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Volume estimation model of forty-five years *Nauclea diderrichii* Plantation in Area J4, Omo Forest Reserve, Nigeria

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Abstract

This study was carried out to determine volume estimation model for Nauclea diderrichii stands in Area J4, Omo forest reserve, Ogun State using fifteen temporary sample plots. Data acquired were analyzed using summary statistics and ordinary least regression analysis (using linear, quadratic, power, exponential and reciprocal model). The results revealed that trees/hectare was 235/ha; the Basal Area was 23.78/ha while mean Dbh (cm) and mean total height were 35cm and 19.32m respectively. Volume was directly correlated with all other parameter in the order; volume α height (0.934) > dbh (0.878) > Basal area (0.872). The results of the regression analysis indicated that the power model gave the most parsimonious model to predict volume of Nauclea didderichi in a plantation. The Durbin-Watson statistics in addition returned for the power model were also about the most preferable (1.804 - 1.329). The volume – height relationship model of the power form was equally the best among others of the power form.

Keywords: Coefficient, Parsimonious, homoscedasticity, autocorrelation, stakeholder.

Introduction

Infinite number of volume can be mentioned of a standing tree including bole volume, big wood stem volume, total stem volume and total volume above ground[1]. These volume types are been tagged gross volume and there exist also the merchantable volume which is of paramount concern to forest stakeholder. Volume is a major component of stand models because of its ability to determine merchantable tree volume and total volume for the purpose of estimating commercial values of stands[2] or average content of the stand[3]. Similarly, volume was found to be of ecological importance to forest development[4] because it plays a key role in forest inventory development[5]. Indeed, total volume estimation and forest area determination were said to be the principal goal of forest survey in the early 19th century. Also, the gross and net quantities of trees are measured through the volumes of such trees[6]. Tree volume estimation serves many purposes (in economics to determine the supply and demand of tree and tree product; in science-for research and development and in sporting competition for gymnastic activities.

Models or statistical models are mathematical relationship between one or more random variables and other non-random variables[7,8]. That is a pair of *X, Y* (where *X* is the set of possible observation and *Y* is the set of probability distribution on *X)* are kindred using a model. Models according to McCullagh and Nelder[9] and McCullagh[10] serve the purpose of prediction, information extraction and description of stochastic structure. Sustainable management of forest resources requires large amounts of supporting information especially when managing a forest for production of commercially valuable materials. Estimation of the present growth variables which cannot be easily measured (such as timber volume) and future growth are essential for sustainable forest development (Subasinghe[11]). Forest models can be used as a successful research and management tools in situation of non-easily measurable parameter. Models can take the form of linear (simple or multiple) or non-linear regression models. A linear regression model is such that fits the equation y = a + bx and the resultant data is linear in nature. Non-linear regression model on the other hand is a form of regression analysis in which observed data are model by a function which is a non-linear combination of the model parameters and are dependent on one or more independent variables. A wide variety of models have been proposed for height-diameter relationships for different species in different forest regions. Krishna *et al*[12] stated the approaches that can be used for modelling height-diameter vary from linear to non-linear regression models. Lumbres *et al.*[13] developed and validated height diameter models for the three *Pinus* species and one *Larix* species in South Korea using the six widely used non-linear regression growth functions. Shamaki *et. al*[14] used two fit methods (Chapman-Richards and Weibull) to model height-diameter relationship height-diameter modelling was carried out on Teak (*Tectona grandis*) plantation in Nimbia Forest Reserve, Nigeria. Regression model which is of wider applicability for predicting and estimating the stand volume of *Nauclea diderrichii* plantation at Area J4, Ijebu-Ode, Ogun State, Nigeria is currently lacking or unknown. Meanwhile, without these models, it might be difficult to carry out strategic planning of the plantation as site value estimation becomes non-feasible. The development of an effective and accurate model to predict forest growth and products during the forest rotation is very essential for strategic forest planning. Growth and yield models depend on the functions of acquired data from a sample of the forest population of interest. These tools can mainly be used to provide decision-support systems that meet basic operational needs for appraising various forest management scenarios (Avery and Burkhart[3]. The objective of this research was thus to evolve volume models for guesstimating the volume of *Nauclea diderrichii* in a plantation (Area J4, Omo forest reserve).

Methodology

Study location: The study was conducted in Area J4, Omo forest reserve, Ogun State, Nigeria. Omo forest reserve is located between latitudes 6º35' to 7º05' N and longitudes 4º19' to 4º40' E in the south-west of Nigeria, and covers an area of about 130,500 hectares. Stand of Forty-five years old *Nauclea diderrichii* plantation was used for this study. Fifteen (15) temporary sample plot of size 25m × 25m was laid. Complete enumerations of all the trees were carried out within the sample plot. Tree growth variables (diameter at breast height -cm, Diameter at the base, middle, top and total height) were collected on *Nauclea diderrichii* in all the sample plots.

