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Fitting Linear and Non Linear Growth Models for Selected Plantations in Omo Forest Reserve Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author ETA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ASA and OAA managed the analyses of the study. Author OAA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study was conducted to assess the suitability of forest models in *Tectona grandis, Pinus caribaea and Nauclea diderrichii* stands at Omo forest reserve, Ijebu East, Ogun State, Southwestern Nigeria. Temporary sample plots of equal size (25 m x 25 m) were laid while complete enumeration were carried out in each sampled plot and tree growth variables such as diameter at breast height (dbh), diameter at the top (dt), diameter at the middle (dm) and diameter at the base (db) as well as total height of all trees were measured. Simple linear models and six non linear models were developed and assessed for the selected plantation. The linear model developed _ R-squared ranged from 77% to 93%. The least R- square was obtained in *Tectona grandis* plantation and the highest was obtained in 93% *Pinus caribaea*. All the models have high F values ranging from 234.71 to 2965.40. In *Tectona grandis* plantation, Logistic power model, gave a good fit in describing the relationship between diameter at breast height and volume with AICC values of -2368.92, 0.22 each. The Sigmond models that gave a good fit in describing the relationship between the diameter at breast height and volume in *Pinus caribaea* were Weibull

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model (-719.19, 0.09) while Gompertz relation is the best for *Nauclea diderrichii,* respectively. The various models generated in the study are highly recommended for use in estimating the growth characteristics of the plantation in the future.

Keywords: Simple linear models; non linear models; Omo forest reserve; Tectona grandis; Nauclea diderrichii; Pinus caribaea.

1. INTRODUCTION

Forests ecosystems are highly complex ecosystems dominated by trees and associated vegetation growing under various physiographic, edaphic and biotic conditions. As an ecosystem, they include all the interacting populations of plants, animals, insects and micro-organisms that occupy the area, plus their physical environment. In view of its inherent complexity, the use of models can enhance one's understanding of the intricacies and sophisticated functioning of the forest ecosystem [1]. Tropical forest plantations and tree farms are becoming more important because they reduce pressures from the natural and residual forest resources by increasing the supply of wood and other forest-based raw materials. They can also increase employment generation while improving the ecological conditions of the denuded forest areas [2].

Forest models are veritable tools for effective management of any forest stand. Models in forestry are that provides long-term decision-making in forest management, estimation of growing stock, timber valuation and allocation of forest areas for harvest. Unfortunately models for yield estimation in tropical natural forest ecosystem are very scarce today because of the complexities and heterogeneity of the ecosystem [3]. According to Wainwright and Mulligan [4], models of various kinds have been very useful to forest management for a long time. The most basic models provide at least an estimate of how much timber is available and what it may be worth on the market, so that managers can determine the economic feasibility of timber cutting. The potential impacts of future changes in global environment (such as climate, land use, fire disturbance, and forest harvesting) on the sustainability of forest ecosystems, forest resource managers will require forest simulation models to predict and determines the changes (Changui, 2000).

According to Osho [5], population growth matrix and succession Markov models for his study at Idanre forest reserve by replacing age with diameter. Linear regression equations were developed for Nigeria natural forest data. The total species encountered were classified into eleven groups with k-cluster algorithm. Four sets of logarithm-transformed models were tried with volume as dependent variable and basal area and height as independent variables for each group and all species together [6].

The main objective of this study is to develop and assess the suitability of forest models in *Tectona grandis, Pinus caribaea and Nauclea diderrichii* stands at Omo forest reserve forest reserves southwest Nigeria using simple linear and non linear models. According to Avery and Burkhart [7], volume equations are used to determine the average content of trees of various sizes and species. The reliability of volume estimates depends on the range and extent of the available data, and how well volume equations fit the data. The 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 [8].

