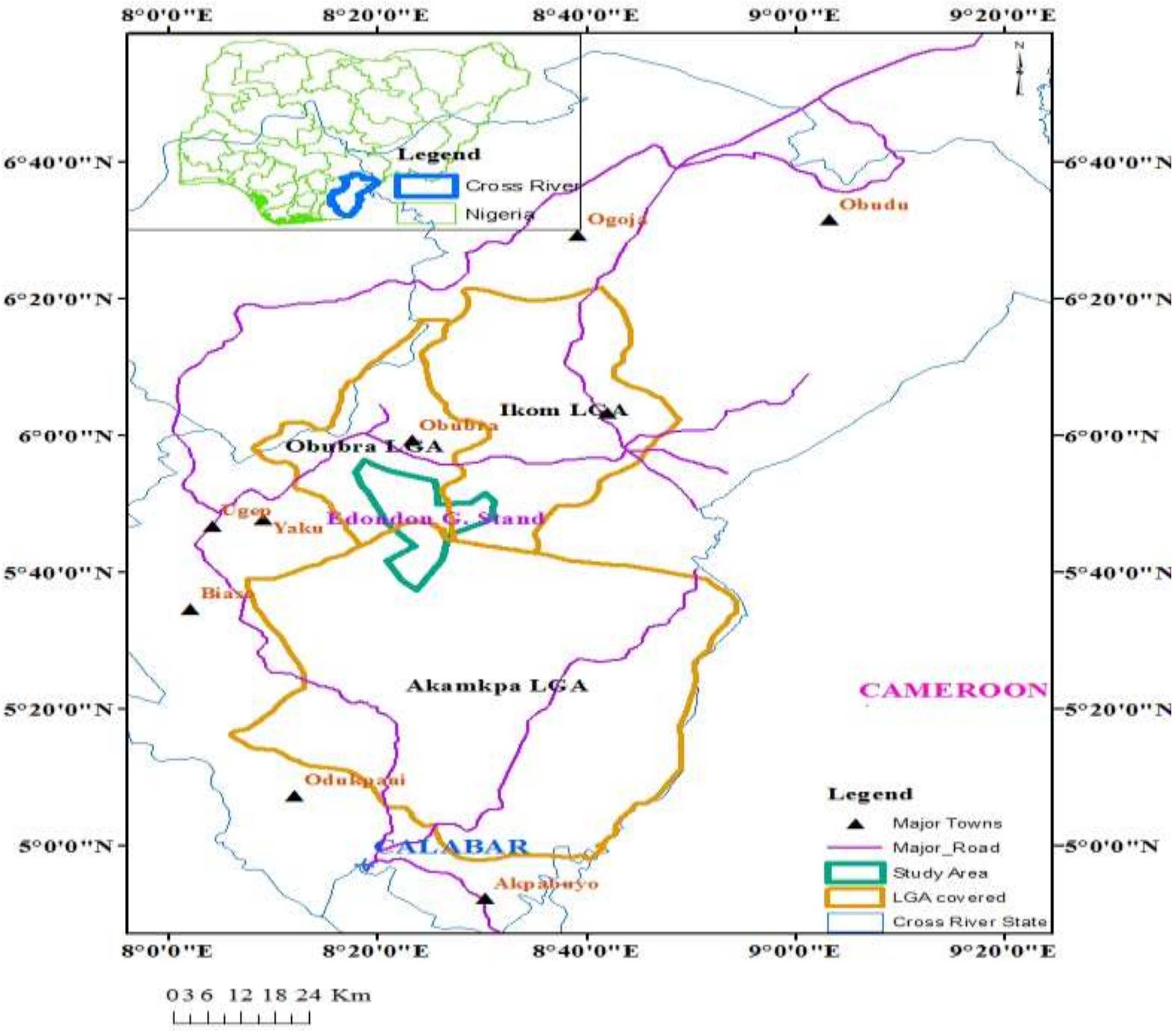

Figure 1: Map of the study area

Data Collection

A simple random sampling technique was adopted for plot locations. Forty (40) 25 m × 25 m (0.16 ha) were randomly selected for the study using a table of random numbers. These were then located on the field for tree parameter measurements. Data on tree growth parameters, namely: Dbh; diameter at the base, middle and tree top; tree total height were measured on the trees with Dbh ≥10 cm within the 40 sample plots. The measurements were carried out using diameter tape and Spiegel Relaskop.

