TREE SLENDERNESS COEFFICIENTS AND CROWN RATIO MODELS FOR *Gmelina arborea* (ROXB) STAND IN AFI RIVER FOREST RESERVE, CROSS RIVER STATE, NIGERIA

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ABSTRACT

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Tree slenderness coefficient (SC) and crown ratio (CR) have been viewed as major attributes considered most efficient in determining health status of a forest. Hitherto, there is dearth of information on growth characteristics of Gmelina arborea plantation in Afi River Forest Reserve (ARFR), and there was no documented information on health status of the plantation. Therefore, we assessed health and stability of Bateriko Gmelina Plantation within ARFR in Cross River State. Simple random sampling technique was adopted for plot location. Thirty-four (34) sample plots of size 25 × 25 m were used. Tree growth variables including diameter at breast height (Dbh); total height (THT); merchantable height (MHT); stem quality (SQ), crown length (CL) and crown diameter (CD) were measured on all trees with Dbh ≥10 cm to compute CR, SC, basal area (BA) and stem volume (SV). Data were analysed using descriptive statistics and regression analysis. The fitted models were evaluated using significance of regression, co-efficient of determination (R^2) and root mean square error (RMSE). Model validation was achieved using t-test and mean bias. The results revealed that the mean Dbh (39.35±8.91 cm) was lower than the stipulated minimum for timber in Nigeria. However, the mean BA (74.61±12.74 m^2/ha) was far more than 24 m^2/ha suggested for a well-stocked forest in Nigeria. Most (78.8%) of the stems/ha had low to moderate SC, indicating that most of trees in the plantation were less susceptibility to damage. The best CR model was $lnCR = -1.81 - 0.708lnSQ^2 + 0.993lnSC + 3.497BA$ having R^2; RMSE and bias values of 0.59, 0.3138, and -0.01±0.08, respectively. For this model, the mean observed and the predicted CR values were not significantly different (P>0.05). Therefore, it is recommended for CR prediction in the study area.

Keywords*: crown size, stand health, susceptibility to damage, prediction models*

INTRODUCTION

Gmelina arborea is a member of the family *Verbanaceae* (Keay, 1989), fast-growing, exotic tree species with very good coppicing ability (Al-Amin and Alamgir, 2003). It has a straight trunk, wide spreading branches and shady crown, and attains a height and diameter of 10-30 m and 60-100 cm respectively. The optimum climate for *G. arborea* is an area with short dry spell of 3-5 months and an average relative humidity of about 40%, average monthly temperatures of between 18 and 30°C for the coolest and warmest months respectively. *Gmelina arborea*, introduced widely to countries in the tropics with largest plantations in Brazil, Ghana and Nigeria, and most of which were originally intended for pulp and paper production (Lauridsen and Kajaer, 2002). Tree slenderness coefficient (SC) has been used as the simplest empirical stability indicator for single tree or stand dimensions (Hinze and Wessels, 2002). It is the ratio of tree total height to diameter at breast height (Dbh), with both variables measured in the same unit (Nunes *et al*., 2010). According to Wang *et al.* (1998), the susceptibility of a stand to wind-induced damage is largely influenced by the tree SC. According to James *et al*. (2006), the size of trees, their shape and structure influence mechanical stability. Therefore, in order to predict the stability and susceptibility of a stand to damage, accurate information about SC of a stand becomes very essential. Furthermore, tree crown condition is a good indicator of the health of a tree as it plays a key role in tree primary productivity provides habitats for myriads of wildlife (Adeyemi *et al*., 2013).

Literature is replete with different tree growth models, which predict yields of forests and explore silvicultural options. However, crown ratio models, which predict visual quality of forest, are uncommon, and little attention had been given to growth characteristics of exotic tree species in Nigeria, particularly the *G. arborea* in Afi River Forest Reserve (ARFR), hence silvicutural interventions had been adopted without good knowledge of growth characteristics. This may, or may have resulted in bad management decision with attendant adverse effect on stand productivity. In spite of the fact that wind damage to trees is a major problem since it can result in huge economic losses, attempts have not been made to ascertain the susceptibility of this stand to wind-throw through the knowledge of individual tree SC. Therefore, this study evaluated tree slenderness coefficients and developed crown ratio models for *G. arborea* in ARFR with a view to assessing health status of the forest plantation.