2. MATERIALS AND METHODS

2.1 Study Area

Omo forest reserve is located between latitude 6°45 to 7°05N and longitude 4°19 to 4°40E in the South-West of Nigeria, about 135 km North-East of Lagos and 80 km East of Ijebu-Ode. It covers an area of about 130,500 hectares. Abeku sector is located in the north-eastern end of Omo forest reserve. The vegetation of Omo Forest Reserve is a mixed moist semi-deciduous rainforest. This can be distinguished into a dry evergreen mixed deciduous forest in the northern part and a wet evergreen forest in the southern part. With the exception of the 640 hectare Strict Nature Reserve, now a Biosphere Reserve at the centre of the forest reserve, most of the forest are disturbed with a substantial parts converted to tree plantations.

2.2 Method of Data Collection

Simple random sampling was adopted for plot layout after 20m edge effect was observed, Six sample plots of (25x25 m) were therefore selected from 30 sample plots (total area of the forets divided by the plot size).

2.3 Tree Growth Variable Measurement

Measurement was limited to selected plantations (*Tectona grandis, Pinus caribaea and Nauclea diderrichii* plantation, The following tree growth variable were measured in each sample plots:

- dbh (≥ 10 cm) (stem diameter at a position of 1.3 m above the ground level),
- diameters over bark at the base, middle and merchantable top,
- total height using Spiegel Relaskop)

2.4 Basal Area Computation

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

$$\text{Basal area (BA)} = \frac{\pi D^2}{4}$$

Where,

BA = Basal area (m^2) _, D = Diameter at breast height (cm), π = Pie (3.142)

2.5 Volume Computation

The volume of all trees were also calculated using Newton's Formula:

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

Where,

V= volume (m^3), h = Total height of the three (m), D_b = Diameter (m)_at the base of the tree, D_m = Diameter (m) at the middle of the three, D_t = Diameter (m) at the top of the tree, π= 3.142.

Since there are 16 sample plots (25 m x 25 m) in a hectare, the basal area and volume of trees per hectare were obtained by multiplying the volume of trees per plot by 16.

2.5.1 Height calculation

The height of all trees in the sample plots will be calculated using the formula

$$H = \frac{Rt - Rb}{100} \times HD$$

Where H= Height, Rt = Reading at the top, Rb = Reading at the base, HD = Horinzontal distance

Descriptive analysis was carried out at the two parallel transect to observe the differences between the transects.

2.5.2 Linear regression volume models

Volume models are mathematical expression which relates tree volume to tree's measurable attributes such as diameter at breast height. They are used to estimate the average content for standing trees of various sizes and species [7].