Data Analysis

Basal Area Computation

Individual tree basal areas within each of the sample plots were computed using

$$BA = \frac{\pi \, Dbh^2}{4} \ldots.$$

Where: BA = basal area (m^2); π = constant (3.1429).

Basal area for each plot was obtained by adding the individual tree basal areas in each plot as follows:

$$BA_p = \sum_{i=1}^{n} BA_i \ldots$$

Where: BA_p = basal area (m^2) per plot; BA_i = basal area for *ith* tree in the plot.

Basal area per hectare for each plot was then obtained by multiplying the plot basal area by 16 (16 being the number of 0.16 ha-plots in a hectare).

Stem Volume Computation

The individual stem volumes were computed using Newton's formula as:

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

Where: h = tree total height; D_b = tree diameter at the base; D_m = tree diameter at the middle; D_t = tree diameter at the top.

The plot volume was obtained by adding the individual tree volumes in each plot. The stem volume/ha were then obtained by multiplying plot volumes by 16.

Development of Tree Height-diameter Models

These involved the development of regression equations at individual tree level. The following height-diameter models were tried, namely: linear, logarithmic, polynomial, power and exponential, as presented in equations 4, 5, 6, 7 and 8, respectively.

$$H = b_o + b_1 Dbh \ldots\ldots\ldots\ldots\ldots\ldots$$

$$H = b_o + b_1 \ln Dbh \ldots\ldots\ldots\ldots\ldots$$

$$H = b_o + b_1 Dbh + b_2 Dbh^2 \ldots\ldots\ldots$$

$$H = b_o Dbh^{b_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$H = b_o e^{b_1 Dbh} \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Development of Stem Volume Models

The following stem volume (yield) functions were adopted, viz: linear, logarithmic, polynomial, power and exponential models, as presented in equations 9, 10, 11, 12 and 13, respectively.

$$V = b_o + b_1 Dbh \ldots\ldots\ldots\ldots\ldots\ldots$$

$$V = b_o + b_1 \ln Dbh \ldots\ldots\ldots\ldots\ldots$$

$$V = b_o + b_1 Dbh + b_2 Dbh^2 \ldots\ldots$$

$$V = b_o Dbh^{b_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$V = b_o e^{b_1 Dbh} \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

where: H = tree total height (m); Dbh = diameter at breast height (cm); V = stem volume (m^3);
ln = natural logarithm ($\log_e$); b_0, b_1 and b_2 = regression parameters.

Model Evaluation

This involved examination of the structure and properties of the models. It implicitly means comparing and evaluating candidate models. The models developed in this study were verified using the following statistics:

Coefficient of Determination (R^2)

This measured the proportion of variation in the dependent variable that is being accounted for, or explained by the independent variable(s). It was computed as:

$$R^2 = 1 - \left(\frac{RSS}{TSS}\right) \ldots\ldots$$

The R^2 values range between 0 and 1, and can be expressed in percentage by multiplying the value by 100.

Root Mean Square Error (RMSE)

This was computed using:

$$RMSE = \sqrt{\frac{RSS}{n-p}} \text{ ....}$$

Where: p = number of parameters in the model, or total number of variables been considered; n = total number of observations; RSS = regression sum of squares; TSS = total sum of squares. The most suitable models are those with large values of R^2 and small values of *RMSE*.

Significance of Regression (F-ratio)

This was used to test the overall significance of the regression equations (models). The critical value of F (F-tabulated) at 'α' equals 0.05 was compared with the variance ratio (F-calculated). Where the F-calculated is greater than the critical values (F-tabulated), such equation (model) is therefore significant, and was accepted for prediction.

Model Validation

In this study, model validation was done by dividing the data into two sets. One set for calibrating the developed models and the other set was used for the validation of the models. The calibrating set was used for model construction while the validating set was used to test the constructed models as suggested by Reynold *et al*. (1988), and adopted by Adesoye (2002), Akindele (2005) and Adeyemi (2012).The models were validated by: (i) testing for the significant differences in the mean predicted and observed values of the dependent variables in each of the scenarios, using student t-statistics given as:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S^2 \frac{(N_1 + N_2)}{(N_1)(N_2)}}} \text{.....}$$

Where;

$\bar{X}_1$ = the mean observed value for a particular response variable in the models;

$\bar{X}_2$ = the mean predicted value for that variable; N_1 = the total number of the observed values; N_2 = the total number of the predicted values; S^2 is the pooled within-group variance (for independent samples with equal variance). The t has $(N_1$-1) + $(N_2$-1) degrees of freedom.