MATERIALS AND METHODS

The study was conducted in Bateriko *Gmelina* plantation in Afi River Forest Reserve. The stand is a part of major *Gmelina* plantations established in Cross River State between 1975 and 1990. It is located in Eastern Boki, Boki Local Government Area (LGA) of Cross River State on latitude 6.36° N and longitude 9.13° N. It is bounded in the west by the Okwangwo forest (Fig. 1). The plantation, established in 1982 (about 35 years ago), covers an area of 100 hectares. The study area has a typical climate of Boki LGA with distinct wet and dry seasons. The mean annual temperature is 25 °C with average relative humidity of 80% during the rainy season, and decreases drastically during the dry season with high rate of evapo-transpiration (Okpiliya, 2013). Annual rainfall is between 2000 mm and 3500 mm. The vegetation lies within the lowland rainforest, and predominantly composed of highly deformed continuous N-S trending polymetamorphic rocks (Egesi and Ukaegbu, 2010). The area is well-drained with many streams and rivers such as Afi River, Okorn River and Arena River (Amalu and Takon, 2013).

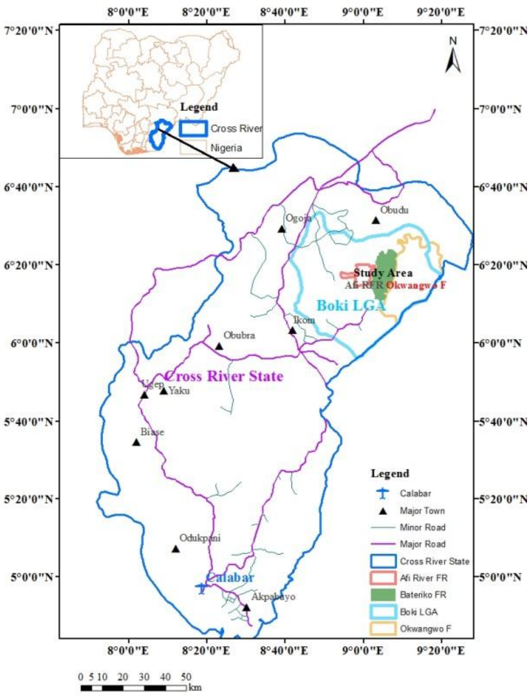

Fig. 1: Map of the study area

Sampling procedure and data collection

A simple random sampling technique was adopted for plot locations. Thirty-four (34) 25 m × 25 m plots were randomly selected for the study. Data on tree growth parameters, namely: diameter at breast height (Dbh); diameters at the base, middle and top; tree total height; merchantable height; stem quality (SQ); crown length (CL) and crown diameter (CD) were taken on trees with Dbh ≥ 10 cm within each of the randomly selected plots to compute basal area (BA), stem volume (SV), SC and CR. The measurements were carried out using diameter tape and Spiegiel Relaskop.

Data analysis

Basal area computation

The individual tree basal area within each sample plot was computed using:

$$BA = \frac{\pi Dbh^2}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where: BA = basal area (m^2); Dbh = diameter at breast height.

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

$$BA_p = \sum_{i=1}^{n} BA_i \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

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

Basal area per hectare was obtained by multiplying mean basal area per plot by 16 (16 being the total number of 25 m × 25 m plots in a hectare).

Crown Projection Area Computation

The crown projection area for individual tree in the study area was estimated as:

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

Where: CPA = crown projection area; CD = crown diameter.

Tree volume estimation

The individual tree volume was computed using a modified Newton's formula as:

$$V = \frac{\pi H}{24}(D_b{}^2 + 4D_m{}^2 + D_t{}^2)\text{...}4$$

Where: V = stem volume; H = tree total tree height; D_b = tree diameter at the base; D_m = tree diameter at the middle; D_t = tree diameter at the top.

Determination of Volume for each sample plot was done by adding the volume of the individual trees within each plot. The stem volume per hectare was then obtained on plots basis by multiplying the plots volume by 16 (16 being the total number of 25 m × 25 m plots in a hectare).

Tree slenderness coefficient estimation

Tree Slenderness Coefficient was estimated for all trees using:

$$SC = \frac{H_i}{Dbh_i}\text{...}5$$

Where: H_i = total height of the ith tree; Dbh_i = corresponding Dbh.