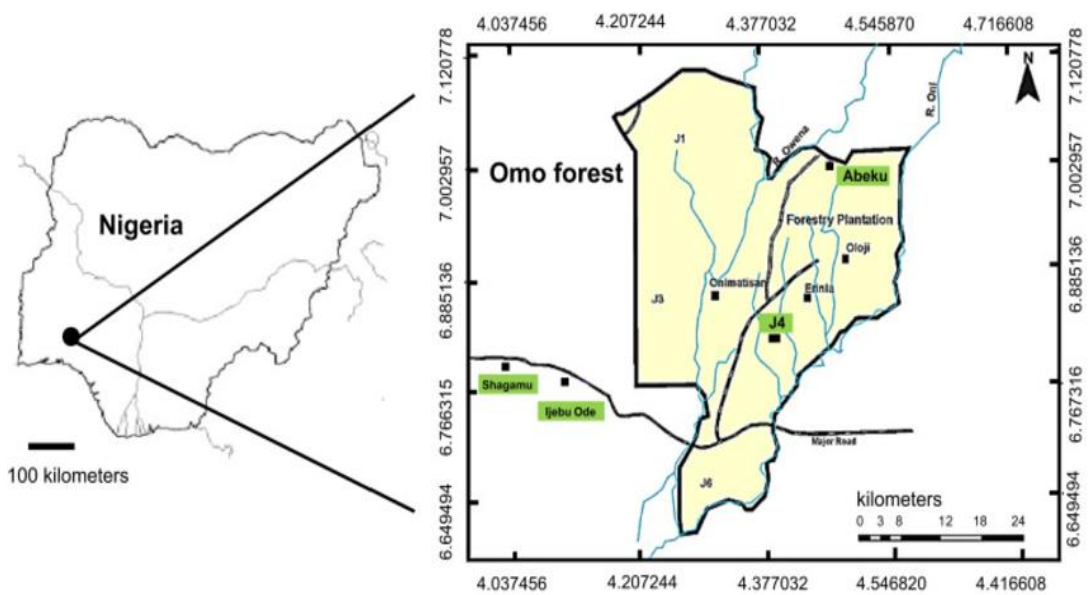

Image 1. Map of Study Area

For volume model generation, the field inventory data were divided into two. The first set (calibrating set), which comprises 70% of the tree data of each selected plantations were used to generate the models and the individual tree growth variables across all the sample plots. The generalized allometric equation for mathematics and science and the linear regression models that followed the general Schumacher [9] yield models were used. The Schumacher model is of the form:

Y=f (A, SQ, SD)

Where,

Y = function of yield e.g. volume, A = age, SQ = function of site quality e.g. site index, height, SD = function of stand density e.g diameter at breast height, basal area.

So, the linear regression models that were adopted in this study followed Schumacher function:

Simple Linear model: $Y = \beta_0 + \beta_1 x$
Binomial Model: $Y = \beta_0 + \beta_1(x) + \beta_1(y)$
Polynomial Models: $Y = \beta_0 + \beta_1 x_1 + = \beta_2 x^2 + \beta_3 x^3$

Logarithm transformed Models: $LnY = \beta_0 + \beta_1 \ln(x)$

2.5.3 Non-linear regression volume models

The non-linear regression models were generated using Curve Expert Professional software. Some of the models and the model functions are as represented below:

Non-Linear Volume Models and their Model function.

2.6 Assessment of the Models

The volume models were assessed with the view of recommending those with good fit for further uses. The following statistical criteria were used:

2.6.1 Significance of regression (F-ratio)

This is to test the overall significance of the regression equations. The critical value of F (i.e., F-tabulated) at $p < 0.05$ level of significance will be compared with the F_ratio (F-calculated). Where the variance ratio (F_calculated) is greater than the critical values (F-tabulated) such equation is therefore significant and can be accepted for prediction.

2.7 Coefficient of Determination (R2)

This is the measure of the proportion of variation in the dependent variable that is explained by the behaviour of the independent variable [10]. For the model to be accepted, the R2 value must be high (>50%).

2.8 Standard Error of Estimate (SEE)

This is also referred to as the standard deviation or residual of the error variance of the estimate. It measures the spread of data and is a good indicator of precision. The value must be small.

2.9 Models Validation

The validation process also examines the usefulness or validity of the models [11]. The original data from the study site will be divided into two. The first set (calibrating set), which comprised tree data from six plots, will be used for generating the models while the second set (validating set) which comprised tree data from two plots was used from the plantation for validating the models (Reynolds et al. [12] and Cooper and Weekes [13]. The models' output will be compared with observed values obtained from the field with student t-test and simple linear regression for any significant difference.

2.9.1 The student t-test

This was used to test for any significant difference between the actual values or field values and the predicted values (model output) of the various models generated according to Goulding [14].

2.10 Percentage Bias Estimation

The absolute percentage difference (% bias) was determined by dividing the difference between volumes obtained with Newton's formula (observed volume) and models output by the same observed volume and multiplied by 100.

$$\text{Bias}(\%) = \left(\frac{V_o - V_p}{Vo}\right) \times 100$$

Where,

V_o = The observed volume, V_p= The predicted volume (models output).

Table 1. Non linear models and functions

Model	Model function
Logistic Power	V = a/(1 +(x/b)**c)
Gompertz Relation	V = a*exp(-exp(b-c*x))
MMF	V = (a*b + c*x^d)/(b + x^d)
Weibull	V = a – b*exp(-c*x^d)
Logistics	V = a/(1 + b*e^(-cx))
Ratkowsky model	V = a/(1 + exp(b-c*x))

a, b, c and d are parameters to be estimated, V is the volume in (m^3), x is the Dbh (cm) while exp. is the exponential

The value must be relatively small for the model to be acceptable for management purpose.

