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GROWTH FUNCTIONS OF *Gmelina arborea* (ROXB) FOR SUSTAINABLE MANAGEMENT OF AN EVEN AGED FOREST IN UKPON RIVER FOREST RESERVE, OBUBRA, CROSS-RIVER STATE, NIGERIA

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ABSTRACT

This study involved developments of growth functions for predicting future individual tree characteristics, stem volumes and yield using stand age, stocking, diameter at breast height (dbh) and total height as predictor variables for Gmelina arborea plantation in Ukpon river forest reserve, in Obubra local government area of Cross River State, Nigeria. Data were collected from sample plots within five (5) age series (3, 5, 7, 9, and 11 years) in Gmelina plantation. Five sample plots of 0.04 hectare each were randomly selected from each age bracket. Diameter at breast height (dbh) of all trees in each plot was measured using diameter tape and grouped into 10cm diameter classes. Two trees with mean diameter in each class were randomly selected and measured for total height using Sunnto altimeter. Four dominant trees were randomly selected and measured for dominant diameter at breast height and dominant total height in each plot. Over bark diameter at the hohenadls positions (0.1, 0.3, 0.5 and 0.9) along the free bole for the two trees with mean dbh were measured using Haga altimeter for volume and form factor computation. Seven growth models were fitted to age, stocking diameter, and height using linear and non-linear regression techniques. The model selection criteria were based on high coefficient of determination (R^2), low goodness of fit, high significant of variance ratio (F) and least residual mean square error (MSE). The results showed that Gmelina species had the fastest initial height growth of 3.6m per year within the first five years of growth. The mean diameter at breast height increased from 13.31cm at age 3 to 6.99cm at age 11 with mean diameter increment of 4.4cm per year in the first five years and 2.3cm per year thereafter between ages of 7 and 11 years. Mean total height increased from 13.3m to 25m from age 3 to 11 years with corresponding dominant height of 17.28m to 33.88m respectively. The average stands form factor of 0.412 was obtained. The mean basal area increased from 15.44m²/ha to 33.18m²/ha for ages 3 to 11 years respectively while the mean annual increment (MAI) declined from 27.46m²/ha/yr at age 3 to 21.34m³/ha/yr at age 9 and increased slightly to 28.69m³/ha/yr at age 11 years. This study serves as a useful tool for proper evaluation and prediction of future stand growth for sustainable management of forest plantation under similar environmental conditions.

Keywords: Growth function, stand parameters, growth rate, sustainable management.

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INTRODUCTION

Information on growth functions of *Gmelina* plantations is very vital for prediction of growth parameters of *Gmelina* species. The parameters to be predicted include the basal area in m^2/ha and volume in m^3/ha, stem diameter distribution serves as an assortment of the growing stock and also as a basis for economic decision. Height distribution is of important purpose for site index determination (Adeyemi and Adesoye 2010).

Diameter is the widely used descriptor of stand structure, stand models that provide accurate estimates of stand growth and yield have become essential tool for evaluating the numerous management and utilization decision (Adeyemi and Ukaegbu, 2016).The distribution of diameter and height might be summarized into a stand table showing number of trees per unit area by diameter class or used to obtain parameter estimates for mathematical distribution function used to describe stand structure (Mackie and Mathews 2006). In an even aged stand, the distribution approximately normal.

Gmelina plantations constitute the country's most sizeable reforestation investment which must be protected, maintained and sustainably managed. Among the exotic species, it is the most successfully established plantations which covers a wide range of sites throughout the country (Akindele *et al.*, 2001). *Gmelina arborea* has a great potential in Nigeria economy due to its excellent pulping properties and other valuable uses including timber production, match boxes and splint production, cork stock production for plywood and pit prop in coal mines. Present the Gmelina plantations had overgrown their opinion rotation age specified for pulp wood production due to its deteriorating quality, high lignin center and short fibre length (Urrego, 2004).

This situation has created a serious management problem for Gmelina production crouch now requires more research into the species growth rate, increment site index and yield in order to formulate it future management plan. There is bane of information on growth studies of *Gmelina* species in Cross River State. The need to assess the growth of *Gmelina* species by finding the relationship between tree age, height, diameter and other derivable variables for *Gmelina arborea* in Ukpon River Forest Reserve, Nigeria cannot be over emphasized.