The measured trees were classified according to the SC as follows:

SC < 70: low slenderness coefficient; SC: 70 - 80: moderate slenderness coefficient;

SC > 80: high slenderness coefficient. The number of trees/ha and percentage of trees in each of the SC categories was computed for the area.

Crown ratio computation

Individual tree crown ratio was computed using:

$$CR = \frac{CL_i}{H_i}\text{...}6$$

Where: CL_i = individual tree crown length; H_i = tree total height of the ith tree.

This was computed for individual tree in the stand as a response variable for the crown ratio prediction models.

Models Development

The following linear regression models were fitted to the tree growth variables with CR as the response variable.

$lnCR = a + b_1SC + b_2SQ^2 + b_3lnDbh$..................7

$lnCR = a + b_1SQ2 + b_2SC^2 + b_3Dbh$...................8

$lnCR = a + b_1lnSQ + b_2lnBA + b_3SC$..................9

$lnCR = a + b_1lnSQ^2 + b_2SC + b_3BA$...................10

$lnCR = a + b_1lnSQ^2 + b_2Dbh + b_3SC$.................11

$lnCR = a + b_1lnSQ^2 + b_2lnSC + b_3BA$................12

$lnCR = a + b_1lnSQ^2 + b_2lnSC + b_3lnBA$.............13

$lnCR = a + b_1lnBA + b_2lnSC + b_3MHT^2$.............14

Where: CR= tree crown ratio; BA = basal area; SQ = stem quality; MHT = merchantable height; SC = slenderness co-efficient; Dbh = diameter at breast height

Model validation

The model validation was done by dividing the data into two sets. One set for calibrating the models and the other sets for the validation of the models to be developed. This was done by: testing for the significant differences in the mean predicted and observed values of the dependent variables in all cases, using student t-statistic given as:

$$t = \frac{\bar{X}_1 + \bar{X}_2}{\sqrt{s^2 \frac{(N_1 + N_2)}{(N_1)(N_2)}}}\text{..}15$$

Where: $\bar{X}_1$ = mean observed CR; $\bar{X}_2$ = mean predicted CR; N_1 = number of data points for the observed CR; N_2 = number of data points for the predicted CR; S^2 = pooled within-group variance (for independent samples with equal variance).

The fitting method consistency was evaluated using mean bias values with the following expressions:

$$Bias = \frac{\sum_{i=1}^{N} \bar{Y}_1 - \bar{Y}_2}{N}\text{..}16$$

Where: $\bar{Y}_1$ = mean observed value; $\bar{Y}_2$ = mean predicted value; N = number of data points or observations.

RESULTS AND DISCUSSION

The *Gmelina arborea* mean Dbh and total height (THT) in the area were 39.35±8.91 cm and 25.51±3.42 m respectively. The mean CPA and BA were 41.15±36.82 m^2 0.13±0.06 m^2 respectively. The individual mean stem volume (SV) was 1.64±0.91 m^3. Tree slenderness coefficient (SC) values were between 4.94 and 129.00 with a mean of 67.75±16.22. Tree crown ratio (CR) ranged between 0.01 and 5.58 with a mean of 0.38±0.21 (Table 1).

Although the tree mean Dbh of 39.35 cm recorded in the study area was below the minimum merchantable limit of 48 cm stipulated by logging policy in Nigeria, the figure was higher than 36.31 cm reported by Adeyemi and

Ukaegbu (2016) for Edondon *Gmelina* plantation in Cross River State, Nigeria, planted in 1976, established six (6) years earlier before the plantation considered in this study.

Table 1: Descriptive statistics for the individual tree growth variables

Variable	Minimum	Maximum	Mean	Std. deviation
Dbh (cm)	20.00	77.61	39.35	8.91
THT (m)	2.40	33.00	25.51	3.45
CPA (m^2)	0.10	258.73	41.15	36.82
BA (m^2)	0.03	0.47	0.13	0.06
SC	4.96	129.00	67.75	16.22
SV (m^3)	0.18	6.18	1.64	0.91
CR	0.01	5.58	0.38	0.21

N.B.: Dbh = diameter at breast height; THT = tree total height; CPA = crown projection area; BA= basal area; SC = slenderness coefficient; SV = stem volume; CR = crown ratio

