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Non-Linear Regression Models for Volume Estimation of *Gmelina arborea* (Roxb.) in Uyo Ravine Plantation, Akwa Ibom State, Nigeria

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ABSTRACT

This research elucidates non linear relationship for volume estimation of *Gmelina arborea* in Uyo Ravine plantation, Akwa Ibom State Nigeria. Series of functional models were developed and the estimates of measurement of stand parameters such as diameter at breast height (DBH), stump diameter (Dst), total height (THT), merchantable height, (MTH), merchantable length (MLT) were used for modeling procedures for best fit models for stand volume estimation. Twenty temporary sample plots of 20m x 20m were randomly established without replacement and all trees in each plot were measured. Quantitative data collected were subjected to correlation and regression analyses for determination of empirical relationship between the growth variables. The developed models for volume estimation were evaluated by confirming the goodness of fit of the model and the statistical significance of the parameters using statistical relevant fit indices and criteria. The results of the study showed there were significant associations between the *Gmelina arborea* growth characteristics both at the individual and stand levels. The correlation analyses revealed a significant association with coefficient of correlation (r) ranging from 0.576 – 0.836 among the *Gmelina arborea* growth characteristics at the stand level while the association between the volume and diameter at breast height gave r-value of 0.978 which was very significant $P<0.05$. Similarly, the results of the study in testing for relationship among the growth parameters using volume models showed that the non linear regression volume models significantly fulfilled the criteria for model selection or goodness of fit among cubic, logarithm and quadratic non linear regression models with their coefficient of determination (R^2) ranging from 0.640-0.881 and low values of standard error of the estimate (SEE) at $P< 0.05$. These models were recommended for volume

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estimation of *Gmelina arborea* in the study area and other *Gmelina arborea* plantations for effective plantation forest management in Nigeria.

***Keywords*:** *Gmelina arborea*, Volume estimation, Models, Non-linear Regression

1. INTRODUCTION

The forest is any vegetal formation with minimum of 10 percent crown cover with trees of (minimum height 5 meters) and bamboos generally associated with wildlife, fauna and natural soil conditions and not subjected to agricultural practices. These forest areas, including plantation forest provide the means of livelihood for nearly 500 million forest dwellers and nearby residents or settlers who depend on forest resources. In Nigeria alone, over 4,600 plant species have been identified (Colins and Ertel, 2008).

Gmelina arborea is a tree species found in low land rain forest zone of Nigeria. It is moderately sized to large deciduous tree with a straight trunk and wide spreading leaves (Kumar *et. al*., 2003). It has numerous branches forming a large shady crown, attains a height of 12m - 30m or more and 60 cm - 100 cm in diameter. Bark smooth, pale ashy grey to yellow with black patches and conspicuous corky circular lenticels. Drupes ovate or pyriform, 2 cm - 2.5 cm long, smooth, becoming orange yellow, pulpy with large egg shape stones, having 1-4 cells (Kumar *et. al*. 2003). It grows on many soils such as acidic, laterites and calcareous loams, doing poorly on thin or poor soils with hardpan, dry sands, or heavily leached acidic soils, well-drained basic alluviums. *Gmelina arborea* is reported to tolerate annual precipitation of 7 to 45 dm, annual temperature of 20 to 26 ºC, and pH of 6 to 8. It can tolerate a 6-7months dry season (Kumar *et. al*. 2003).

Effective forest management requires estimates of growing stock. Such information guide forest managers in timber valuation as well as in allocation of forest areas for harvest (Aigbe *et al* 2012). For timber productions, an estimate of grow stock is often expressed in form of timber volume, which can be estimated from easily measurable tree dimensions (Akindele and Le May, 2006). The most common estimate of a growing stock is to use volume equations based on relationships between volume and variables such as diameter and height. According to (Avery and Burkhart, 2002), volume equations are used to estimate average content of standing tree of various sized and species.

It is imperative to emphasis that in developing a model, it is central to think in terms of controllable variable and the relationship that exist between them; especially for non linear regression model which is a form of regression analysis in which data are fit to a model expressed as a mathematical function.

In Nigeria and Akwa Ibom state in particular, forest estates have been mismanaged. Most of the forest estates in the state are more of nomenclature than of status. In terms of structures, species composition and physiognomy the forest estates has since lost its meaning (Medugu *et al.* 2010).

The forest estate lacks baseline data on estimate of growing stock of forest resources. Changes in growing stock along different land use patterns have not been quantified and documented over the years, as a result, there is need to provide information along this line and to provide data and model for determination and adoption of an appropriate management strategy for the sustained use of resources of the plantation.

Though there have been enormous works in this area by various scientists to improve the understanding of the complex and dynamic components in the forest. In Nigeria alone, much work has been done in this regard to plantation species of both indigenous and exotic plants (Okojie and Nokoe, 1976; Abayomi, 1983, Osho, 1983; Onyekwelu and Akindele, 1995). Akindele and Le May (2006) reported that models in forestry are tools for providing long-term decision in forest management, estimation of growing stock, timber valuation and allocation of forest areas for harvest. However, none have been particularly developed for Uyo Ravine plantation. This study fills this gap and would in turn ensure the sustainability potential of managing the species using non-linear modeling procedure. Thus, the need to develop a non linear regression model for volume estimation of *Gmelina arborea* and project a data base on stand level parameters by determining the relationship between the trees volume, stump diameter and diameter at breast height (DBH) with a view to building a predictive model.