3. RESULTS

3.1 Result of Growth Assessment

The sum of the tree growth variables for selected plantations in Omo Forest Reserves is presented in Table 2. Three plantations were selected for this study which includes *Nauclea diderrichii* of two age series of 1974 and 1976, *Pine caribae*a and *Tectona grandis*. A total number of 1237 trees were enumerated. The table shows that 8 years old teak plantation had the highest number of trees per hectare (1177) followed by 24 years old pine with (664) and the least number is obtained from 45 years old *Nauclea diderrichii* with 229. This density trend was a result of planting enspacement and poor management of the plantation at the growing stage. The dominant DBH (ranged from 58.22 to 24.42 cm) was highest at 45 years of *Nauclea diderrichii* and lowest at 8 years old of teak plantations, respectively. The result of the dominant tree height reveals that 45 years old of *Nauclea diderrichii* had the highest value of 25.28 m and the lowest values was obtained for teak plantation with 23.20 m, this revealed that the plantations follow an increasing order from 8 to 45 years. The result further revealed the value obtained for basal area per hectare ranged from 49.84 m^2/ha to 25.28 across the plantations respectively. Also, the result of the volume per hectare followed the same trend which ranged from 493.63 m^2/ha for teak plantation to 221 m^2/ha of 43 years for *Nauclea diderrichii* plantation respectively.

3.2 Result of Linear Volume Generation

The results of the models for this study were presented in Table 3. The R-squared ranged from 77% to 93%. The least R- square was obtained in *Tectona grandis* plantation and the highest was obtained in 93% *Pinus caribaea*. All the models have high F values ranging from 234.71 to 2965.40 indicating significant equations, with relatively small standard error ranging from 0.07 to 0.35. All the models were highly significant and with relatively small standard error of estimate as shown in Table 3.

3.3 Linear Model Validation

The best model estimates were compared to observed data using numerical analysis. The validation revealed that the models are of good fit because there was no significant difference in the observed and predicted volumes for the models.

The comparison between estimated and observed volumes was carried out for all the models using the student t-test and percentage bias (Table 3). The results revealed that all the models generated for all the locations are of good fit and there were no significant differences ($p \geq 0.05$) between the predicted and observed values. The percentage bias for each age series was relatively below 30%.

3.4 Result of Non Linear Volume Model Generation

In *Tectona grandis* plantation, Logistic power model, Weibull and Gompertz relation models gave a good fit in describing the relationship between diameter at breast height and volume with AICC values of -2368.92, -2367.91 and -2363.36 with standard error of 0.22 each. The graph showing the results of for the best models for non linear volume for *Tectona grandis* plantation is represented (Fig. 1).

The Sigmond models that gave a good fit in describing the relationship between the diameter at breast height and volume in *Pinus caribaea* were Weibull model (-719.19, 0.09) which ranked first, Logistic power (-719.80, 0.09) ranked second and Weibull model (-789.84, 0.09) ranked third. The graph showing the results for the best models for non-linear volume for *Pinus caribaea* is represented (Fig. 2).

The overall result for the *Nauclea diderrichii* plantation has Gompertz relation, logistic power and Weibull as the first second and third with AICC and SE of -290.04 and 0.45 for the first, second 290.64 and 0.45 and for the third model - 288.67 and 0.45 respectively.

4. DISCUSSION

The tree growth variable measured of the selected plantations in the study area showed that the mean diameter at breast height value ranged from 15.19 to 35.12 cm which is considered low for the stands, this shows that most of the trees encountered in the study area are below the minimum merchantable size of 48 cm stipulated by logging policy of Southwestern Nigeria [3]. This could be attributed to poor management of the plantation. The basal area per hectare calculated for each age series ranges from 25.28 to 50.73.