The descriptive statistics for *G. arborea* stand growth characteristics are presented in Table 2. There were about 584±76 trees/ha with BA of 74.61±12.74 m^2/ha. The mean SV/ha was 961.09±262.80 m^3 with a CPA of 24009.81±16804.51 m^2/ha (Table 2). On stand basis, an impressive value was obtained with regards tree BA per hectare with about 74.61 m^2, which is far more than the 24 m^2/ha recommended for a well-stocked plantation in Nigeria according to Alder and Abayomi (1994). By implication, the plantation appeared to be growing unhindered or relatively less-disturbed, or perhaps the sight conditions appear favourably suitable for *G. arborea*.

Table 2: *Gmelina arborea* stand growth characteristics in the study area

Plot	N per ha	BA per ha (m^2)	SV per ha	CPA per ha (m^2)
1	640	66.12623	1163.5752	37390.01
2	736	94.35085	1668.1103	45172.28
3	656	80.07879	1139.5887	38036.83
4	704	79.55306	771.12216	40420.07
5	672	80.39831	930.74417	28012.76
6	672	74.28518	863.40994	20262.51
7	672	69.07025	866.68332	14261.8
8	608	85.28039	902.03746	12616.94
9	672	83.91822	1219.2906	6069.959
10	656	74.09961	1142.7653	3369.194
11	624	78.41053	1061.9888	3864.302
12	656	82.8005	1120.4902	26229.76
13	624	85.91642	1022.9776	50654.27
14	640	67.63364	960.66651	62678.66
15	560	60.5468	917.19766	57350.09
16	608	64.95338	761.31097	46706.27
17	544	64.87467	804.30407	42543.21
18	592	100.0039	1177.3085	45459.82
19	512	68.95247	823.15342	31620.01
20	496	57.74151	538.65195	2393.098
21	544	69.91143	678.18993	4020.214
22	576	77.94803	687.4768	2705.071
23	544	73.60826	886.25132	16532.86
24	592	83.06335	1117.6127	20543.97
25	592	86.56334	1041.3607	18295.52
26	480	66.57867	734.98936	13620.58
27	544	101.6602	1493.9945	14643.94
28	528	93.62051	1415.2053	16527.92
29	496	76.23303	1099.093	14585.47
30	464	61.46536	799.16748	16699.5
31	528	62.65624	1021.7061	18493.59
32	480	52.70587	791.62305	10599.17
33	480	61.86905	602.48342	17267.22
34	448	49.97243	452.43545	16686.69
Mean ± SD	584 ± 76	74.61 ± 12.74	961.09 ± 262.80	24009.81 ± 16804.51

N.B.: CPA/plot = crown projection area per plot; CPA/ha =crown projection area per hectare; BA/plot =basal area per plot; BA/ha =basal area per hectare

The tree diameter classifications for the *Gmelina* stand in the study area are shown in Fig. 2. About 80 trees/ha fell in the diameter 20-30 cm, which constituted 13.6% of the trees per hectare. There were 284 trees/ha in the diameter class 30-40 cm, about 43% of the trees/ha. About 189 trees/ha (32.3%) were in diameter class 40-50 cm. The diameter class with least number of trees/ha was >50 cm with 11.5% of the trees encountered per hectare.
The stand exhibits a better horizontal tree structural development in relative terms. This may be attributed to the gain recorded as a result of official ban placed on logging by the Cross River state Government between 2007 and 2011. However, very few trees/ha (12%) of the total trees encountered in the area are currently harvestable, above the minimum merchantable size for timber production (>50 cm). This implies that only trees in this category are expected to be harvested should there be any need to do so, in order to meet local wood consumption demand in the state
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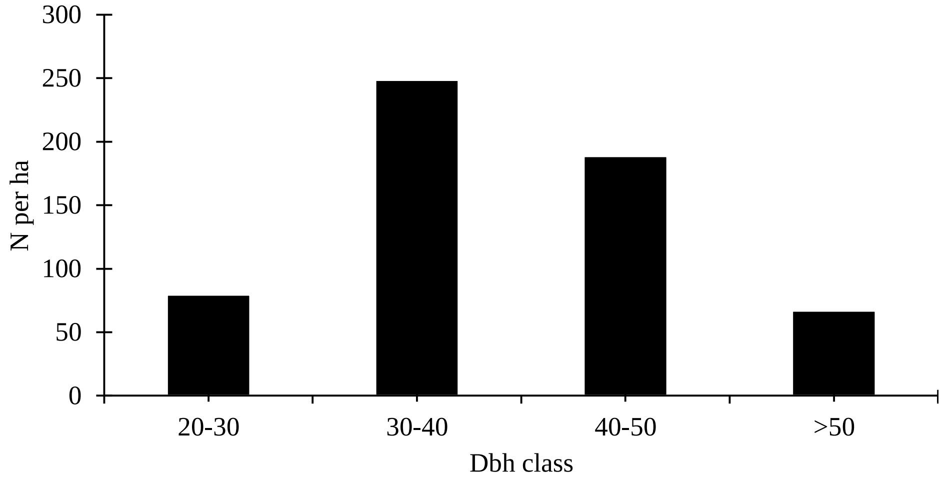

