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Growth Comparison and Volume Models for 23-Year Old Forest Plantation Species in Southwest Nigeria

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Abstract
Growth measurement of plantation species is very important to afforestation projects and models are necessary for sustainable management of forest ecosystems. Tree growth variables were assessed and compared for four 23-year old plantation species (*Gmelina arborea, Pinus caribaea, Terminalia superba* and *Triplochiton scleroxylon*) in this study and models for estimating their volumes were developed. Data were collected from ten equal size plots (25 x 25m) randomly located in stands of each species and linear regression models were fitted for species. Comparison of tree growth variables was done with the one-way analysis of variance and all the models were assessed and validated. The results revealed that the indigenous species are better than the exotic ones in terms of dbh and height growth only but higher stocking were recorded for the exotic species due to lower mortality in the stands of the exotic species. *Terminalia superba* has the highest mean and dominant dbh (39.55 and 56.55 cm respectively) while the least was recorded for *Pinus carbaea* (25.41 and 41.41 cm respectively). *Gmelina arborea* has the highest volume/ha (497.02 m^3) and the least was obtained for *Terminalia superba* (168.58 m^3). The ANOVA results show a significant difference ($p<0.05$) in the species' growth characteristics. The selected models that were recommended for each of the species have good fit and are very suitable for stand volume estimation in this location and in other locations with similar edaphic and environmental factors. Adequate maintenance of the stands and establishment of permanent sampling plots to monitor growth were suggested.

Key Word: Plantation, Volume Equations, Forest Stand, Reserves, Dominant Diameter

Introduction

Forestry is concerned with the theory and practice of growing trees, the management of forests and the utilization of both wood and non-timber forest products. Forest is determined by both the presence of trees, which is able to reach a minimum height of 5m in situ, and the absence of other predominant land uses (IUFRO, 2008). Forest plantations are forest stands established by planting or/and seeding in the process of afforestation or reforestation, which are either of introduced species or intensively managed indigenous species that are of even aged class and regular spacing (FAO, 2004). CPF (2005) define forest plantation as forest stand in which trees are predominantly established by planting, deliberate seeding of coppicing, where the coppicing is of previously planted trees.

Forest resources are contributing significantly to rural development and national economy of many countries (UNEP, 2006; FAO, 2008). The main importance of forest plantation therefore is to supplement the supply of industrial wood from natural forests. About 90% of the plantations established in Nigeria from the first half of the 20th century to the 1970s have the provision of industrial wood as their primary objective. Currently, the contribution of forest plantation to global wood supply is on the increase (FAO, 2008). Although forest plantations account for less than 3% of the world's total forest area, they supply over 20% of the global wood supply (FAO, 2004).

In Nigeria, different silvicultural techniques (e.g. tropical shelter wood system, selective logging, enrichment planting etc) have been employed to increase growth rate of the natural forests, but the result to date have met with little success (Adekunle, 2005). Average yields of timber in the natural rainforest are in the range of 2-3m^3/ha/year while 1m^3/ha/year is common in the savanna region. In contrast, average increment of plantations of selected exotic tree species is in the range of 15-40m^3/ha/year (Evans et al 2004). Besides the problem of growth rate, forest management is complex in natural forests ecosystems because of species diversity. Plantations could be sited near the point of use or consumption and there is possibility of devoting an entire stand solely to the desired species that can grow in that locality. Some other reasons in favour of the current trend towards plantation forestry in Nigeria are the increasing demand for forest products, possibility of introducing genetically improved stock, maximum use of land by complete stocking, reduced cost of logging and improved log quality. In view of the above, the three tiers of governments decided to embark on massive tree planting through mass mobilization of rural farmers, civil servants, the private sectors. Various afforestation projects were funded by foreign agents with Nigerian government providing the counterpart fund.

For effective and scientific management of the forest ecosystem, knowledge of the growth characteristics and yield of the tree species are very essential. The data obtained from forest stands are very useful in fitting models for predicting expected growth of the stands. Models in forestry are tools for providing long-term decision-making in forest management, estimation of current and future growing stock, timber valuation and allocation of forest areas for harvest (Adekunle, 2007). At a determined economic rotation age, the current value of the stand can be compared with its potential value. This comparison will provide the basis for estimating the profit that can be made if the stand is felled and sold at a future date rather than now (Sedio and Botkin, 1997; Pandey and Ball, 1998).