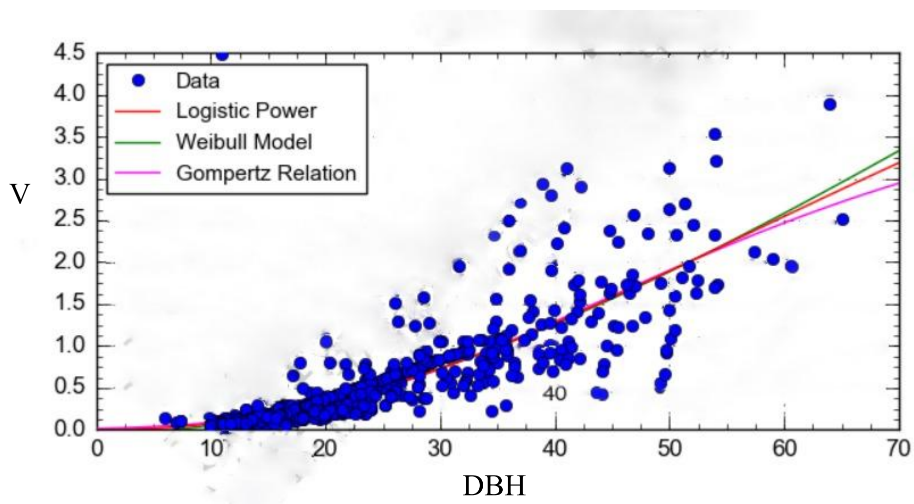

Fig. 1. Graph showing the results the best models for non-linear volume models for *Tectona Tectona grandis* Plantation

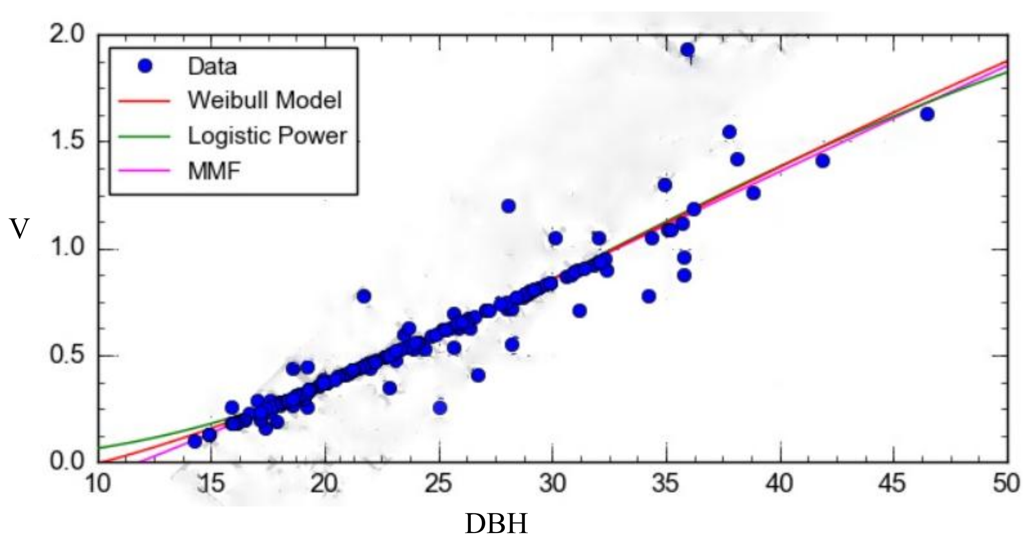

Fig. 2. Graph showing the results the best models for non-linear volume models for *Pinus caribaea* plantation

Table 2. Summary of tree growth variables for selected plantation

Tree Plantations	Age (years)	No of trees/ha	DBH (cm)	Height (m)	Dominant DBH(cm)	Dominant height(m)	BA (m^2/ha	Volume (m^3)/
Nauclea diderrichii	45	229	35.12±1.30	17.45±0.51	58.22±2.59	25.28±0.26	25.28	278.76
	43	253	34.03±1.08	16.01±0.44	54.36±1.69	24±0.92	25.45	221
	Total	**482**					**50.73**	**499.76**
Pinus caribaea	24	664	24.03±0.48	18.29±0.29	40.24±1.83	25.10±0.33	32.32	377.34
Tectona grandis	8	1177	15.19±0.16	15.47±0.13	24.42±0.56	23.20±0.26	49.84	493.63