This study was carried out not only to develop such growth models based on age, height, diameter and stocking for the species but also for proper evaluation and prediction of future stand growth for sustainable management of forest plantation in Ukpon River Forest Reserve, Nigeria.

MATERIALS AND METHOD

The study Area

This study was conducted in an even-aged plantation of *Gmelina arborea* in Ukpon River Forest Reserve situated between latitude $5^0.30^/$and $5^0.57^/$ north and longitude $8^0.10^/$ and east $8^0.32^/$ in Obubra, Cross River State, Nigeria. The climate of Ukpon River Forest Reserve is comprised of distinct dry and rainy seasons. Rainy season span from April to September while dry season begins in October and end in March. Mean annual rainfall varies from 320mm in January to 515.7mm in August.

Mean annual temperature ranges from 23.2^0C in July to 33^0C in February while average daily relative humidity ranges from 10% in February to 89% in August. Soil were derived from Eze Aku formation of Turonian and Canomanian age of Precambrian series. The soil is brown, sandy loam overlaid with clay and iron stone gravels in some areas.

Field sampling

The major challenge in sampling is to obtain a sample that is a representative of the target population (Avery and Burhart, 2002). Therefore, a trial sampling was adopted in order to determine the required number of sample plots for each age class and a total of twenty-five sample plots were required for this study (that is five sample plots per age class) grids of 20 metres by 20 metres were made on the map and this represents the sampling frame. Stratified random sampling based on equal allocation was used to randomly select five sample plots for age series. In each sample plot, trees were numbered with the help of white marker.

Data collection

Diameter at breast height (dbh) in centimetres of the sampled trees was measured using diameter tape along the bole at 1.3 metres above the ground the dbh was grouped into 10cm classes and two mean trees within each class were randomly selected and measured for total height using Sunnto altimeter. Top height of four dominant trees per plot were also randomly selected and measured for dominant dbh and dominant height. The total number of stems within each plot was noted. Diameter over bark was taken at the hohenadl's positions is 0.1, 0.3, 0.5, 0.7 and 0.9 along the bole of the tree for the purpose of volume and from factor computation. It also helped to describe the shape of the stem.

Model formulation

Five data sets were used and this allows for a minimum of two (2) degrees of freedom for test of significance. In the absence of permanent sample plot in the study area temporary sample plot was used for growth data collection. Growth models were fitted to age number of stems, diameter at breast height (dbh) and height using linear and non-linear regression techniques. Simple and multiple regression analysis were used to developed equations relationship between age diameter, height and number of stems.

Data analysis

The linear and semi-log (common and natural) forms of equations were used to select the best equation. The selection of the best predicting growth functions for different stand parameters was based on Eric (2011). Each model was fitted to data sets using statistical package for social sciences (SPSS version 20).

The basic forms of the selected growth functions are stated below:

$LogH_0 = a_0 + a, \log H + a_2 A^{-2}$ - -----……(1)
Log N $= a_0 + a, \log D$ - - - - - - - - - - ------(2)
$D_o = a_0 + a, D + a_2 H_0 + a_3 N^{½}$ - - - - - -----(3)
$D = a_0 + a, A + a_2 H$ - - - - - - - - - - - (4)
$H = a_0 + a, A + a_2 A^2$ - - - - - - - - ------- (5)
$B = a_0 + a, A + a_2 H_0 + a_3 H_0 A$ - - - - - - ---- (6)
$V = a_0 + a, A^{-1} + a_2 H_0 + a_3 H_0 A^{-1}$ - - - - - - (7)

Where: H_0 = Dominant height (m)H = mean total height (metre); A = Age (year); N= number of stems per hectare D = Mean diameter at breast height (centimeters); D_0 = Dominant diameter (cm); B = Basal area (m^2/ha) V = volume (m^3/h); Log = logarithm at base 10; a_0 = intercept; a, ----- a_3, are regression coefficient .