Fig. 2: Diameter classifications for *G. arborea* stand in the study area

The tree height classifications in the study area are shown in Fig. 3. Most (522) of trees encountered per hectare were within the height class 20-30 m (Co-dominant), constituting about 90% of the trees sampled. About 37 trees/ha were within the height class >30 m (Dominant), constituting 6.4% of the total stems per hectare. The trees that fell in intermediate class (10-20 m) were 23, which constituted 3.9% of the total. This conforms to the general trend observed in a planted stand of *G. arborea* because of the nature of the establishment, which is usually done within the same period (even-aged). Only one tree/ha (constituting 0.2% in all) was suppressed (with height of <10 m) in the stand. This must have probably been a case of a tree with retarded growth, or was recruited in a beat-up operation.

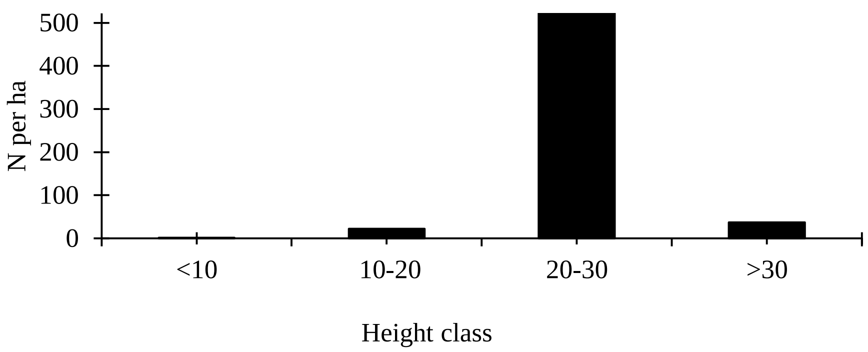

Fig. 3: Height classification for *G. arborea* in the study area

The result of tree slenderness coefficient (SC) categorization for *G. arborea* in the area revealed that about 315 trees/ha had SC<70 (low slenderness co-efficient), constituting 58.4% of the trees encountered in a hectare (Fig. 4). There were 122 trees/ha (19.7%) with SC: 70-80 (moderate slenderness co-efficient). Trees with SC >80 (high slenderness co-efficient) were 148 trees/ha (21.9%). On the whole 78.1% of the trees/ha had low to moderate slenderness coefficients. This implies high stability, and low susceptibility to wind-induced damage or breakage. In sum, very few trees/ha (21.9) in the area may be exposed to the risk of wind-induced damage or susceptible to wind-throw, going by their slenderness co-efficient values (SC: >80). The high percentage of trees/ha with low SC may be a result of adequate silvicultural treatments such as thinning at the early stage of stand development.

For example if a forest stand remains unthinned for several decades the vertical growth (height) may become disproportional to the diameter growth of the tree stem (Liu *et al*., 2003; Adeyemi and Adesoye, 2016). According to Rudnicki *et al*. (2004), trees with SC values over the threshold of 80 are prone to wind-induced damage. For forest and plantation trees, SC below 80 indicates excellent stability, and a low susceptibility to risks of damages (Adeyemi and Adesoye, 2016).