**Each value is the mean ± standard error*

Table 3. Volume models and their assessment criteria for selected plantations in the study area

Plantation	Models	R	R^2	R adj	SEE	F ratio
Tectona grandis	LNV= -3.37+2.75LNDbh	0.87	0.77	0.77	0.15	2088.41
	LNV=-4.04+0.91LNDbh^{2}H	0.91	0.82	0.82	0.13	2965.40
	LNV=-4.08+0.22LNDbh+0.99LNDbh^{2}H	0.91	0.81	0.81	0.14	1485.16
Pinus caribaea	V=-0.62+0.03Dbh	0.96	0.91	0.91	0.09	1775.87
	V=-0.71+0.05Dbh+0.01H	0.96	0.92	0.92	0.09	970.21
	LNV=-3.34+2.21LNDbh	0.97	0.93	0.93	0.07	2267.84
Nauclea diderrechii	V=-0.82+0.06dbh	0.89	0.81	0.81	0.14	493.54
	V=-2046+0.06dbh+0.08H	0.87	0.78	0.78	0.35	543.71
	V=-3.10+1.97lnDbh	0.89	0.79	0.79	0.20	234..71

D=diameter at breast height, Ht.= height, V=volume

Table 4. Model validation using student T Test and percentage bias of the models

Plantation	Equation	Observed mean volume	Mean predicted volume	T-Stat	T-Critical	P-value	Bias	Bias%
Tectona grandis	LNV= -3.37+2.75LNDbh	232.77	173.94	1.89	1.96	0.23	0.25	25%
Pinus caribaea	V=-0.62+0.03Dbh	29.39	24.67	1.86	1.98	0.18	0.22	22
Nauclea diderrichii	V=-0.82+0.06dbh	49.13	47.07	0.49	1.98	0.31	0.04	4

Table 5. The Non-linear models and Thier assessment criteria

Plantations	Models	Parameters estimate				AICC	Std Error
		A	B	C	D		
Tectona grandis	Logistic power	8.57	8.90	-2.18		-2368.92	0.26
	Weibull	1.19	1.19	1.15	1.88	-2367.91	0.26
	Gompertz Relation	4.22	1.75	3.96		-2363.36	0.26
	Logistic	-4.12	-3.57	5.17		-2195.02	0.29
	MMF	-3.92	5.58	1.06	1.25	-2288.61	0.27
	Ratkowsky	2.69	4.05	9.97		-2335.10	0.27
Pinus caribaea	Weibull	3.28	3.44	6.60	1.84	-791.19	0.09
	Logistic Power	3.03	4.28	-2.64		-791.80	0.09
	MMF	-3.71	8.51	1.04	1.38	-789.84	0.09
	Gompertz Relation	2.49	1.85	5.96		-791.28	0.09
	Logistic	1.83	5.29	1.29		-786.49	0.09
	Ratkowsky	1.83	3.97	1.28		-786.49	0.09
Nauclea diderrichii	Gompertz Relation	1.26	1.65	2.01		-290.50	0.45
	Logistic Power	2.85	2.76	-1.94		-290.64	0.45
	Weibull	1.21	1.21	7.42	1.94	-288.67	0.45
	MMF	-4.74	1.00	1.63	1.29	-280.94	0.46
	Ratkowsky	4.87	3.67	6.44		-289.75	0.45
	Logistic	4.87	3.99	6.44		-289.75	0.45