Criteria for model selection

In model selection, the basic relationships considered include;

(a) fit index (i) =
$1 - \Sigma(\hat{y}_i - y_i)^2 (\Sigma y_i - \bar{y})^2)^{-1}$ - - - - - - -(8)

(b) (b)Mean difference (D) – $1/n \sum(\hat{y}_{i} - y_i)$ - - - - -- - - - - - - - - - Eq (9)

(c) Root mean square error (RMSE) = $1/n (\hat{y}_i - y_i)^2)^{\frac{1}{2}}$ - - - - - Eq(10)

(d) Percent mean difference (D%) = – $1/n \sum(\hat{y}_{i} - y_i / y_i)$ x 100 - -Eq(11)

(e) coefficient of determination (R^2) = $\Sigma(\hat{y}_i - \bar{y})^2 (\Sigma y_i - \bar{y})^2)^{-1}$----(12)

(f) Significance of regression (F_{ratio}) = $MS_R / RMSE$- - - - - - - - - - - - --(13)

Where:
$\hat{y};$ = predicted value; $\bar{\hat{y}}$ = observed mean value;

MS_R = regression mean square, y; = observed value validation of the growth functions

After a model has been constructed, it must be validated before such a model could be adjudged sustainable for use as a predictive model for the sustainable management of plantations. Validation provides an acceptable level of confidence that an inference drawn about the simulated process is a valid inference about the actual process. According to Adeyemi (2012), the need to validate a model cannot be over emphasized because the user of the model is usually difference from the developer who may have little or no control over the model. Paired t-test and test of bias were varied out on the error associated with the final prediction. Ten (10) trees were randomly selected from each of the age series independent of those of used in the model building for the purpose of validation as thus:

Null hypothesis (H_0): Paired observations are not different

Alternative hypothesis (H_A): paired observations are different

The formula is given as:

$t = D(S_a / j\overline{n})^{-1}$ - - - - - - - - - - - - (14)

Where; t = student's t-value; D = difference between paired observation; $S_a / j\overline{n}$ = standard error of the difference; The formula for the bias is given as:

Bias = $(\Sigma (y - \hat{y}) / \Sigma y)$ x 100 - - - - - - (15)

$\sum (y = \hat{y}) = D$ Total residual value $\sum y$ = Total observed value

RESULTS

Various growth parameters of *Gmelina arborea* were obtained and their values are presented in Table 1 The number of stems / ha ranged from 580 trees / ha as the lowest in year to 1110 trees/ha as the highest in year 3 the spacing was 2.5 metres by 2.5 metres with initial stocking of 1600 trees/ha which dropped between 69.4% and 36.3% in the 3rd and 11th year respectively. The number of stems/ha ranged between 1000 and 1200 trees/ha in year 3 to 500 and 650 stems /ha in year 11(Table2).

The mean diameter at breast height (dbh) was 13.31cm in year 3 as the lowest to 20.99cm as the highest in year 11. Accordingly, the mean dbh ranged between 7.46cm and 19.5cm in year 3 to 13.9 and 42.2cm in year 11. This study performed better in terms of basal area values which ranged between 4.3 and 47.0 m^2/ha to 9.0 and 54.6m^2/ha at ages 5 and 9 compared to 4.5 and 32.5m^2/ha to 9.0 and 42.5m^2/ha (Table 1and 2).

The mean height increases gradually from 13.3m to 25m in year3 to year 11 with a corresponding range of 9.3-16.5m and 14.4-34.6m respectively. The dominant height increases gradually from 17.28m in year 3 to 33.8m in year 11. It ranges from between 13.5m and 17m at year 3 to 14m and 26m and 37m at year 11(Table 1and 2). Basal area per hectare followed the same trend as mean dbh and increased from 15.44m^2/ha at year 3 to 31.18m^2/ha at year 11. It ranges from 4.4 to35.8m^2/ha at year 3 to 7.6 to 90.9m^2/ha at year 11. Form factor ranges from 0.401 as the lowest in year 3 and 0.419 as the highest in year 11(Table1and 2).

The volume per ha at the age of 3 was 82.39m^3/ha as the lowest to 315.5m^3/ha as the highest in year 11 with corresponding ranges of 16m^3/ha to 249.6m^3/ha at age 3 and 28m^3/ha to 1226.8m^3/ha/yr at year 11(Table1and 2). The mean annual increment declined from 27.46m^3/ha/yr at year 3 to 21.34m3/ha/yr at year 9 and slightly increased to 28.69m^3/ha/yr at year 11. It ranges from 5.3 –83.2m^3/ha/yr at year 3 to 2.6 to 111.5m^3/ha/yr at year 11(Table1and 2).