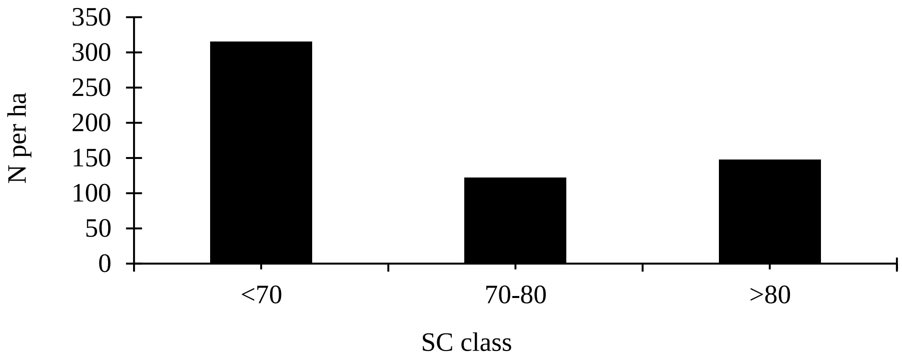

Fig. 4: Tree SC classification for *G.arborea* in the study area

In all, the best crown ratio model (model 6) is of the form: $lnCR = -1.81 – 0.708lnSQ^2 + 0.993lnSC + 3.497BA$ with R^2 and RMSE values of 0.59 and 0.3138 respectively (Table 3). The bias value (-0.01±0.08) was very small, and there was no significant difference in mean observed and the predicted values for the response variable (*lnCR*) (Table 4). The least suitable model (model 3) was of the form: $lnCR = 3.04 – 0.747lnSQ + 0.689lnBA + 0.21SC$ with R^2 and RMSE values of 0.64 and 0.2962 respectively. Although this model had high R^2 with low RMSE values, the bias value was very high (-15.17 ± 0.99) However, all the selected models were significant ($P < 0.05$). A low value of RMSE is an indication of model good fit, and suggests a good predictive ability of such model (Adekunle *et al.*, 2004). The validation results, which involved testing the developed models, and comparing the results with the real (observed) data showed that model 6 ($lnCR = -1.81 – 0.708lnSQ^2 + 0.993lnSC + 3.497BA$) was the most suitable for crown ratio prediction in the area. The t-test result for comparing this model with the observed crown ratio was not significant, and the mean bias for the model was very small. This indicates a good predictive ability for crown ratio prediction in the study area. The suitability of stem quality (SQ) and basal area (BA) for crown ratio prediction is in line with the report by Adeyemi *et al*. (2013), who reported BA and SQ as the only suitable predictors of crown ratio in Oban Forest of Nigeria. This result also corroborates the findings of Akindele (2003) and Temesgen *et al*. (2005), who independently noted that tree size variables are the best predictors of crown ratio.

Although, other models presented had high R^2 and very low RMSE values, especially models 1, 2 and 3 (i.e. $lnCR = -4.76 – 0.016SC – 0.003SQ^2 + 0.965lnDbh$, $lnCR = -1.35 – 0.03SQ^2 + 0.00009SC^2 + 0.018Dbh$ and $lnCR = 3.04 – 0.747lnSQ + 0.689lnBA + 0.21SC$) with 0.66, 0.64 and 0.64, respectively. However, their mean bias values were large, and the t-test results for comparing the mean observed and the predicted crown ratio were significant, indicating that the model outputs and the real data significantly differed, hence, unsuitable for predictions.

Table 3: Selected models for *G. arborea* crown ratio prediction in the study area

S/N	Model	R^2	RMSE	P
1	$lnCR = -4.76 – 0.016SC – 0.003SQ^2 + 0.965lnDbh$	0.66	0.2871	0.000
2	$lnCR = -1.35 – 0.03SQ^2 + 0.00009SC^2 + 0.018Dbh$	0.64	0.2971	0.000
3	$lnCR = 3.04 – 0.747lnSQ + 0.689lnBA + 0.21SC$	0.64	0.2962	0.000
4	$lnCR = 1.22 – 0.643lnSQ^2 + 0.016SC + 3.695BA$	0.60	0.3121	0.000
5	$lnCR = 1.15 – 0.710lnSQ^2 + 0.018Dbh + 0.014SC$	0.58	0.3211	0.000
6	$lnCR = -1.81 – 0.708lnSQ^2 + 0.993lnSC + 3.497BA$	0.59	0.3183	0.000
7	$lnCR = -0.65 – 0.728lnSQ^2 + 1.129lnSC + 0.543lnBA$	0.60	0.3123	0.000
8	$lnCR = -3.83 +0.573lnBA + 1.166lnSC – 0.003MHT^2$	0.60	0.3147	0.000