2. METHODS

2. 1. Study site

This study was carried out in Uyo Local Government Area of Akwa Ibom State of Nigeria. The plantation lies between latitude 5º2’40”N and longitude 7º567”E. It was established in 1985 with plantation number EP-AK-06-85. It is purely *Gmelina arborea* plantation. (Isidore, 2006). The whole of Akwa Ibom State is underlain by sedimentary formation of late tertiary and Holocene ages. Quart is the sole framework element, and monocrystalline Quartz constitutes about two-thirds of the quartz varieties in the state. The soil has low to moderate water holding capacity due to coarse texture (Figure 1).

2. 2. Data Sampling and Collection

Random sampling was adopted. Twenty temporary sample plots, each of size 20m x 20m (0.04 hectare in size) were randomly established in the *Gmelina arborea* plantation. All the trees in each plot were measured. The sample plots were selected randomly without replacement.

2. 3. Models development

A series of regression equations were fitted to the data. The equations were assessed and compared on the bases of coefficient of determination R^2, variance ratio (F ratio) and overall test standard error of estimate (SEE). Some regression equation forms that were fitted to the data in this study are presented below (equations 3-11)

$V = aD^b$ ………………………………… Equation 1

$V = aD + bD^2H$ ………………………... Equation 2

$LogV = Log\ a + b\log D^2H$…………………. Equation 3

$LogV = a + b\log D^2H$ ……………………... Equation 4

$\ln V = a + b\ln D$ ………………………… .. Equation 5

$V = aD + bD^2$ ………………………….. Equation 6

$$V = a + b_1D\ b_2D^2 \quad \text{Equation 7}$$

$$V = a + b_1D + b_2D^2H \quad \text{Equation 8}$$

$$\ln V = aD + b\ln D^2 \quad \text{Equation 9}$$

where:

V = dependent variable

D = independent variable

H = independent variable

a, = slope

b, b_1, b_2 = gradient

ln = natural logarithm

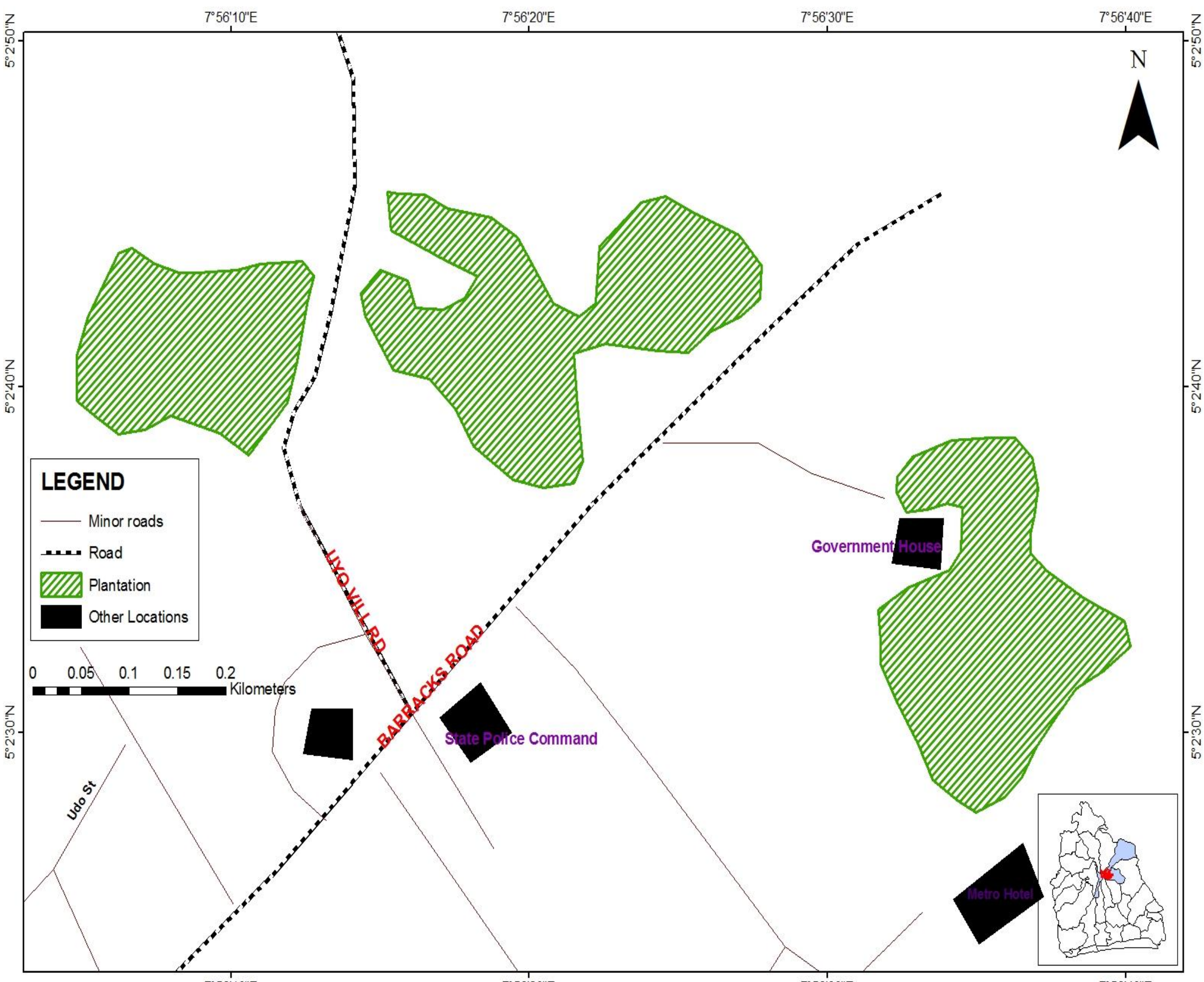

Figure 1. Map of Uyo Ravine plantation

2. 4. Data Analysis

The preliminary analysis of the *Gmelina arborea* plantation was done for computation of individual tree volume and per-hectare estimate of stand parameters from the raw data. The procedures used at this stage were the mean tree method used by Abayomi (1983). The calculations also include the range of value (minimum and maximum).

The procedures include the following steps:

(1) Estimation of minimum, maximum and mean basal areas per hectare from stump diameter and dbh using the formula

$$BA = \frac{\pi d^2}{4} \quad \text{... Equation 10}$$

where BA = basal Area (m^2)
π = 3.142 (constant)
d = diameter at breast height

(2) Calculation of tree volume for each of the trees in each plot, using Newton's formula

$$V = \frac{H}{6}\left(A_b + 4A_m + A_t\right) \quad \text{........... Equation 11}$$

where A_b = Tree cross – sectional area at the base
A_m = Tree cross – sectional area at the middle
A_t = Tree cross – sectional area at the top

(3) Estimation of stand parameters in per hectare bases. The parameters estimated on per hectare bases are numbers of trees, basal area and volume. The number of trees per hectare was obtained by multiplying the average number of tree per plot by 25, since each plot is 0.04 ha in size. Multiplying mean basal area and mean volume by the number of trees per hectare resulted in per hectare estimate of basal area and volume for each plot.

3. RESULTS

Table 1. Descriptive statistic for major growth *Gmelina arborea* in the study area

Variables	Number	Mean ± S.E	Maximum	Minimum
Total height (m)	253	26.209±0.294	39.00	10.00
Merchantable height (m)	253	20.170±0.322	38.00	4.50
Merchantable length (m)	253	17.100±0.287	29.90	4.80
Volume (m^3)	253	1.839±0.092	12.46	0.17

Diameter at breast height (m)	253	0.326±0.005	0.72	0.19
Stump diameter (m)	253	0.344±0.005	0.73	0.19
basal area for Dbh	253	0.088±0.003	0.41	0.03
basal area for Dst	253	0.098±0.003	0.41	0.03

Table **2.** Correlation matrix for individual tree growth characteristics in *Gmelina arborea* at the study area

	Volume (m^3)	Dbh (m)	D_{st} (m)	Log volume (m^3)	Total height (m)	Merchantable height (m)	Ln height (m)	Ln Dbh (m)	Ln volume (m)
Volume (m^3)	1.000								
Dbh (m)	0.836**	1.000							
D_{st} (m)	0.846**	0.970**	1.000						
Log vol (m^3)	1.000**	0.836**	0.846**	1.000					
Total height (m)	0.708**	0.499**	0.475**	0.708**	1.000				
Merchantable length (m)	0.610**	0.563**	0.580**	0.601**	0.576**	1.000			
Ln height (m)	0.708**	0.499**	0.475**	0.708**	1.000**	0.576**	1.000		
Ln Dbh (m)	0.836**	1.000**	0.970**	0.836**	0.499**	0.563**	0.499**	1.000	
Ln vol (m^3)	1.000**	0.836**	0.846**	1.000**	0.708**	0.601**	0.708**	0.836**	1.000

V = Volume (m^3), Dbh = Diameter at breast height (m), Ln height = Natural logarithm of total height (m), Ln Dbh = Natural logarithm of diameter at breast height (m), Ln vol = Natural logarithm of volume (m^3)

Table 3. Correlation matrix for major growth characteristics of *Gmelina arborea* stand in the study area.

	MEANTHT	MEAN DBH	MEAN Dst	MEANMHT	MEANVOL	MBA/PLT	BA/HA
MEANTHT	1.000						
MEAN DBH	0.341	1.000					
MEAN Dst	0.273	0.982	1.000				

MEANMHT	0.533	0.591	0.611	1.000			
MEANVOL	0.553	0.926	0.891	0.717	1.000		
MBA/PLT	0.288	0.978	0.993	0.628	0.911	1.000	
BA/HA	0.288	0.978	0.993	0.628	0.911	1.000	1.000

MEANTHT = Mean total height (m); MEANDBH = Mean diameter at breast height (m); MEAN Dst = Mean stump diameter (m); MEAN VOL = Mean volume (m^3); MBA/PLT = Mean basal area per plot; BA/HA = Basal area per hectare