(ii) evaluating the fitting method consistency using mean bias values, with the following expressions:

$$Bias = \frac{\sum_{i=1}^{N} Y_i - \hat{Y}_i}{N} \text{.....}$$

Where; Y_i = observed value;

$\hat{Y}_i$ = predicted value,

N = number of data points or observations.

RESULTS

Table 1 presents the descriptive statistics for the individual tree growth variables for pooled data. Tree Dbh ranged between 10.00 cm and 86.00 cm with a mean value of 36.31±14.36 cm. The tree total heights (H) ranged between 5.20 m and 41.40 m with a mean value of 20.99±6.46 m. The individual tree stem volumes were between 0.10 m^3 and 8.67 m^3 with a mean value of 0.96±0.61 m^3, while the basal areas ranged between 0.01 m^2 and 0.58 m^2 with a mean of 0.12±0.09 m^2.

Table 1: Descriptive statistics for individual tree growth variables for pooled data

Variable	Minimum	Maximum	Mean ± SD	SE
Dbh (cm)	10.00	86.00	36.31 ± 14.36	0.365
H (m)	5.20	41.80	20.99 ± 6.46	0.164
BA (m^2)	0.01	0.58	0.12 ± 0.09	0.00235
SV (m^3)	0.10	8.67	0.96 ± 0.61	0.0156

N.B.: Dbh = tree diameter at breast height; H =tree total height; SV = stem volume; BA = basal area

The summary statistics for *G. arborea* growth variables on plot and stand bases are presented in Table 2. The mean plot Dbh, height, stem volume and basal area for *G. arborea* in the study area were 36.23 cm, 21.19 m, 0.12 m^2 and 0.96 m^3, respectively. On stand basis, the mean basal area (BA)/ha and stem volume (SV)/ha were 1.99 m^3 and 15.41, respectively.

Table 2: *Gmelina arborea* growth variables on plot and stand bases in the study area

Plot	Mean Dbh (cm)	Mean H (m)	Mean BA (m^2)	Mean SV (m^3)	N/ha	BA/ha (m^2)	SV/ha (m^3)
1	29.56	19.53	0.07	1.16	720	1.20	18.50
2	29.26	19.12	0.07	1.20	748	1.19	19.23
3	30.22	19.42	0.08	1.06	720	1.26	16.95
4	30.25	19.65	0.08	0.73	640	1.28	11.66
5	29.04	17.46	0.07	1.07	736	1.18	17.12
6	31.12	20.31	0.08	0.87	656	1.34	13.86
7	29.75	19.15	0.08	0.67	704	1.25	10.79
8	30.23	19.19	0.08	1.05	672	1.30	16.83
9	31.88	20.49	0.09	0.87	672	1.43	13.84
10	31.55	19.06	0.09	1.03	720	1.40	16.51
11	32.89	20.8	0.10	1.005	624	1.52	16.08
12	33.17	20.16	0.09	0.87	672	1.52	13.95
13	3.34	21.47	0.09	0.74	656	1.47	11.81
14	33.15	20.85	0.09	0.91	624	1.50	14.55
15	32.8	19.49	0.09	0.71	656	1.47	11.28
16	36.07	21.14	0.12	0.85	624	1.86	13.66
17	37.0	22.15	0.13	0.76	640	2.01	12.15
18	36.74	21.1	0.12	0.86	560	1.91	13.82
19	36.21	21.01	0.11	0.86	608	1.83	13.69
20	37.32	20.6	0.12	1.07	544	1.96	17.13
21	34.45	19.17	0.11	1.12	592	1.69	17.96
22	39.93	22.01	0.14	1.09	512	2.28	17.50
23	45.38	23.71	0.18	1.15	496	2.85	18.34
24	41.67	22.3	0.15	1.35	544	2.44	21.62
25	37.63	21.03	0.13	1.41	576	2.05	22.53
26	35.94	19.27	0.12	0.85	544	1.86	13.65
27	34.64	19.21	0.11	1.03	592	1.74	16.47
28	34.64	19.21	0.11	0.85	592	1.74	13.61
29	42.24	22.73	0.16	0.66	480	2.55	10.49
30	45.26	23.69	0.18	0.78	544	2.95	12.52
31	43.15	21.99	0.17	1.27	528	2.64	20.30
32	45.16	23.2	0.18	0.89	496	2.89	14.25
33	38.44	21.21	0.13	1.03	464	2.11	16.54
34	38.45	21.24	0.13	0.91	528	2.09	14.51
35	36.06	20.73	0.12	0.65	480	1.86	10.43
36	47.67	24.53	0.20	1.20	480	3.26	17.54
37	48.71	25.96	0.22	1.11	448	3.45	17.81
38	48.12	26.26	0.21	0.93	400	3.32	14.96
39	46.68	24.85	0.20	1.00	464	3.13	15.99
40	43.25	23.04	0.18	0.99	432	2.84	15.80
Mean	**36.23**	**21.19**	**0.12**	**0.96**	**583**	**1.99**	**15.41**