Gmelina arborea belong to the family of Verbenaceae. It grows naturally in Australia, Southeast Asia and Burma but widely planted as an exotic species in some West and Central African Countries as well as in countries like Costa Rica, Brazil, Nicaragua, Belize, Solomon Island, etc. The stem is generally without buttress and tapers towards the crown. This species can survive in both moist and dry forest. It tolerates a temperature that varies between -1^{0}C and 48^{0}C and annual rainfall of between 700 – 4,500mm (Onyekwelu and Stimm, 2002). *Pinus caribaea* is in the family of Pinaceae and the common name is Caribbean Pine. It grows naturally in Belize, Honduras, Nicaragua and Gautama but widely introduced as plantation species throughout the world. *Triplochiton scleroxylon* belongs to the family Sterculiaceae with common names as Arere or Obeche in Nigeria, Samba in Cote de Ivoire, Ayous in Cameroon and Wawa in Ghana. It is an important and economic timber species, widely distributed in tropical West Africa and predominantly along water ways and abandoned farms. *Terminalia superba* is another important economic species in Nigeria, highly desired for the construction of furniture items. It is in the family of Combretaceae. It has broad distribution in west and central Africa. It prefers a climate with an annual rainfall of 1400 – 2000 mm and a mean temperature of 23 - 26^{0}C.

Methodology

The Study Area

The plantation species (*Gmelina arborea, Pinus caribaea, Terminalia superba* and *Triplochiton scleroxylon*) used for this study were established within the Shasha forest reserve (215 km^2), belonging to Osun State Forestry Department. The forest is located within Latitude 7^o 05′ and 7^o 24′N and Longitude 4^o 32′E and 4^{o}54′E. The altitude is 122m with a mean annual rainfall of 1,421 mm. The soil type is the ferruginous tropical soils on crystalline acid rock and the topography is gently undulating plain. It is well drained with fine texture. The four 23-year old stands were established under the Federal Government Pulpwood Development Project (*Gmelina arborea*) and the Rural Forestry Development Project (Pines, *T. superba* and *T. scleroxylon*) executed by the Osun State Government to boost sawn wood production.

Method of data collection

Measurement of Tree Growth Variables

Ten equal size plots (25 x 25m) were randomly located at the centre of each of the stands and all measurements were done in these plots. The dbh of all trees encountered in a sample plot were measured and their basal areas were determined. Two mean trees (i.e. trees whose dbh were the closest to the mean dbh of trees in the plot) were selected per plot. Diameters over bark at the base, middle and merchantable top, as well as total height of these mean trees in each of the plots were measured. All diameters were measured with girth-diameter tape, and tree heights were measured with wide scale metric spegiel relaskop.

Data Analysis

Basal Area Calculation

The basal area of all trees in the sample plots were calculated using the formula:

$$BA = (\pi D^2)/4$$

where BA = Basal area (m^2), D = Diameter at breast height (cm) and л = pie (3.142).

To obtain the plot basal area, the mean basal area of the plot (i.e. average of the two mean trees) was multiplied with the number of trees in each corresponding plot. The basal area values of the sample plots were added and divided by the number of sample plots to obtain a mean basal area for the sampling plots. This was multiplied with the number of 25 x 25m sampling units in a hectare (16) to obtain the basal area per hectare.

Volume Calculation: Volumes of the two mean trees per plot were calculated using the Newton's formula (Husch *et al.,* 2002):

$$V = h/6(A_b + 4 A_m + A_t)$$

where: V = Tree volume (in m^3), A_b, A_m and A_t = tree cross-sectional area at the base, middle and top of merchantable height, respectively (in m^2) and h = total height (in meters).

Volume for each plot was also obtained by multiplying the mean volume of their two mean trees with the number of trees in that plot. Volume obtained for all the sample plots were added and divided by the number of sample plots to obtain plot mean value. This was multiplied with the number of 25m x 25m plots in a hectare (16 plots) to obtain volume of tree per hectare.