Table 4. Parameters and estimated coefficient for volume and diameter at breast height models in the study area

Relationship	Model	Parameter	Coefficient	Model Type	R^2	SEE	F-value	P-value
Volume/ Dbh	$V=b_o+b\ln Dbh$	b_o b_1	7.842 5.228	Logarithmic	0.67	0.84	516.29	0.00
	$V=b_o-b_1Dbh^{-1}$	b_o b_1	6.597 -1.471	Inverse	0.54	0.99	296.31	0.00
	$V=b_o-b_1Dbh+b_2Dbh^2$	b_o b_1 b_2	1.489 -11.966 37.776	Quadratic	0.87	0.53	850.17	0.00
	$V=b_o-b_1Dbh+b_2Dbh^2+b_3+Dbh^3$	b_o b_1 b_2 b_3	0.997 -7.840 26.91 8.918	Cubic	0.87	0.53	565.19	0.00
	$V=b_oDbh^{b_1}$	b_o b_1	25.788 2.502	Power	0.66	0.42	475.95	0.00
	$V=b_oe^{b_1 Dbh}$	b_o b_1	0.140 7.1927	Exponential	0.64	0.43	454.96	0.00

V = volume, b_o = slope, b_2-b_3=gradient, ln = natural logarithm, e = exponential, R^2 = coefficient of determination, SEE = standard error of estimate, Dbh = diameter at breast height

Table 5. Parameters and estimated coefficient for volume and stump diameter models in the study area

Relationship	Model	Parameter	Coefficient	Model Type	R^2	SEE	F-value	P-value
Volume/D_{st}	$V=b_o+b_1\ln D_{st}$	b_o b_1	7.425 5.102	Logarithmic	0.67	0.85	503.52	0.00
	$V=b_o-b_1D_{st}^{-1}$	b_o b_1	6.549 1.534	Inverse	0.54	0.99	299.29	0.00

	$V=b_o-b_1D_{st}+b_2D_{st}^2$	b_o b_1 b_2	1.748 -12.307 34.381	Quadratic	0.85	0.57	718.53	0.00
	$V=-b_o+b_1D_{st}^2-b_2D_{st}^3$	b_o b_1 b_2 b_3	-2.174 19.509 -46.882 65.034	Cubic	0.86	0.56	504.70	0.00
	$V=b_oD_{st}^{b}{}_1$	b_o b_1	20.829 2.429	Power	0.64	0.43	451.58	0.00
	$V=b_oe^{b}{}_1{}^{D}{}_{st}$	b_o b_1	0.153 6.556	Exponential	0.63	0.44	423.73	0.00

V = volume, b_o = slope, b_2-b_3 = gradient, ln = natural logarithm, e = exponential, R^2 = coefficient of determination, SEE = standard error of estimate, Dst = stump diameter.

Table 6. Parameters and estimated coefficient for volume and diameter at breast height square multiply by merchantable height models in the study area

Relationship	Model	Parameter	Coefficient	Model Type	R^2	SEE	F-value	P-value
Volume/Dbh^{2}H	$V=b_o+b_1\ln Dbh^2H$	b_o b_1	0.656 1.761	Logarithm	0.63	0.89	421.62	0.00
	$V=b_o-b_1Dbh^2H^{-1}$	b_o b_1	2.968 -1.789	Inverse	0.29	1.23	107.27	0.00
	$V=b_o+b_1Dbh^2H+b_2(DbhH)^2$	b_o b_1 b_2	0.366 0.530 0.018	Quadratic	0.87	0.53	840.46	0.00
	$V=b_ob_1Dbh^2H+b_2(Dbh^2H)^2b_3Dbh^2H)^3$	b_o b_1 b_2 b_3	0.531 -0.400 0.044 0.001	Cubic	0.87	0.53	564.15	0.00
	$V=b_oDbh^2H^{b}{}_1$	b_o b_1	0.822 0.853	Power	0.63	0.44	418.07	0.00
	$V=b_0eb_1^{Dbh2H}$	b_o b_1	0.744 0.274	Exponential	0.55	0.48	309.58	0.00

V = volume, b_o = slope, b_2-b_3=gradient, ln = natural logarithm, e = exponential, R^2 = coefficient of determination, SEE = standard error of estimate, Dbh = diameter at breast height, H = merchantable height

Table 7. Parameters and estimated coefficient for volume and stump diameter square multiply by merchantable height models in the study area.