NB.: α= 0.05; ln= natural logarithm; R^2= coefficient of determination; SEE= standard error of estimate; CR= crown ratio; MHT= merchantable height; BA= basal area; SQ=stem quality; SC= slenderness coefficient; Dbh=diameter at breast height

CONCLUSION

The study has revealed that the plantation is well-stocked in terms of density as the mean basal area/ha was higher than the prescribed value for a well-stocked forest in Nigeria. However, the mean diameter at breast height was below the suggested harvestable minimum for timber. Therefore, it is recommended that logging should be restricted to avoid abuse, while ensuring adequate growth of the stand. Most of the tree stem/ha were with low to moderate slenderness coefficient, indicating that the plantation is stable and less susceptibility to wind-induced damage. Sustainable management is indispensable to preserve the healthy quality of the stand.

Table 4: Result of model validations for the selected crown ratio models

SN	Model	Mean	t	P	Mean bias
1	$lnCR = -4.76 – 0.016SC – 0.003SQ^2 + 0.965lnDbh$	1.07 ± 0.24 3.15 ± 0.23	33.07	0.00	2.08 ± 0.17
2	$lnCR = -1.35 – 0.03SQ^2 + 0.00009SC^2 + 0.018Dbh$	1.07 ± 0.24 8.27 ± 1.98	19.12	0.00	7.13 ± 1.85
3	$lnCR = 3.04 – 0.747lnSQ + 0.689lnBA + 0.21SC$	1.07 ± 0.24 14.10 ± 0.97	68.97	0.00	-15.17 ± 0.99
4	$lnCR = 1.22 – 0.643lnSQ^2 + 0.016SC + 3.695BA$	1.07 ± 0.24 0.73 ± 0.18	6.15	0.00	-0.35 ± 0.09
5	$lnCR = 1.15 – 0.710lnSQ^2 + 0.018Dbh + 0.014SC$	1.07 ± 0.24 1.04 ± 0.18	0.54	0.59	-0.03 ± 0.10
6	$lnCR = -1.81 – 0.708lnSQ^2 + 0.993lnSC + 3.497BA$	1.07 ± 0.24 1.07 ± 0.19	0.13	0.90	-0.01 ± 0.08
7	$lnCR = -0.65 – 0.728lnSQ^2 + 1.129lnSC + 0.543lnBA$	1.07 ± 0.24 1.07 ± 0.20	0.14	0.89	-0.01 ± 0.07
8	$lnCR = -3.83 +0.573lnBA + 1.166lnSC – 0.003MHT^2$	1.07 ± 0.24 1.02 ± 0.20	0.95	0.35	-0.06 ± 0.06

NB.: α= 0.05; ln= natural logarithm; R^2= coefficient of determination; SEE= standard error of estimate; CR= crown ratio; MHT= merchantable height; BA= basal area; SQ=stem quality; SC= slenderness coefficient; Dbh=diameter at breast height

Tree growth parameters, especially stem quality, slenderness coefficient and basal area are good predictors of crown ratio. Most of the developed models are good, going by their modelling efficiencies and small bias values. However, three of the models were poor as they have very high bias values, and the test of comparison between the observed and the predicted crown ratio values were not significant. If adopted, they would either under- or over-estimate the crown ratio. Hence, they are not suitable for predicting *G. arborea* crown ratio in the study area. The most suitable model for crown ratio prediction in the area was $lnCR = -1.81 – 0.708lnSQ^2 + 0.993lnSC + 3.497BA$ with R^2 and RMSE of 0.59 and 0.3138 respectively. When the model output was compared with the field data, there was no significant difference in the mean values. Therefore, it is recommended for prediction. Although this study provided baseline information about the growth and health status of the trees in the stand, data for the study were obtained from temporary sampling plots, which would not allow for a continuous or subsequent evaluation of the future conditions. Therefore, it is recommended that permanent sample plots be established and maintained so as to ensure regular growth, yield and health monitoring.

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