Comparison of Tree Growth Variables: To test for the presence of significant difference in the growth variables (mean Dbh, Mean height, Basal area per hectare and Volume per hectare) of the four species, one-way analysis of variance (ANOVA) was used. Mean separation was carried out with Fishers' Least Significant Difference (L S D) where significant differences occurred ($P \leq 0.05$).

Correlation Coefficient and Volume Equations: To examine the linear relationship between volume and the growth variables, the results were paired and correlated using the spearman correlation. Various volume models were constructed for each of the species using volume/ha as the dependent variable and the independent variables were Dbh and height. The stand models that were adopted for each of the species in this study were modification of the Schumacher (1939) volume models. The model is of the general form:

V= F (D, H, A), Where V= Volume/ha, D = Dbh, H = Height and A = Age. However, the following volume models were simulated for each species:

Model 1 $V = b_0 + b_1 X$ (simple linear regression model)

Model 2 $\text{Ln}V = b_0 + b_1X$ (semi-log regression equation)

Model 3 $\text{Ln}V = b_0 + b_1\text{Ln}X$ (Double log)

Model 4 $V = b_0 + b_1X + b_2X^2$ (Quadratic)

Model 5 $V = b_0 + b_1X + b_2X^2 + b_3X^3$ (Polynomial)

Where V = Volume per hectare (m^3/ha), X, X_1 and X_n are independent variables i.e. Basal Area, b_0 = Regression constant (intercept) and b_1, b_2, b_n = Regression coefficients that were determined.

Stand basal area was adopted as the independent variable because it is an important variable in predicting tree growth and stand dynamics (Vanclay, 1994).

Assessment of the Models

The models were assessed with the view of selecting the best for validation and for further use. Assessment criteria were based on the significance of Regression equation (F-ratio), high correlation coefficient (r) and coefficient of determination ($r > 0.5$ and $r^2 > 50$ %) and the mean standard error of estimate (SE). The F-ratio is an indication of whether or not the models are acceptable for prediction. F-ratio must be significant for the model to be of good fit. Multiple correlation measures the reliability of the regression equation and the degree of association between the two variables (Mead *et al* 1994).The r^2 measures the goodness of fit of the regression line. In order words, it measures the proportion of the variation in the dependent variables, which is explained by the variation in the independent variables. Standard Error (SE) is a measure of the spread of data and an indication of the precision of the predicted response. The Furnival index (FI), which is the most appropriate factor for comparing the precision of regression equations whose dependent variables are variously defined (Furnival, 1961), was also used. The equation is given as:

$$FI = \frac{\sum LogV_i}{N}$$ where, FI = Furnival index, Log = natural logarithm

V_i = volume /ha (m^3), N = number of observations

Validation of the Regression Equations

The original data were divided into two sets. The first set (60%) was used for model generation (calibration set) while the second set (40%) for validation (validation set) as recommended by Marshall and Northway (1993). This was to identify and recommend the best models for further use. The student's t-test was used to test for significant difference ($P \leq 0.05$) among the output of the models (predicted volumes) and observed volumes (volumes obtained with Newton's formula). There must be no significant difference for the model to have good fit.

Percentage Bias

The percentage bias (%B) was computed to determine the deviations of the predicted values (V_p) from the observed value (V_o) using the following formula:

$$\%B = \frac{V_o - V_p}{V_o} x100$$

This value must be very small for the models' output to be valid.

Results

The Growth Data

The summary of tree growth data obtained for this study is presented in Table 1. *Terminalia superba* had the highest mean DBH and dominant DBH of 39.55 cm and 56.55 cm respectively. This was followed by *T. scleroxlylon* with a mean DBH of 38.84 cm. The result indicted a generally higher value in some tree growth variables for the indigenous species (*T. superba* and *T. scleroxylon)* than the exotic ones. But, highest number of trees per hectare was obtained for *G. arborea* (566 trees/ha), followed by *P. caribaea* (437 tree/ha). Furthermore, *G. arborea* had the highest volume (497.02 m^3). This is followed by *T. scleroxylon* (473.52 m^3) while the least (168.58 m^3) was obtained in the *T. superba* stand.