Relationship	Model	Parameter	Coefficient	Model Type	R^2	SEE	F-value	P-value
Vol/D_{st}^2H	$V=b_o+b_1 lnD_{st}^2H$	b_o b_1	0.503 1.716	Logarithm	0.62	0.91	406.31	0.00
	$V=b_o-b_1D_{st}^2H^{-1}$	b_o b_1	2.924 -1.897	Inverse	0.29	1.24	102.93	0.00
	$V=b_o+b_1D_{st}^2H+b_2(D_{st}^2H)^2$	b_o b_1 b_2	0.518 0.376 0.023	Quadratic	0.89	0.51	902.86	0.00
	$V=b_o+b_1D_{st}^2H+b_2(D_{st}^2H)^2$ $b_3(D_{st}^2H)^3$	b_o b_1 b_3	0.442 0.443 0.010	Cubic	0.88	0.51	601.73	0.00
	$V=b_oD_{st}^2H^{b}{}_1$	b_o b_1	0.765 0.828	Power	0.61	0.45	395.13	0.00
	$V=b_oe^{b_1 Dst_2 H}$	b_o b_1	0.745 0.244	Exponential	0.55	0.48	310.01	0.00

V = volume, b_o = slope, b_2-b_3 = gradient, ln = natural logarithm, e = exponential, R^2 = coefficient of determination, SEE = standard error of estimate, Dst = stump diameter, H = merchantable height

Table 8. Parameters and estimated coefficient for Lnvolume and diameter at breast height models in the study area

Relationship	Model	Parameter	Coefficient	Model Type	R^2	SEE	F-value	P-value
Lnvol./Dbh	$lnV=b_o+b_1 lnDbh$	b_o b_1	3.250 2.502	Logarithmic	0.66	0.42	475.95	0.00
	$lnV=b_o-b_1Dbh^{-1}$	b_o b_1	2.852 -0.765	Inverse	0.62	0.43	413.60	0.00
	$lnV=-b_o+b_1Dbh-b_2Dbh^2$	b_o b_1 b_2	-2.875 12.350 -6.874	Quadratic	0.66	0.42	238.82	0.00
	$lnV=-b_o+b_1Dbh-$ $b_2Dbh^2+b_3Dbh^3$	b_o b_1 b_2 b_3	-3.123 14.429 -12.346 4.492	Cubic	0.66	0.42	158.68	0.00

V = volume, b_o = slope, b_2-b_3 = gradient, ln = natural logarithm, e = exponential, R^2 = coefficient of determination, SEE = standard error of estimate, Dbh = diameter at breast height,

Table 9. Parameters and estimated coefficient for Lnvolume and stump diameter models in the study area

Relationship	Model	Parameter	Coefficient	Model Type	R^2	SEE	F-value	P-value
Ln vol./D_{st}	$\ln V = b_o + b_1 \ln D_{st}$	b_o b_1	3.036 2.429	Logarithmic	0.64	0.43	451.59	0.00
	$\ln V = b_o - b_1 D_{st}^{-1}$	b_o b_1	2.813 -0.794	Inverse	0.62	0.44	406.84	0.00
	$\ln V = -b_o + b_1 D_{st} - b_2 D_{st}^2$	b_o b_1 b_2	-2.862 11.849 -6.672	Quadratic	0.64	0.43	223.15	0.00
	$\ln V = -b_o + b_1 D_{st} - b_2 D_{st}^2 + b_3 D_{st}^3$	b_o b_1 b_2 b_3	-4.000 21.082 30.255 18.874	Cubic	0.64	0.43	149.79	0.00

V = volume, b_o = slope, b_2-b_3 = gradient, ln = natural logarithm, e = exponential, R^2 = coefficient of determination, SEE = standard error of estimate, Dst = stump diameter

Table 10. Parameters and estimated coefficient for volume square and diameter at breast height models in the study area

Relationship	Model	Parameter	Coefficient	Model Type	R^2	SEE	F-value	P-value
$V^{0.5}$/Dbh	$V^{0.5} = b_o + b_1 \ln Dbh$	b_o b_1	3.233 1.700	Logarithmic	0.77	0.22	822.36	0.00
	$V^{0.5} = b_o - b_1 Dbh^{-1}$	b_o b_1	2.895 -0.499	Inverse	0.67	0.26	511.71	0.00
	$V^{0.5} = b_o + b_1 Dbh + b_2 Dbh^2$	b_o b_1 b_2	0.035 2.733 3.153	Quadratic	0.83	0.19	598.88	0.00
	$V^{0.5} = b_o + b_1 Dbh + b_2 Dbh^2 - b_3 Dbh^3$	b_o b_1 b_2 b_3	0.290 0.590 8.796 -4.633	Cubic	0.83	0.19	398.75	0.00
	$V^{0.5} = b_o {b_1}^{Dbh}$	b_o b_1	5.078 1.251	Power	0.66	0.21	475.95	0.00
	$V^{0.5} = b_o e^{{b_1}^{Dbh}}$	b_o b_1	0.374 3.596	Exponential	0.64	0.21	454.96	0.00

$V^{0.5}$ = volume square, b_o = slope, b_2-b_3 = gradient, ln = natural logarithm, e = exponential, R^2 = coefficient of determination, SEE = standard error of estimate, Dbh = diameter at breast height.