N.B.: Dbh = tree diameter at breast height; H = tree total height; SV = stem volume; BA = basal area

The selected height-diameter models for *Gmelina arborea* in the study area are presented in Table 3. Generally, all the height-diameter models presented in this study are good, going by their modelling efficiencies (R^2-values). The best model was Logarithmic, for its high R^2 and low RMSE values of 0.91 and 0.1293, respectively. This was followed by the polynomial model with R^2 and RMSE values of 0.90 and 0.1556, respectively. The least-suitable height-diameter model was the exponential with R^2 and RMSE values of 0.75 and 2.2683, respectively. However, the five selected models were significant ($P<0.05$).

Table 3: Selected height-diameter models for *Gmelina arborea* in the study area

Function	Model form	R^2	RMSE	P-value
Linear	$H = 5.69 + 0.42Dbh$	0.89	0.2127	0.000
Logarithmic	$H = - 30.22 + 4.60\ln(Dbh)$	0.91	0.1293	0.000
Polynomial	$H = 0.37 + 0.73Dbh - 0.004Dbh^2$	0.90	0.1556	0.000
Power	$H = 1.12Dbh^{0.82}$	0.88	0.2650	0.000
Exponential	$H = 8.80e^{0.02Dbh}$	0.75	2.2683	0.003

N.B.: $\alpha = 0.05$; ln = natural logarithm; R^2= co-efficient of determination; RMSE = root mean square error

Table 4 presents the selected yield models for *Gmelina arborea* in the study area. Generallyall the yield models presented in this study were poor, going by their modelling efficiencies (R^2-values). They all have very low R^2- values, although with low RMSE values. However, the five models were significant ($P<0.05$). The best among the models was the power model with R^2 and RMSE values of 0.40 and 0.3787, respectively. The worst being the polynomial model with R^2-value of 0.19 and RMSE of 0.8399.

Table 4: Selected stem volume models for *Gmelina arborea* in the study area

Function	Model form	R^2	RMSE	P-value
Linear	$V = 0.95 + 0.0002Dbh$	0.30	0.6900	0.001
Logarithmic	$V = 0.89+ 0.022\ln(Dbh)$	0.20	0.7190	0.025
Polynomial	$V =0.81 + 0.008Dbh -0.0001Dbh^2$	0.19	0.8399	0.043
Power	$V = 0.75Dbh^{0.025}$	0.40	0.3787	0.000
Exponential	$V = 0.81e^{0.0005Dbh}$	0.20	0.3901	0.016

N.B.: $\alpha = 0.05$; ln = natural logarithm; R^2= co-efficient of determination; RMSE = root mean square error

The results of model validation for the height-diameter models are presented in Table 5. The result revealed that there was no significant difference between the observed (measured) and the predicted mean total heights under the linear, logarithm, polynomial and power models ($P>0.05$). However, there was a significant difference between the observed and the predicted mean height value under the exponential model ($P<0.05$).