The results of the one-way analysis of variance revealed that there were significant differences ($P<0.05$) in all the tree growth variables (mean Dbh, mean height, dominant Dbh, basal area and volume) for the four species. However, the results of the mean separation revealed that there was no significant difference ($p>0.05$) in some growth characteristics of some of the species (table 1). For example, there was no significant difference in mean DBH and the dominant DBH of the two indigenous species (*T. superba* and *T. scleroxylon).* Figures 1-6 illustrated the variation in the tree growth variables among the four plantation species. For diameter distribution, a normal distribution curve was obtained for the indigenous species but the curves for the two exotic species did not follow a specific pattern (Fig 7).

Table 1: Results of analysis of variance for growth parameters of four 23-year old plantation species in Shasha forest reserve, Nigeria

Species	No of trees/ha	M DBH(cm)	D.DBH (cm)	Mean Ht (cm)	BA/ha(m^2)	V/ha (m^3)
P. caribaea	437a	25.41± 0.48a	41.41±1.54a	19.02±0.46a	24.14 ± 0.003a	204.64 ± 0.02a
T. scleroxylon	296b	38.84± 2.05b	58.15±2.01b	23.91±2.96b	38.88 ± 0.010b	473.52 ± 0.25b
G. arborea	566c	31.07± 0.80c	53.74±2.06c	18.61±0.60a	48.47 ± 0.003b	497.02 ± 0.08c
T. superb	187d	39.55± 2.65b	56.55±3.18b	17.89±0.31a	24.34 ± 0.01a	168.58 ± 0.06d

Means followed with the same letter along the columns do not significantly differ (P>0.05)