Table 11. Parameters and estimated coefficient for volume square and stump diameter models in the study area

Relationship	Model	Parameter	Coefficient	Model Type	R^2	SEE	F-value	P-value
$V^{0.5}/D_{st}$	$V^{0.5}=b_o+b_1 lnD_{st}$	b_o b_1	3.09 1.65	Logarithmic	0.76	0.22	793.68	0.00
	$V^{0.5}=b_o-b_1D_{st}$	b_o b_1	2.87 0.52	Inverse	0.67	0.26	516.78	0.00
	$V^{0.5}=b_o+b_1D_{st}+b_2D_{st}^2$	b_o b_1 b_2	0.08 2.47 2.76	Quadratic	0.81	0.19	540.89	0.00
	$V^{0.5}=b_o+b_1D_{st}-b_2D_{st}^2+b_3D_{st}^3$	b_o b_1 b_2 b_3	-0.41 6.51 -0.75 8.26	Cubic	0.81	0.19	360.02	0.00
	$V^{0.5}=b_o b_1^{D_{st}}$	b_o b_1	4.56 1.21	Power	0.64	0.21	451.59	0.00
	$V^{0.5}=b_o e^{b_1 D_{st}}$	b_o b_1	0.39 3.28	Exponential	0.63	0.23	423.73	0.00

$V^{0.5}$ = volume square, b_o = slope, b_2-b_3 = gradient, ln = natural logarithm, e = exponential, R^2 = coefficient of determination, SEE = standard error of estimate, Dst = stump diameter.

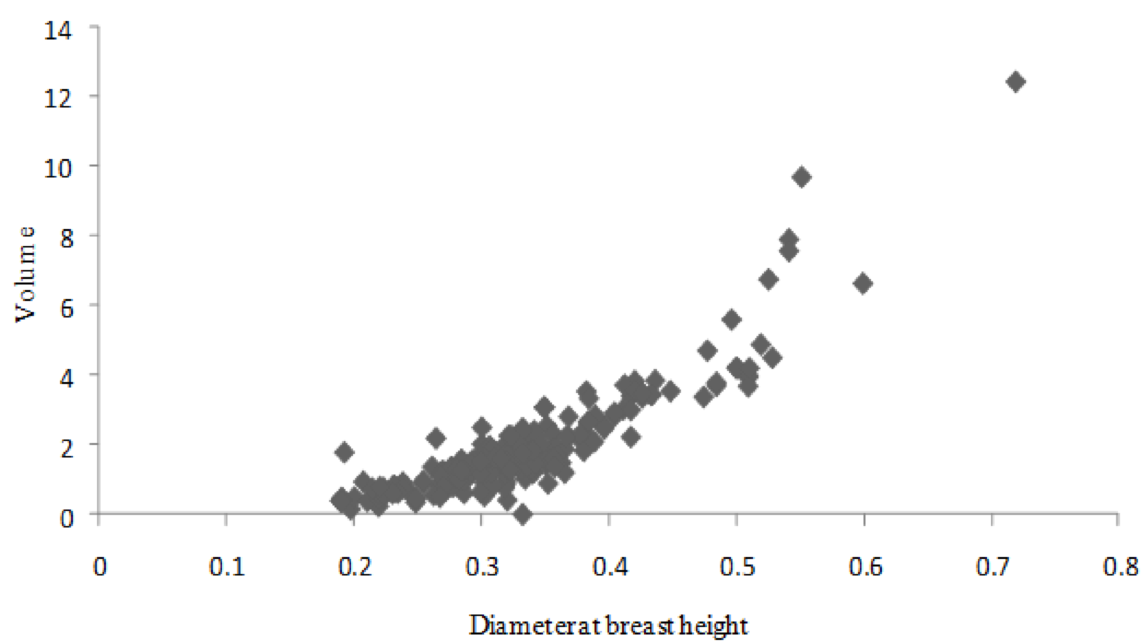

Fig. 2: Scatter diagram of relationship between volume and diameter at breast height