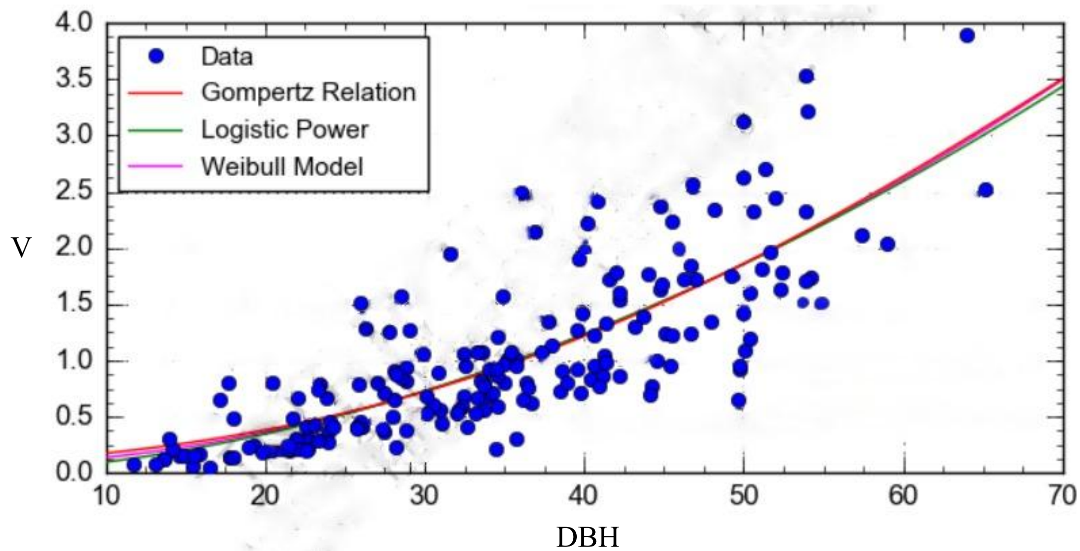

Fig. 3. Graph showing result of the best model for non linear volume models for *Nauclea diderrichhi* plantation

The development of growth model is very vital in determining the forest management strategies. Modelling objectives is crucial and very useful for management decision. Due to increase used of models in decision making, models credibility is becoming increasingly important in forest management. According to Segura and Kennien [15] the use of model in forest inventory is fast, cost efficient and requires less labour as few parameters such as DBH and height required for modelling can be measure accurately from the field.

However the growth models developed for this study were significant with high adjusted R ($p < 0.05$) and low standard error. The models are biologically plausible, with the percentage biasness less than 30% and the result of t-test shows that there is no significant difference between the observed volume and the predicted volume.

Furthermore, the paired mean t-test was also used in several studies to test the adequacy of models. All the assessment criteria revealed that the models have a good fit and are suitable for predicting the growth of *Nauclea diderrichii*, *Pinus caribaea* and *Tectona grandis* in the study area. Moreover, the correlation of DBH and total Height as input variables for the model were easily measurable, highly correlated with volume, more precise, less biased. The logarithmic transformation of the models was very efficient. This results agreed with the report of many authors including Shamaki et al. [16] in development of volume equation for teak in Nimibia forest, and Louis, [17] in developing total volume model for teak in Tanzania, he reported the logarithmic transformed provides an excellent fit to the sample data using linear regression.

Different non linear models for estimating volume in the tropical ecosystem are also tested there for effectiveness in this study. Gompertz Relation, Ratkowsky, MMF, Logistic, Logistic Power and Weibull models were tested suitable for describing the volume models of the selected plantation in the study area. Furthermore, the assessment criteria (AIC and standard errors) showed that the entire models are suitable for volume estimation of the plantations in the Omo forest reserves [18]. The results reveals that Logistic power models gave the best predicted volume for *Tectona grandis* and *Pinus caribaea* when compared with the observed volume, and Gompertz relation model gave the best in *Nauclea diderrichii* stand. All the non-linear models were discovered to have a good fit and as a result, they are very effective and adequate for tree volume estimation.

5. CONCLUSION

The linear and nonlinear models for volume estimation developed and validated for *Tectona grandis, Pinus caribaea and Nauclea diderrichi* plantations in Omo forest reserve, Ogun state. The tree growth data was collected from temporary sample plots in the study area. In the study, the frequencies and yield predicted with the models are significantly different from their observed values based on the validation results with Biase and t-test values. Furthermore, linear and nonlinear models are very suitable for yield estimation in the study area. More forest plantations should be established in Omo forest reserve. The data used for this study was collected from temporary sample plots established in all the stands, which cannot provide means for subsequent monitoring of performance of the sites in the study area. It is recommended that permanent sample plots are establish and maintained in these stands so as to ensure regular data collection for future linear and non-linear modeling studies. It is recommended that further studies be carried out on construction of linear and nonlinear models for estimating volume for both young and old stands of the plantations.