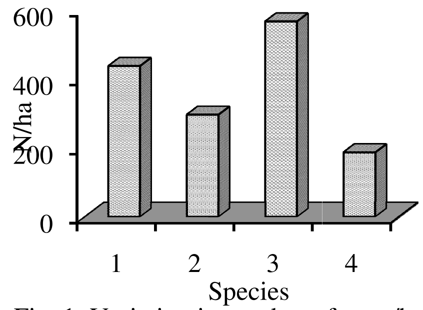

Fig. 1: Variation in number of trees/ha among the selected species

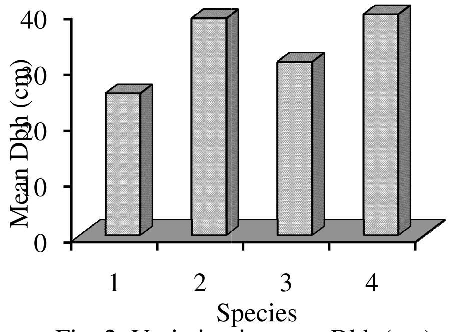

Fig. 2: Variation in mean Dbh (cm) among selected species

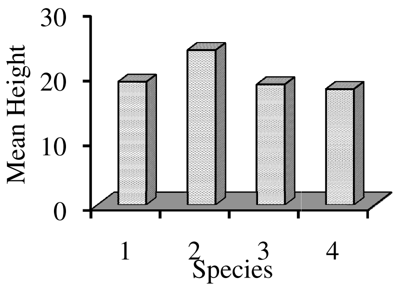

Fig. 3: Variation in mean height (m) among the selected species

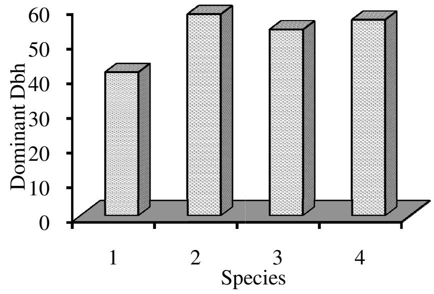

Fig. 4: Variation in mean dominant Dbh among the selected species

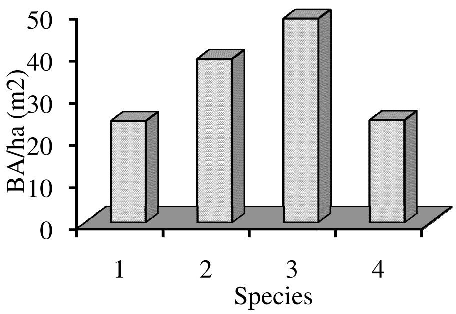

Fig. 5: Variation in BA/ha (m2) among the selected species

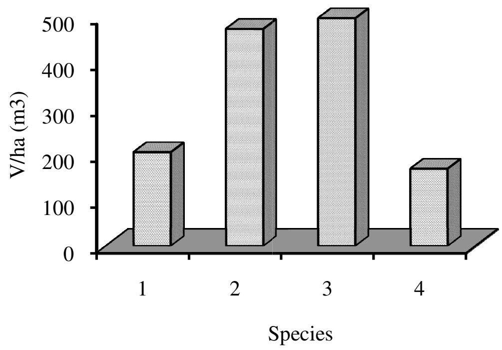

Fig. 6: Variation in V/ha (m3) among the selected species

1- Pinus caribea, 2 – Triplochiton scleroxylon 3 – Gmelina arborea 4. – Terminalia superba

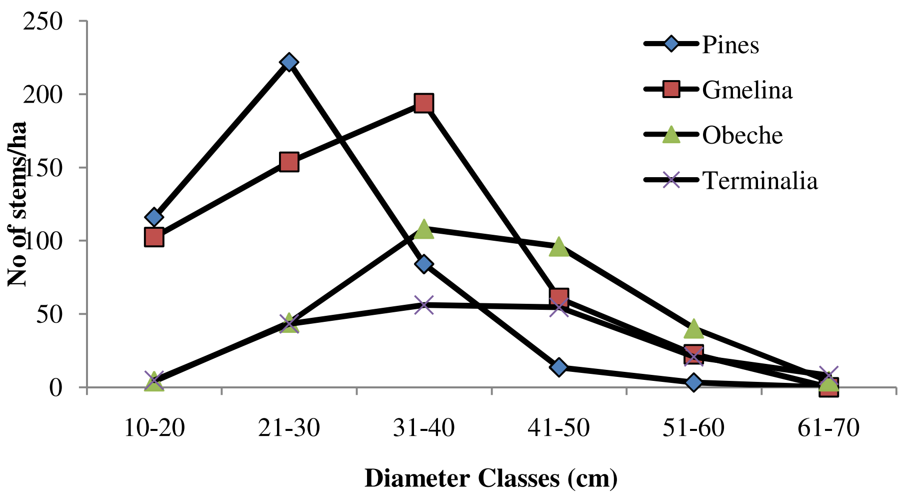

Fig. 7: Diamater distribution curve for stands of the species

Volume Equations with good fit

The results of the models generated for stand volume estimation for each of the species are presented in Table 2. The first two models were logarithmic transformed models while the others were untransformed regression models (simple linear, quadratic and polynomial models respectively). Generally, all the models have correlation coefficient (r) that is higher than 0.50 and coefficient of determination (r^2) which is greater than 50% except for model one of Pine stand. All the models were significant, with small standard error of estimate. The models for *P. caribaea* have r-values that ranged between 0.70 and 0.86 and the r^2 values are between 48 and 73%. For *T. scleroxylon*, the transformed models have the r-values of 0.94 for model one and 0.95 for model two. The r^2 values of 88 and 84% respectively, were obtained for these models too. The other models (untransformed) have 98%, 99% and 99% as their r^2 values. The r^2 values for *G. arborea* varied between 73% and 90% while that of *T. superba* varied between 70% and 85%. All the models met the criteria for selection as adequate for volume estimation except model 1 in Pine plantation. However, the most suitable models for each species were model 1 for *T. scleroxylon*, model 2 for *G. arborea* and *P. caribaea* and model 5 for *T. superba.* The selection was based on the result of the Furnival index. Generally, the model with the least FI was considered the most suitable for volume estimation.

The result of the Student's t-test used to validate the selected models is presented in table 3. The result showed that there was no significant difference (p>0.05) between the measured volumes and the predicted volumes (equations' output). This shows that the models have good fit and are very suitable for estimating stand volumes.