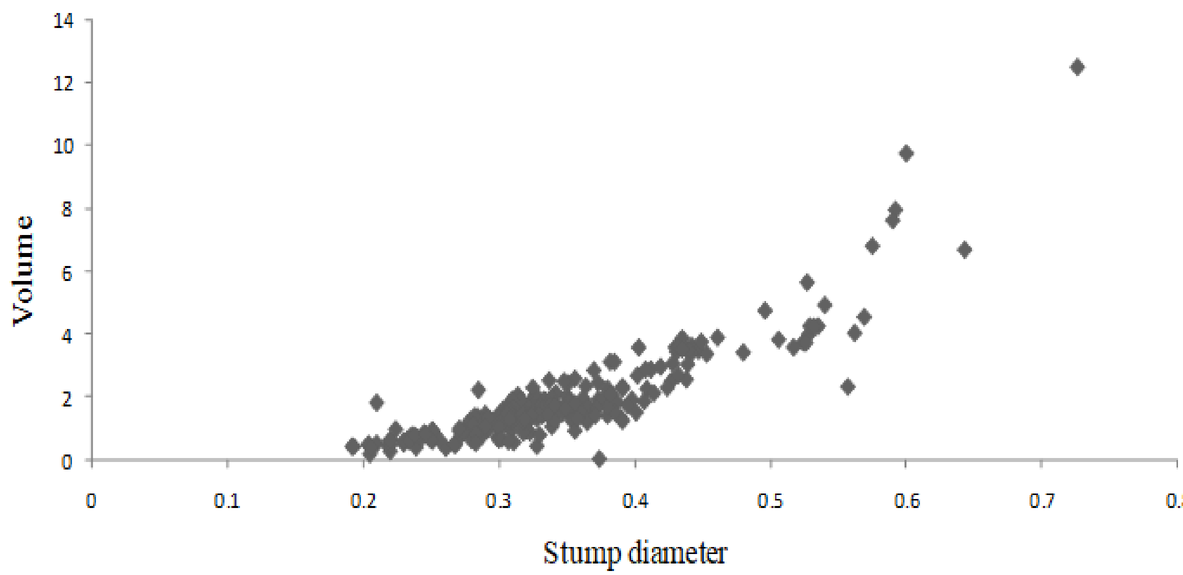

Fig. 3: Scatter diagram of relationship between volume and stump diameter

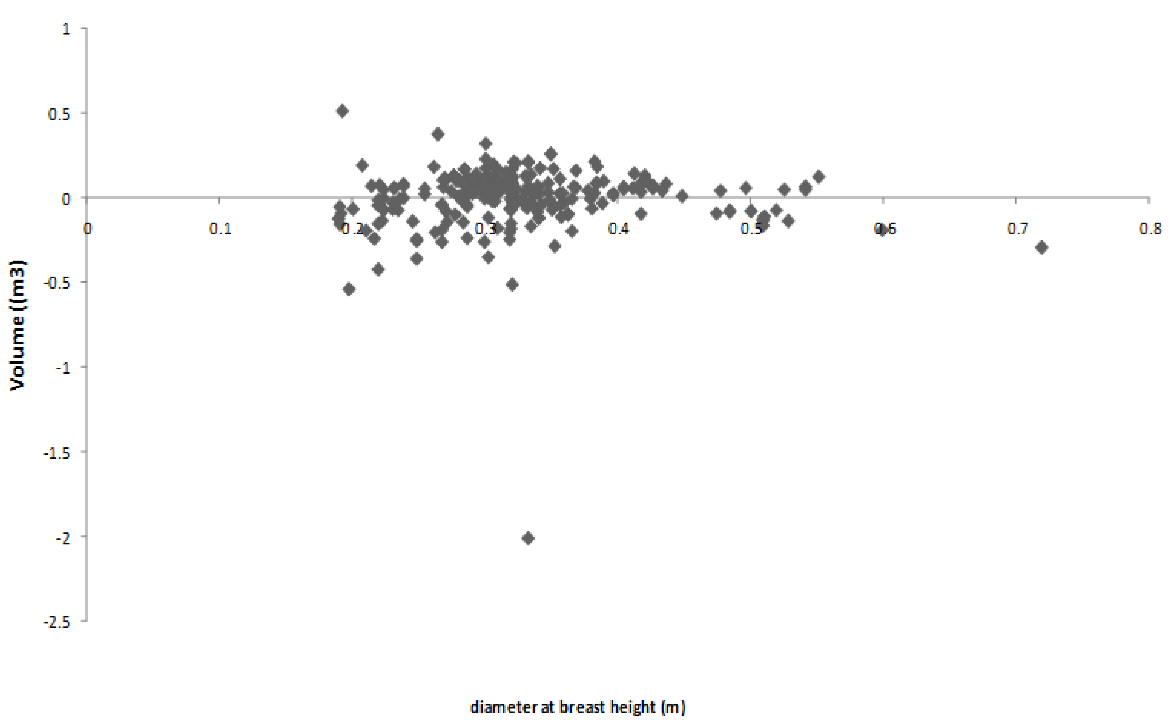

Fig 4:Residual Plot for volume and diameter at breast height of Gmelina arborea in the study area

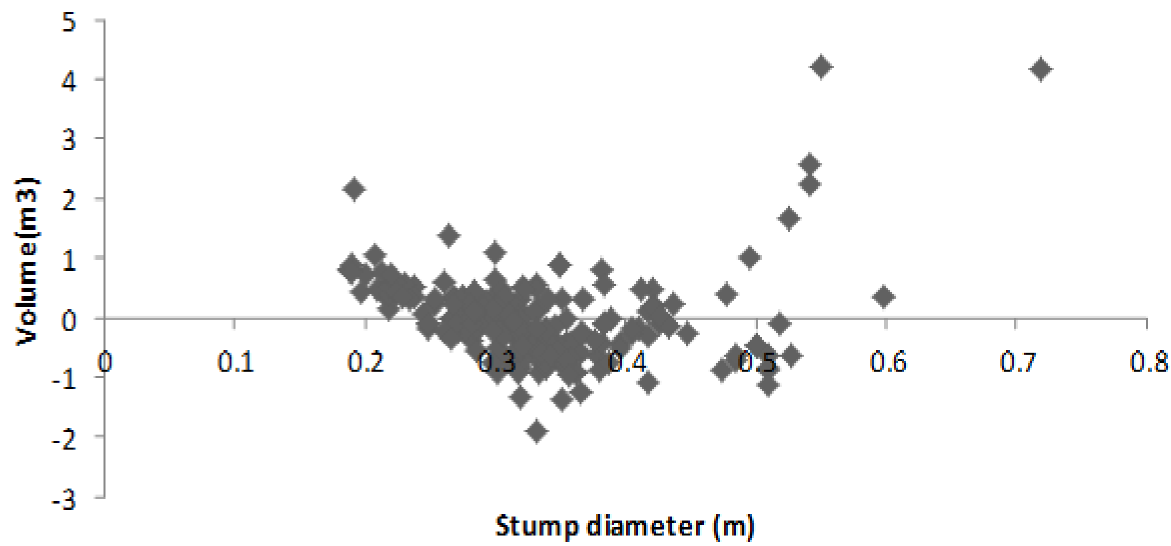

Fig.5:Residual Plot for volume and stump diameter of Gmelina arborea in the study area