Table 5: Results of model validations for the *Gmelina arborea* height-diameter models

Function	Model form	Mean obs.	Mean pred.	df	t_{cal}	P-value
Linear	$H = 5.69 + 0.42Dbh$	20.99 ± 6.46	20.94 ± 6.03	3096	0.20	0.840
logarithm	$H = - 30.22 + 4.60\ln(Dbh)$	20.99 + 6.46	21.00 ± 6.17	3096	0.08	0.940
Polynomial	$H = 0.37 + 0.73Dbh - 0.004Dbh^2$	20.99 ± 6.46	20.78 ± 5.99	3096	0.93	0.350
Power	$H = 1.12Dbh^{0.82}$	20.99 ± 6.46	21.06 ± 6.89	3096	0.29	0.770
Exponential	$H = 8.80e^{0.02Dbh}$	20.99 ± 6.46	15.85 ± 3.76	3096	27.05	0.000

N.B.: α = 0.05; mean obs. = mean observed value; mean pred. = mean predicted value

Table 6 presents the results of model validation for the *Gmelina arborea* yield models in the area. The results revealed that there were no significant differences between the mean observed and the predicted values for the linear and logarithm models (P>0.05). With respect to the polynomial, power and exponential functions, the mean observed and predicted values were not significantly different from each other in the respective cases (P<0.05).

Table 6: Results of model validations for the *Gmelina arborea* stem volume models

Function	Model form	Mean obs.	Mean pred.	df	t_{cal}	P-value
Linear	$V = 0.95 + 0.0002Dbh$	0.96 ± 0.62	0.96 ± 0.004	3096	0.27	0.790
logarithm	$V = 0.89+ 0.022\ln(Dbh)$	0.96 ± 0.62	0.97 ± 0.009	3096	0.32	0.750
Polynomial	$V =0.81 + 0.008Dbh -0.0001Dbh^2$	0.96 ± 0.62	1.25 ± 0.231	3096	17.42	0.000
Power	$V = 0.75Dbh^{0.025}$	0.96 ± 0.62	0.82 ± 0.0003	3096	9.17	0.000
Exponential	$V = 0.81e^{0.0005Dbh}$	0.96 ± 0.62	0.81 ± 0.0003	3096	9.74	0.000

N.B.: α = 0.05; mean obs. = mean observed value; mean pred. = mean predicted value

The results of assessments for the height-diameter model consistencies are shown in Table 7. The mean bias values under the linear, logarithm, polynomial and the power functions were very small. However, value for the exponential model was high, indicating an over-estimation of the tree heights in the area. With respect to the yield models, all the models presented in Table 8 produced very small mean bias values. Details of the model fitting consistencies for the height-diameter and stem volume models are presented in Tables 7 and 8, respectively.

Table 7: Model fitting consistencies for the *Gmelina arborea* height-diameter models

Function	Model form	Mean obs.	Mean pred.	Mean bias
Linear	$H = 5.69 + 0.42Dbh$	20.99 ± 6.46	20.94 ± 6.03	0.0454
Logarithm	$H = - 30.22 + 4.60\ln(Dbh)$	20.99 + 6.46	21.00 ± 6.17	0.0167
Polynomial	$H = 0.37 + 0.73Dbh - 0.004Dbh^2$	20.99 ± 6.46	20.78 ± 5.99	0.2071
Power	$H = 1.12Dbh^{0.82}$	20.99 ± 6.46	21.06 ± 6.89	0.0701
Exponential	$H = 8.80e^{0.02Dbh}$	20.99 ± 6.46	15.85 ± 3.76	5.1387

N.B.: Mean obs. = mean observed value; mean pred. = mean predicted value

Table 8: Model fitting consistencies for the *Gmelina arborea* stem volume models

Function	Model form	Mean obs.	Mean pred.	Mean bias
Linear	$V = 0.95 + 0.0002Dbh$	0.96 ± 0.62	0.96 ± 0.004	0.0048
Logarithm	$V = 0.89+ 0.022\ln(Dbh)$	0.96 ± 0.62	0.97 ± 0.009	0.0052
Polynomial	$V =0.81 + 0.008Dbh - 0.0001Dbh^2$	0.96 ± 0.62	1.25 ± 0.231	0.2909
Power	$V = 0.75Dbh^{0.025}$	0.96 ± 0.62	0.82 ± 0.0003	0.1432
Exponential	$V = 0.81e^{0.0005Dbh}$	0.96 ± 0.62	0.81 ± 0.0003	0.1520

N.B.: Mean obs. = mean observed value; mean pred. = mean predicted value

The trends exhibited by the *Gmelina arborea* tree height-diameter relationships in the study area under the five functions (i.e. linear, logarithm, polynomial, power and exponential) and those exhibited by stem volume-diameter relationships under the five functions are presented in Figures 2 and 3, respectively.