Table 2: Volume Equations for the plantation species and the their assessment criteria

Species	Equations	R	R^2	Adj R^2	SE	F- ratio*	FI
Pinus Caribaea	1 LnV = 1.92 + 0.37BA	0.70	48%	45%	0.28	16.86	0.887
	2. LnV= 2.23 + 0.77LnBA	0.81	65%	63%	0.23	33.76	1.079
	3. V = 5.83 + 4.61BA	0.73	53%	50%	3.17	20.14	1.096
	4. $V = 17.20BA - 2.99BA^2 - 5.06$	0.85	73%	70%	2.47	22.95	1.083
	5. $V = 23.02BA - 6.04BA^2 + 0.47BA^3 - 8.23$	0.86	73%	68%	2.53	14.61	1.086
T. Scleroxylon	1. LnV = 2.61 + 0.31BA	0.94	88%	86%	0.09	43.31	1.432
	2. LnV = 2.86 + 0.62LnBA	0.92	84%	81%	0.10	31.41	1.444
	3.V =8.43 + 8.97BA	0.91	83%	81%	2.99	29.93	1.442
	4.$V = 20.88 - 23.48BA + 9.85BA^2$	0.90	81%	75%	2.83	14.66	1.443
	5. $V = 85.43BA - 58.28BA^2 + 13.39BA^3 - 33.08$	0.92	85%	78%	2.66	11.77	1.442
G. arborea	1. LnV = 2.32 + 0.35BA	0.75	56%	51%	0.26	10.34	1.468
	2. LnV = 2.31 + 0.98 LnBA	0.74	55%	49%	0.26	9.62	1.461
	3. V = 11.13BA – 2.66	0.69	47%	41%	9.92	7.15	1.475
	4. $V = 68.71 - 40.15BA + 8.62BA^2$	0.73	54%	41%	9.92	4.08	1.475
	5. $V = 212.86BA - 76.91BA^2 + 9.35BA^3 - 172.04$	0.75	56%	34%	10.49	2.51	1.473
T. superba	1. LnV = 1.21 + 0.69BA	0.82	67%	63%	0.27	16.50	0.981
	2. LnV = 1.90 + 0.98LnBA	0.78	61%	57%	0.30	12.71	0.979
	3. V = 5.40 + 1.08BA	0.88	78%	75%	2.86	27.69	0.846
	4 $V = 20.88 -23.48BA + 9.85BA^2$	0.90	81%	75%	2.83	14.66	0.988
	5. $V = 85.43BA-58.28BA^2 + 13.39BA^3 - 33.08$	0.92	85%	78%	2.66	11.77	0.989

*** Significant for all the models (P<0.05)**

Table 3: Comparison of measured volume with the output of selected equation for each of the species

Species	Selected model no.	Mean Observed vol (m^3)	Mean Predicted Vol (m^3)	t-test value	P-value
Pinus caribaea	2	12.79± 1.00	12.57± 0.97	0.765	0.316ns
T. scleroxylon	1	28.35± 2.39	27.61± 2.04	0.451	0.799ns

G. arborea	2	31.06± 4.06	29.83± 2.43	0.413	0.689ns
T. superba	5	10.53±1.80	7.04± 0.18	2.108	0.064ns

ns – no significant difference (P>0.05)

Percentage bias for the models

The appropriateness of the selected models, for further use, was again authenticated with the result of the percentage bias (Table 4). The results revealed that the deviation of the predicted volumes from the measured volumes was very little. For *P. caribea*, the % bias was 0.0.32, while 0.80 was obtained for *T. scleroxylon.* The values for *G. arborea* and *T. superba* were 3.96 and 0.14 respectively.

Table 4: Percentage bias showing the deviation of the predicted volumes from the measured volume

Species	% bias
P. carribaea	1.72
T. scleroxylon	2.60
G. arborea	3.96
T. superba	0.14

DISCUSSION

The tree growth parameters obtained in this study revealed significantly higher ($p<0.05$) values, in some of the tree growth variables (diameter and height), for the indigenous species (*T. superba and T. scleroxylon*) than the exotic (*G. arborea* and *Pinus caribaea*) of the same age, under the same silvicultural treatment, management, and environmental and site conditions. But generally, the exotics ones especially *G. arborea* performed better than the indigenous ones. The stand basal area and volume of *G. arborea* were higher than those of the two indigenous species. While the volume per hectare of *G. arborea* was estimated at 497.02, that of *T. scleroxylon* was estimated as 473.52m^3 and that of *T. superba* was 168.58m^3. The stands of the two exotic species have higher number of trees per hectare (566 and 437 for Gmelina and Pines respectively) than the indigenous species (Table 1). This resulted into a denser stand with increased competition for light, nutrients and moisture. Tree growth, apart from depending on spacing; is also determined by the intensity of thinning operations carried out from time to time (Onyekwelu, 2002). All the stands used for this study were not thinned. This subsequently might have affected their stand volume production. But the high mortality rate that created some space in the stands of the two indigenous species favoured tree diameter growth.