4. DISCUSSION

4. 1. Growth Variables of *Gmelina arborea*

Table 1 reveals the results of descriptive statistics of diameter breast height (DBH), stump diameter (Dst), height, volume, merchantable length and height as well as basal area for diameter at breast height (dbh) and stump diameter. The maximum and minimum values for DBH are 0.72m 0.19m respectively; while the volume and Dst have 12.46m^3 and 0.73m accordingly. The total heights of trees in the study area have 39.00m as maximum and 10.00m as minimum. This table also shows some variations in the growth attributes of *Gmelina arborea* and this variation can be attributed to lack of proper management practices as most of the trees in the field have felled without been replanted. In addition to this, the tree are currently competing with grasses and other plants in the plantation for nutrients, sunlight as regular clearing is not being carried out.

4. 2. Test of Association between Growth Attributes

Tables 2 and 3 express the test of association between the growth attributes using correlation analysis. They show the correlation coefficient of the various growth parameters of individual trees in the study area. The highest correlation coefficient values was obtained between Dbh and Dst (0.970m), followed by volume and Dst (0.846). In Table 3, very weak correlation was seen to exist between mean total height and mean stump (diameter Dst) in the stand. This could be attributed to the fact that numbers of trees in actual sense is not necessarily a tree growth variable (Gregoire and Schabenberger, 1996).

4. 3. Non Linear Regression Models

The results of the non linear regression models for tree volume estimation when data from the study area were fitted are presented in Tables 4 to table 11. In Tables 4, 5, 6 and 7 the models that best satisfied the above criteria are the quadratic models. This suggests that the tree volumes in the field are bigger. Figures 2 and 3 reveal that the relationship between the variables (volume versus diameter at breast height). It was observed from the scattered diagram that all the relationships were positive indicating that increase in value of one variable is associated with an increase in value of another variable (Aigbe *et al.*, 2012). There is linear relationship between the variables. According to Akindele and Lemay (2006), equations are not conditioned to pass through the origin if the dependent variable was merchantable, rather than total height.

Logarithm and Quadratic models satisfied the criteria in Tables 10 and 11; volume square was taken as the dependent variable and Dbh as the independent (Table 10). In Table 11, volume square was used as dependent variable while Dst was used as the independent variable. The assessment criteria revealed that all the models are very suitable for tree volume estimation in plantation. These models were similar to those used by (Akindele and LeMay, 2006) for some timber species and by Nokoe (1980) for some plantation species. The standard error of estimate is a good measure of overall predictive value of regression equations (Akindele and LeMay, 2006; Temesgen *et.al,* 2008; Paulo *et.al,* 2011). It is also a common measure of goodness of fit in nonlinear regression models, with low values indicating better fit. In this study Standard error of estimate (SEE) ranged from 0.528 for model 3, 0.568 for model 9, 0.531 for model 16, 0.514 for model 22, 0.420 for model 26, 0.427 for 30, 0.817 to 0.217 for model 10 and 0.220 for model 40. All the non-linear models developed in this study were discovered to be very adequate for volume estimation in plantation and they are recommended for further use.

4. 4. Model Evaluation and Residual Plots

Figures 4 and 5 are similar in their pattern of distribution of variables in the residual plots and these conform to normal distribution of error in regression analysis. Unbiased estimate of volume was observed (Zakrzewski and Bella, 1988); the variables were normally distributed at 0.2m for Dst^2 (Figures 4 and 5), which revealed that the statistical assumptions for fitting the regression models adjudged as best fits were not violated as also reported by Mabvurira and Miina (2002), Andreassen and Tomter (2003), Trasobares and Pukkala (2004), Zhao et al. (2004), and Sonmez *et. al.* (2009) For all twenty temporary sample plots that were measured, the diameter at breast height and stump diameter were also normally distributed though most data were clustered around the horizontal axis.

5. CONCLUSIONS

This study assessed various growth parameters on stand volume estimation of *Gmelina arborea* in Akwa Ibom state through direct measurements of these parameters (volume, total height, diameter at breast height, merchantable height and length as well as stump diameter). Two hundred and fifty three trees were measured in the study area. The study has revealed that non linear regression was efficient in the estimation of merchantable tree volume. The equation developed can be use efficiently in planning, pre and post harvesting stock assessment of *Gmelina arborea* in the study area and areas that have similar ecological conditions whose stump diameter fall within the diameter range observed in this study. In cases of illegal felling harvesting of trees, the stump diameter left on the ground can be use to determine the volume of tree bole been removed and offenders appropriately charged. The estimation of tree volume is useful as it allows understanding of cut cycle and for sustainable forest management in forest estate and plantation. It is therefore imperative that continuous monitoring and evaluation of stand parameters should be done to provide up to date information about the future stand of *Gmelina arborea* in Akwa Ibom State.

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