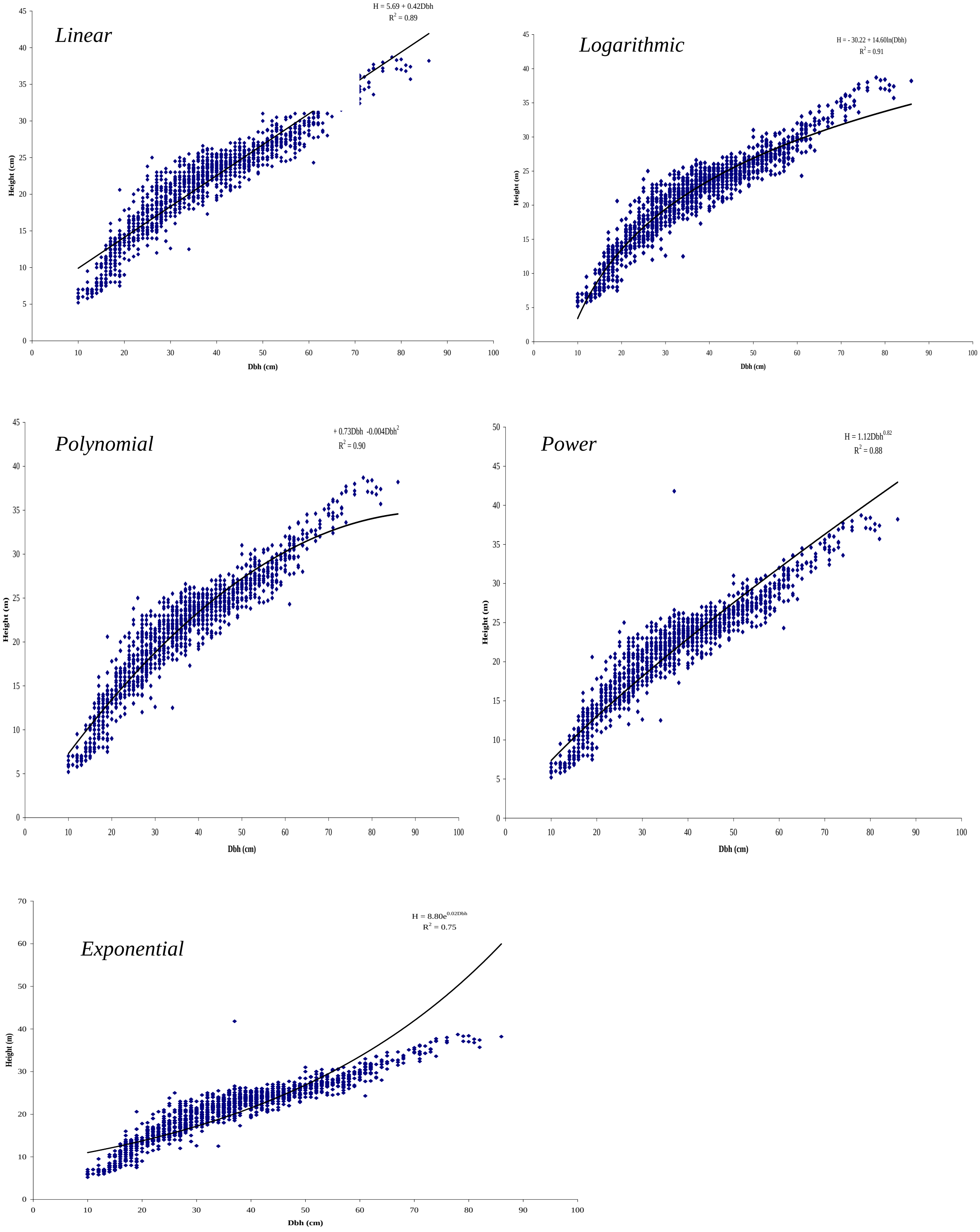

Figure 2: Height-diameter relationships under the five functions

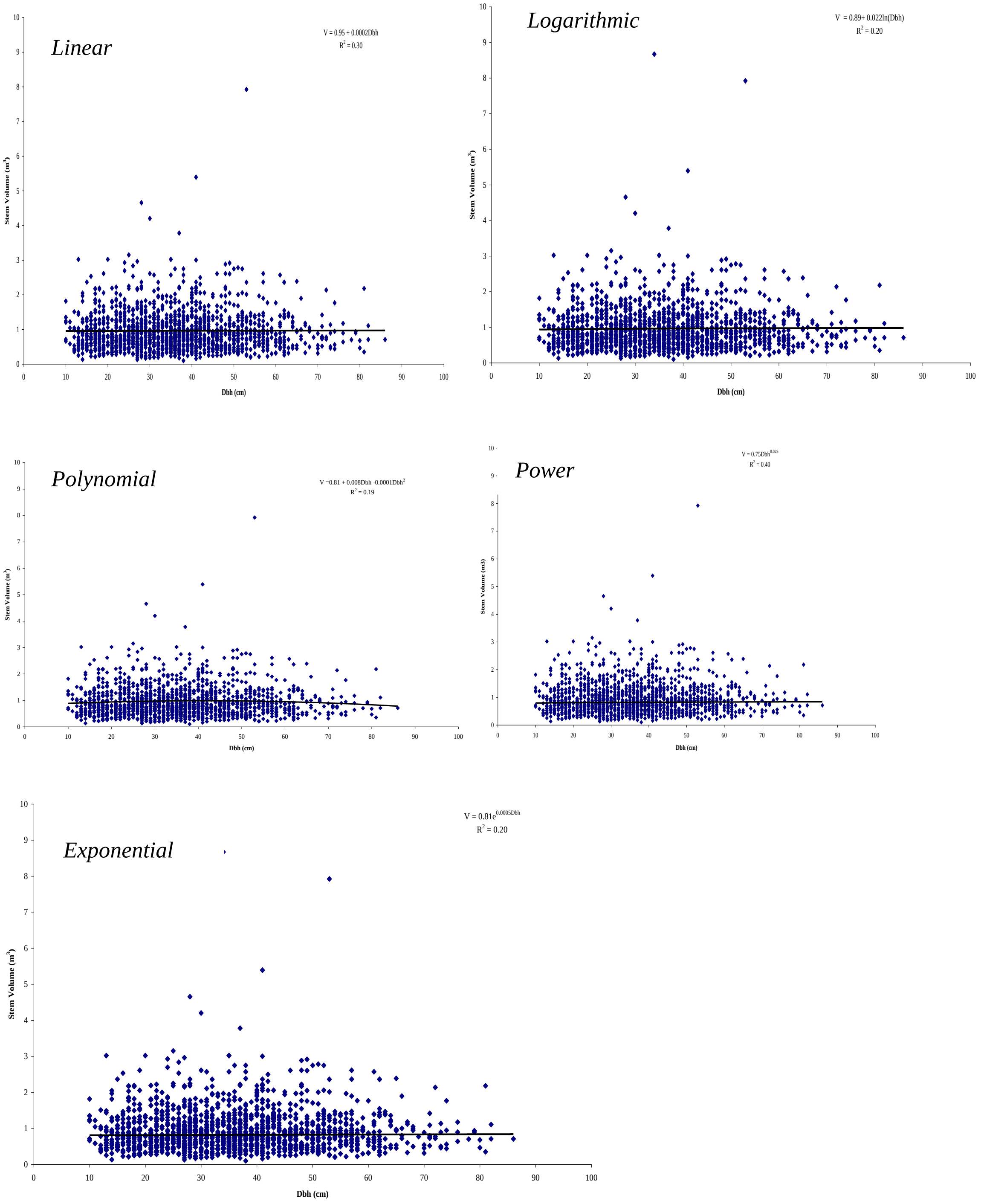

Figure 3: Volume-diameter relationships under the five functions

DISCUSSION

The tree mean Dbh value of 36.31was below the minimum merchantable size of 48 cm stipulated by logging policy of Nigeria. It was also lower than 39.12 cm reported by Adekunle (2007 for a moist tropical forest in south-west Nigeria. The mean stem volume and basal area values per hectare obtained in this study also indicated that the area was poorly stocked. The values were lower than what was reported by Akindele and LeMay (2006). The mean basal area per hectare was far less than the 24m^2/ha prescribed by Alder and Abayomi (1994) for a well-stocked forest or planted stand. This may have resulted from poor past forest management in the state before the moratorium on logging and related activities in the state in 2007 by the then Governor Liyel Imoke through Cross River Forestry Commission. In the stand, numerous stumps were noticed and the current spacing was so irregular, which is indicative of the past extractive uses and perhaps, illegalities.