Table 1: Summary of stocking and tree parameters of Gmelina plantation in Obubra

	Age in years				
Tree parameters	**3**	**5**	**7**	**9**	**11**
Number of stems/ha	1110	910	815	745	580
Survival (%)	69.38	56.88	50,94	46.56	36.25
Mean diameter at breast height (dbh) (cm)	13.31	14.48	15.84	18.88	26.99
Dominant dbh (cm)	18.24	21.04	23.62	25.47	39.18
Mean total height (m)	13.3	13.6	14.9	20.2	25.0
Dominant total height (m)	17.28	18.04	20.72	26.44	33.88
Basal area (m^2/ha)	14.44	15.44	16.59	22.82	33.18
Volume (m2/ha)	82.37	83.56	102.60	192.22	347.56
Mean annual increment (m^3/ha/yr)	27.46	24.66	24.71	21.36	31.59
Form factor	0.401	0.41	0.415	0.417	0.419

Table 2: Ranges of stocking and tree parameters of Gmelina plantation in Obubra

	Age in years				
Tree parameters	**3**	**5**	**7**	**9**	**11**
Number of stems/ha	1000-1200	775-1225	725-900	625-850	500-650
Survival (%)	69.38	56.88	50,94	46.56	36.25
Mean dbh (cm)	7.46-19.5	8.4-22.1	8.2-25.5	11.7-27.8	26.99
Dominant dbh (cm)	14.0-21.5	17.1-23.1	19.6-26.3	20.9-30.2	27-42.7
Mean total height (m)	9.3-16.5	10.9-18.7	9.4-21.4	12.8-26.5	14.4-34.6
Dominant height (m)	13.5-17.0	14-20	16-23	23-28	26-37
Basal area (m^2/ha)	4.4-35.8	4.3-47	3.3-43.4	7.8-54.6	7.6-90.9
Volume (m2/ha)	16-249.6	12.2-361.8	8.9-438.8	33.5-601.7	28.6-1226.8
Mean annual increment (m^3/ha/yr)	5.3-83.2	2.4-72.4	1.3-62.7	3.7-66.9	2.6-111.5

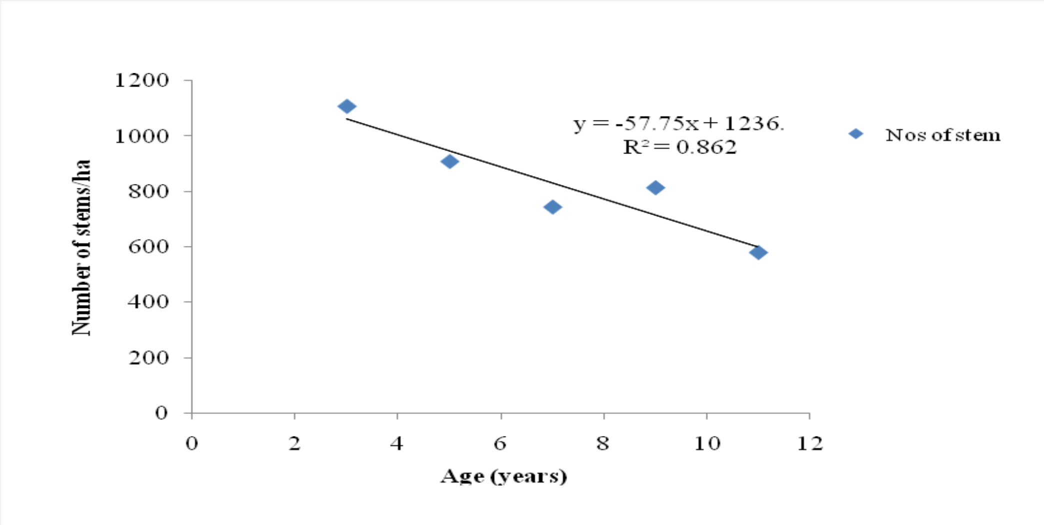

Figure 1: Number of stem /ha against age (years)

A total of seven growth equations were fitted to growth data and the results are presented in Table 3. Model 1 had dominant height (Ho) as dependent variable with age and total height as independent variables. The regression is significant ($p < 0.05$and < 0.01) for the equation, coefficient of determination (R^2) was high, 93.7% with corresponding root mean square error(RMSE) of 0.03, furnival index (FI) of 0.627 and high F-ratio of 164.21