More importantly, the indigenous species are naturally adapted to the soil and site conditions of the area where they grow naturally while the exotic species were introduced into the country. The results of this study revealed that *G. arborea* has the fastest growth and highest volume production when compared with the other tree species in the study area. This present result is corroborated with the findings of other researchers. Nwoboshi (1985) reported that *G. arborea* grew 59% faster than *P. caribaea* of the same age at Onigambari forest reserve, while Onyekwelu (2002) reported that it grows faster than *Nauclea deddirrichii* in Omo Forest reserve. This is similar to the result of this work which showed that its (*G. arborea)* grew 55% faster than *P. caribaea* in Shasha Forest reserve. These three reserves (Onigambari, Omo and Shasha) are located in the tropical rainforest ecosystem of southwest, Nigeria.

The equations adopted in this work were the generalized linear regression models and they were modifications of the Schumacher (1939) growth models. They were made up of simple linear regression, logarithm transformed, quadratic and polynomial models. The models were significant ($p<0.05$), with high correlation and coefficient of determination values. They have very small mean standard error of estimate and small Furnival Index. They adequately satisfied the criteria for model assessment. As a result, they could be regarded as having good fit and are very suitable for stand volume estimation in this ecosystem. The simple linear model also had good fit when it was used by Abayomi (1983) for *Nauclea diderichii* stands in Omo forest reserve. Akindele (1989) used the multiple linear models for teak stands in Onigambari forest reserve and also obtained good fit. Semi logarithmic transformed model was used by Evans (1999) for stands of *Pinus patula* in Usutu forest reserve, Swaziland and he also obtained a very high coefficient of determination.

Models selected as most suitable for each of the plantation species are models 1 for *T. scleroxylon*, model 2 for *G. arborea* and *P. caribaea* and model 5 for *T. superba*. The criteria for recommending these equations for the respective species were based on their Furnival Index, R^2 values, % biases and standard error of estimate. They have the smallest Furnival index, highest R^2 value and the least standard error. The Furnival index was used because it affords the opportunity of comparing the precision of models with either untransformed or transformed dependent variable. This value must be small for the model to be useful. The standard error of estimate is a good measure of overall predictive value of regression equations (Adekunle et al, 2004). It is also a common measure of goodness of fit in regression models (Glantz and Slinker, 2001), with low values indicating better fit. The validation results with the student's t-test and the percentage bias confirmed the validity and precision of these models for volume estimation. There were no significant differences in the output of the selected equations when compared with the corresponding measured volumes. Avery and Burkhart (1983) noted that volume equations could be used to estimate the average content of standing trees of various sizes and species. Akindele and Lemay (2006) reported that growing stock in forestry is usually expressed in terms of timber volume and the most common procedure of obtaining this is the use of volume equation based on relationship between volume and variables such as diameter and height.

Conclusion and Recommendations

This study provided information on the present status of 23-year old plantations of *P. caribaea, T. scleroxylon, G. arborea* and *T. superba* under the same silvicultural, environmental and soil conditions in southwest, Nigeria. The comparison of growth characteristics of these species indicates the indigenous species could also be cultivated in plantations just like the exotic ones. For the indigenous species, the results show that T. *superba* grew faster than *T. scleroxylon* and for exotic ones *G. arborea* grew faster than *P. caribaea*. The recommended volume equations were those with good fit from the assessment and validation criteria. These can be used for predicting stand volume of plantation species of similar age in the tropical rainforest ecosystem of southwest, Nigeria. Any of these equations could also be used outside the range of the field, tree age, soil and site conditions. However, enough precautionary measures must be taken when such a decision arises.

Based on the results of this study, the following recommendations were made.

a. Permanent sample plots are required in these plantations for regular data collection. These data are needed for growth rate assessment and monitoring for the sustainable management of the species.

b. Silvicultural activities, such as thinning, should be carried out in the plantations to improve tree growth rate and wood formation. This is required especially in the plantations of the exotic species

c. The models are recommended for stand volume estimation in plantation species.

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