The high R^2, low RMSE and the significance of regression obtained for height-diameter models in this study are indication model good fits. The fits exhibited by the selected height-diameter models for *G. arborea* were similar to those obtained by Adegbehin (1985) for *Pinus caribea*, *Eucalyptus cloeziana* and *E. tereticomis* stands. This result corroborates the work of Adekunle (2007), who noted that high index of fit such as R^2 are indicators of a suitable model with good fit and therefore suitable for use within the context of the data used. The overall best height-diameter model was logarithmic. The yield models were poor with very low R^2 and bad model validation results. In general, considering the model forms, the intercepts (b_o) were close to 1 across the five models while the slope (b_1) were close to zero under height-diameter. This trend disagreed with the findings of Adekunle (2007), who reported that intercept (b_o) close to zero and slope (b_1) close to 1 are indications of a model with good fit. However, the yield models were generally poor and this may have been responsible for the observed trends.

Avery and Burkhart (2002) noted that volume (yield) prediction usually gives negative intercept. On the contrary, for virtually all the stem volume model, there were positive intercepts. This may have also accounted for the poor model fitting efficiencies and performance. The result of model validation further revealed that linear, logarithmic, polynomial and power height-diameter models were suitable for predictions. However, the exponential function was not found suitable since there was a significant difference between the observed and the predicted mean height values. These are further indications that these models (linear, logarithmic, polynomial and power) have good fit, thereby suitable for use within the context of the field data. Similar findings were reported by Akindele and LeMay (2006) and Adekunle (2007), who independently stated that when observed values and predicted values are closer, it is an indication of models with good fit.

The trends of volume-diameter relationships for all the functions indicated almost even spread of values, to the left and right of the mean with no systematic trends in virtually all the cases. The derivations of the plotted graphs were random. These are indications that the assumption of normality in the distribution was not violated. These trends were similar to the findings of Soares and Tome (2001), Akindele and LeMay (2006), who reported that even spread of residuals above and below zero line is an indication of a suitable model that supported the assumption of normality. However, there appeared to be no relationship between model performance and the trends exhibited by the plots of stem volume and diameter in this study. The disparity in the report of Akindele and LeMay (2006), who predicted stem volume from Dbh, height and form, may be due to the fact that stem volume was predicted only from Dbh in this study, which might not have approximated or explained stem volume adequately.

CONCLUSSION

The study showed that the *Gmelina arborea* plantation is poorly stocked with much signs of past anthropogenic activities. The mean diameter at breast height (Dbh) was below the suggest ed minimum, and the mean basal area per hectare was equally below the prescribed value for a well-stocked planted stand or constituted tropical rainforest in Nigeria. Nevertheless, the good news is that government has placed moratorium on logging in the state, and this appears to be yielding positive results in the plantation, as coppices were noticed with vigorous growths.

The five height-diameter models presented in this study were good, going by the modeling efficiencies and very small mean bias values. However, the exponential function may over-estimate the tree total height in the study area; therefore, it is not suitable for predicting *Gmelina arborea* heights. The most suitable model for tree height predictions in the area was the logarithmic model. The model had very high R^2, consistent, and with a very small RMSE and mean bias values. When the model output was compared with field data, there was no significant difference in the mean values. The study further showed that there was no suitable model for *Gmelina arborea* yield prediction in the stand. All the stem volume models tried consistently gave poor results. For most of the models, there were significant differences between the mean predicted and the observed values, and with very poor R^2 as well as other model fitting criteria.

The data for this study was collected from temporary sample plots, which cannot provide means for subsequent assessment of performance of the sites in the study area. It is recommended that permanent sample plots are established and maintained in these stands so as to ensure regular data collection for future studies. In the available permanent sample plot in the country, inventory data collected are so limited to very few growth variables such as diameter at breast height and height. This has imposed serious limitations to many vital aspects of growth studies necessary for sound forest management. It is therefore recommended that old format of data collection in permanent sample plots be changed and inclusion of more variables (diameter at the base, middle and top, crown length, etc.) be considered during future modeling exercise in the stand, especially for stem volume or yield prediction. It is important to ensure that a model behaves in realistic way for a wide range of site and stand conditions, and also extrapolate safely to conditions not included in the model development data. Hence, further studies should be carried out on construction of different models for stem volume estimation in the other stands in the area; and such studies should cover a wide range of ages.

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