Model 2 had dominantdbh(Do) as dependent variable (Do) with dbh, dominant height(Ho) and stocking(N) as independent variables. The regression equation is also significant ($p<0.05$ and $p <0.01$) with high R^2=99.8%, the RMSE, FI and F-ratio of 0.755, 0.755and 153.5 respectively (Table 3). Model 3 had total height (H) as dependent variable with age(A) of the stand as independent variable. The regression equation is significantly high at $p<0.05$and $p<0.01$with R^2, FI, RMSE and F-ratio of 95.6%, 1.243, 1.024 and 228.16 respectively. Model 4had Stocking (N) as the dependent variable while dbh (D) constitutes the independent variable. The regression equation is significantly high at $p<0.05$ and $p<0.01$with R^2, FI, RMSE and F-ratio of 87.9%, 0.619, 0.002and 21.88 respectively.Model 5had mean dbh(D)as dependent variable with age(A) of the stand as independent variable. The regression equation is significantly high at $p<0.05$ and $p<0.01$ with R^2, FI, RMSE and F-ratio of 97.2%, 1.279, 1.279 and 34.831 respectively. Model 6 had Basal area (B) as dependent variable while age (A) of the stand and dominant height (Ho) are the independent variables. The regression equation was significantly high at $p<0.05$ and $p<0.01$ with R^2, FI, RMSE and F-ratio being 99.9%, 0.074, 0.074 and 14470 respectively. Model 7 had Volume (V) as dependent variable with Mean total height (H) and mean basal area (B) as independent variables. The regression equation was highly significant at $p<0.05$ and $p<0.01$ with R^2 , FI, RMSE and F-ratio of 99.2%, 1.524, 0.033 and 1304.53 respectively (Table 3).

Table 3: Selected growth functions for *Gmelina arborea* in the study area

Model	Regression equation	R^2	FI	RMSE	F-ratio
1	$\text{Log } H_0 = 0.322 + 0.868 \log H – 0.2A^{-2}$	0.937	0.675	0.03	164.21**
2	$D_0 = -4.476 + 2.26D + 0.57 H_0 +0.84 N^{1/2}$	0.998	0.755	0.755	153.5**
3	$H = 16.634 –1.825A+0.237A^2$	0.956	1.243	1.0243	228.16**
4	$\text{Log } N = 3.924 – 0.815 \log D$	0.879	0.619	0.002	21.88**
5	$D = 16.912 –1.0802A + 0.242A^2$	0.972	1.279	1.279	34.831**
6	$B = 9.28 –1.975A+ 0.459A + 0.081H_0A$	0.999	0.074	0.074	14470**
7	$\text{Log } V = 0.399+1.018 \log H+1.04 \text{ Log } B$	0.992	1.524	0.033	1304.53**

Where: H_0 = dominant height (m); H = total height (m); A=age (years); D= Mean diameter at breast height, D_0 = dominant dbh (cm), Log = logarithm to base 10, F1 = Furnival index, RMSE = root mean square error, $F\text{-}_{ratio}$ = significance of regression; R^2 = coefficient of determination

Validation of selected models

The selected models were used to generate predictive values as presented in table 4. The observed and predicted values were not significantly different when they were subjected to t-test. A paired t-test conducted on the residual indicates no significant difference between the observed and predicted values within any correction on the predicted values with estimated bias which ranged from 0.02 to 0.48% as shown in Table 5.

Since all the t-calculated in Table 5 are not significantly different and are less than the tabulated t = 2.303, the null hypothesis is not rejected and concluded that there is no significant difference between the observed and predicted values as presented in Table 4.

Table 4: Observed and Predicted values using developed models

			Age in years				
Model	**Variable**		**3**	**5**	**7**	**9**	**11**
1	H_0(m)	Observed	17.3	18.04	20.74	26.44	33.88
		Predicted	17.5	18.48	20.54	27.0	31.97
2	D_0(cm)	Observed	18.24	21.04	23.62	25.47	39.88
		Predicted	18.51	20.45	24.01	25.44	32.97
3	D(cm)	Observed	13.31	14.48	16.84	18.88	26.99
		Predicted	13.69	13.95	16.16	20.30	26.38
4	H(m)	Observed	13.1	13.6	14.9	20.22	25.0
		Predicted	13.29	13.45	15.5	19.5	25.3
5	N/ha	Observed	1110	910	815	745	580
		Predicted	1118	950	840	766	572
6	B(m^2/ha)	Observed	15.44	14.99	16.59	22.82	33.18
		Predicted	15.47	14.94	16.64	22.79	33.10
7	V(m^3/ha)	Observed	82.37	76.94	102.64	192.04	315.54
		Predicted	83.00	75.24	105.09	190.67	315.88