Findings of this study revealed that linear and non linear models are needed for assessing the growing stock and provide information that are very vital for forest management planning and decision making. The various models generated in the study are highly recommended for use in estimating the growth characteristics of the plantation in the future. Moreover, before applying the models beyond the study area there is a need for validation of the models with data from permanent sample plots.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Mendoza GA. Ecological modeling in forestry. In: Environmental Geology; 1999.
2. Lumbres RIC, Cabral DE, Parao MR, Seo YO, Lee YJ. Evaluation of height-diameter models for the three tropical Plantation Species in the Philippines. Asia Life Sci. 2012b;21(2):455–468.
3. Adekunle VAJ. Non-linear regression models for timber volume estimation in natural forest ecosystem, Southwest Nigeria. Research Journal of Forestry. 2007;1:40-54
4. Wainwright J, Mulligan M. Modelling in forest management, environmental modelling: Finding simplicity in complexity. John Wiley & Sons, Ltd; 2004. ISBNs: 0-471-49617-0 (HB); 0-471-49618-9 (PB).
5. Encyclopedia of Earth Science. Springer, Dordrecht Osho, J.S.A. Tree population dynamics in a tropical moist forest in South-Western Nigeria. Ph.D. Thesis. University of Ibadan, Ibadan, Nigeria. 1988;362.
6. FORMECU. National Forest Resource Survey, Training Manual. Federal Department of Forestry, Abuja, Nigeria. 1997;47.
7. Avery TE, Burkhart HE. Forest Measurements, 5th Ed. New York: McGraw-HilChangui, P. 2000. Understanding the role of forest simulation models in sustainable forest management Environmental Impact Assessment Review. 2002;20(4):481-501.
8. Akindele SO, LeMay VM. Development of tree volume equations for commontimber species in the tropical rain forest area of Nigeria. For. Ecol. Manage. 2006;226:41-48.
9. Schumacher FX. A new growth curve and its application to timber-yield studies. Journal of Forestry. 1939;37:819–820.
10. Thomas JJ. An introduction to statistical analysis for economists. Weidenfeld and Nicholson Ltd., London. 1977;286.
11. Marshall PL, Northway. Suggested minimum procedure for validation of Growth and Yield Model. In: J.K Vanclay et al. (Editor), Growth and Yield estimate; 1993.
12. Reynolds Jnr. MR, Burkhart HE, Daniel RF. Procedures for statistical validation of stochastic simulation models. Forest Science. 1981;7(2):349364.
13. Cooper RA, Weekes AJ. Data models and statistical analysis, Philips Allan. Oxford. 1983;400.
14. Goulding CJ. Validation of growth models used in forest management, New Zealand Journal of Forestry. 1979;24(1):108–124.
15. Segura M, Kennien A. Allometric models for tree volume and total aboveground biomass in a tropical humid forest in Costa Rica. Biotropica. 2005;37:2–8.
16. Shamak SB, Akindele SO, Isah AD. Development of volume equations for teak plantation in Nimbia Forest Reserve in Nigeria Using Dbh and Height Journal of Agriculture and Environment. 2011;7(1): 71-76. [ISSN 1595-465X]

17. Louis VZ. Stem Form, height and volume models for teak in Tanzania. Thesis Presented in Partial Fulfillment of the Requirements for the degree of Master of Science in Forestry at the University of Stellenbosch. 2005;1-83.

18. Adesuyi FE, Akinbowale AS, Olugbadieye OG, Jayeola K. Fitting non-linear models for tree volume estimation in strict nature reserve, South-West, Nigeria. Tropical Plant Research. 2020;7(1):06–13.

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