Where: H_0 = dominant height (m); D_0 = dominant dbh (cm); D = mean diameter at breast height (dbh); H = mean total height (m); N = number stems/ha; B = basal area (m^2/ha); V = volume (m^3/ha)

Table 5: Result of validation tests

Model	**a_0**	**a_1**	**t-cal.**	**Bias (%)**
1	0.500	0.992	0.0017^{ns}	0.08
2	0.021	0.965	0.0416^{ns}	0.48
3	0.025	0.960	0.0179^{ns}	0.02
4	0.117	0.993	0.0007^{ns}	0.05
5	0.028	0.849	0.0184^{ns}	0.36
6	0.003	1.007	0.018^{ns}	0.08
7	0.005	1.002	0.0061^{ns}	0.05

Where: a_0 = regression constant or intercept; a_1= regression coefficient or scope; t_{cal} = t-calculated t_{tab} = t tabulated at $\propto$ = 0.05 level =2.303; ns = not significant at $\propto$ = 0.05 level; df = degree of freedom

DISCUSSION

The equation: Log N = 2.704 - 0.785D had a negative scope signifying decrease in number of stems/ha with increase in age (Figure 1). Indeed, it had effect on mean annual increment (m^3/ha/yr), basal area (m^3/ha) and volume (m^3/ha). This confirms the report by Akindele and Le-May (2006) that number of stem/ha affects mean annual increment culmination age. Increase in mean dbh brought about a corresponding increase in basal area and volumes of a tree as reported by Turan (2009) within the same period. Indeed, it had effect on mean annual increment (m^3/ha/yr), basal area (m^2/ha) and volume (m^3/ha). This confirms reports by Adeyemi (2012) that number of stems/ha affects mean annual increment culmination age. The mean diameter at breast height (dbh) was 13.31cm in year 3 as the lowest to 20.99cm as the highest in year 11 accordingly, the dbh ranged between 7.46cm and 19.5cm in year 3 to 13.9 and 42.2cm in year 11.

This in line with the reports by Oyemakin et al., (2013) that the height 3.5 metres and 3 meters were observed for the forest five years in Gambari and Omo Forest Reserves respectively. This study performed better in terms of basal area values which ranged between 4.3 and 47.0m^2/ha to 9.0 and 54.6m^2/ha at ages 5 and 9 compared to 4.5 32.5 and 9.0-42.5m^2/ha as reported by Oyemakin *et al*. (2013) within the same period (3rd and 11th year respectively). This revealed initial fast growth of 3.6m per year for the first five years and 2.1m per year thereafter between the ages 7 and 11 for *Gmelina* stands at Ukpon River Forest Reserve in Obubra (Levi, and Apolinaria, 2002)

The regression equations were fitted to the growth data and the results presented in table 3were all highly significant at $p<0.05$and $p<0.01$ with very high R^2 values, low root mean square error (RMSE), low fit index (FI) and high F ratio (Adeyemi 2012).

CONCLUSION

Seven growth models were developed using data on tree age, stocking, diameter and height for evaluation of performance of Gmelina plantation in Ukpon River Forest Reserve, Cross River State, Nigeria. The results of the study revealed that the selected growth functions were good predictive models within the age range of 3 to 11 years under similar environmental conditions. The developed models are imperative for estimating future individual tree characteristics, volume and yield of the main crops in the pure stands. The derived models are also useful tools for determining the general productive capacity of the Obubra Gmelina plantation. The development of growth functions is a critical step towards proper assessment of growth and yield of Gmelina growing stock under sustainable plantation management. The study provides reliable information and relevant data which may help in comparing and predicting growth of *Gmelina* species within the age range and similar site.

RECOMMENDATIONS

i. In view of the species fast initial growth within the first five years of its establishment proper maintenance in terms beating up and cleaning should be carried out to stimulate growth and development during this period.
ii. Reliable information on growth and yield are important tools for effective management of any plantation. Therefore, repeated measurements at regular intervals would be a satisfactory means of obtaining reliable growth data.
iii. Attempt should made to collect growth data from more matured Gmelina plantation with ages between 15 and 20 years. This will allow for the construction of appropriate growth functions which covers all age series of *Gmelina arborea*.

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