Volume estimation was computed using:

$$V = \frac{h}{6}(Ab + 4Am + At)$$

While basal area (BA) estimation was done using:

$$BA = \frac{\pi D^2}{4}$$

Data Analysis: The data obtained were analyzed using summary statistics like the mean volume, height, basal area and dbh/stands; the standard error and variance of the trees. Correlation analysis of the tree variables (height, dbh, basal area and volume) was computed while the five (5) following regression model types were investigated;

$$Y = a + bx \quad (1)$$

$$Y = a + bx + cx^2 + dx^3 \quad (2)$$

$$Y = ax^b \quad (3)$$

$$Y = a\lambda^{bx} \quad (4)$$

$$Y = a + bx^{-1} \quad (5)$$

Where: Y = Volume (m^3) and x = independent variable, BA =Basal area (m^2), Dbh= Diameter at breast height (m), H= Tree height (m), ln= Natural logarithm, b_0, b_1, b_2 and b_3= Regression Parameters.

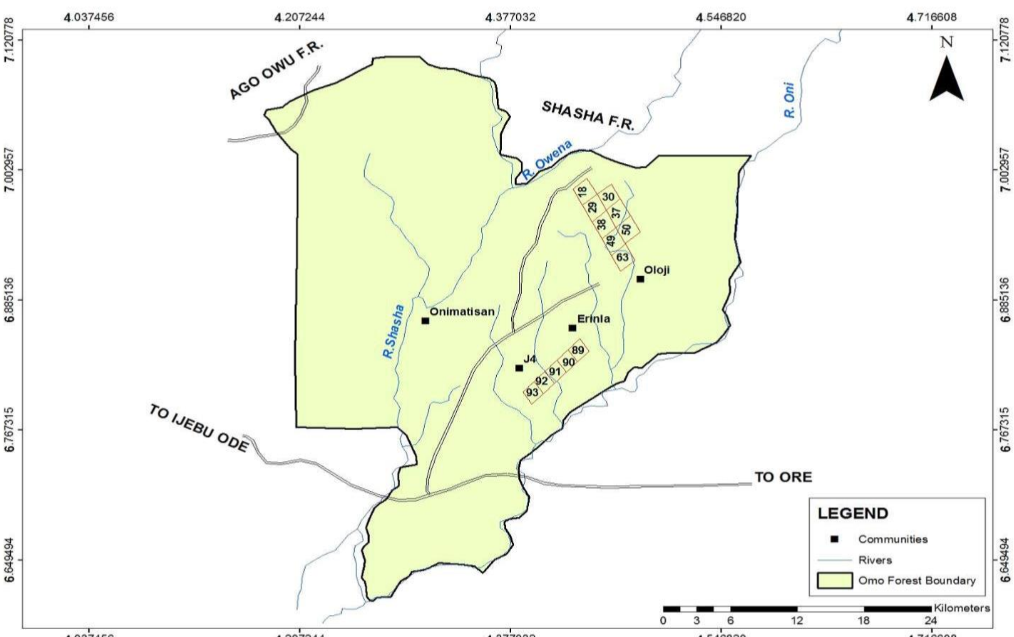

Figure-1: Map of Omo Forest Reserve.

The model statistics including the adjusted coefficient of determination (adjusted R^2), variance of the estimates as well as Durbin-Watson test. Durbin-Watson test the hypothesis no first order autocorrelation among the residuals. Durbin-Watson is given by the relationship;

$$DW = \frac{\sum_{t=2}^{T}(\lambda_t - \lambda_{t-1})^2}{\sum_{t=1}^{T}\lambda_t^2}$$

Where E_t are residuals from an ordinary least square regression. The Durbin-Watson test report a test statistics with a value from 0 to 4 (Farebrother[15]) with a preferable range of 1.5 – 2.5. The analysis was carried out using SAS (version 9) and KyPlot.

Result and Discussion

Summary Statistics and correlation analysis of the Trees and the variables measured: The summary of the stand growth variables of *Nauclea diderrichii* plantation in Area J4, Omo Forest Reserve is presented in Table-1. The number of trees per hectare is 235/ha; the Basal Area is 23.78/ha, the average Dbh (cm) and the average total height are 35cm and 19.32m respectively. The confidence limit of volume estimate at the lower and upper are 241.66 and 246.86 respectively. The maximum volume per hectare is 5.259m^3 and the minimum volume per hectare is 0.006m^3 for the stand.

The summary statistics analysis of the *Nauclea diderichi* stands encountered indicated uneven height growth though the study area is a plantation. Mean height per plots ranged between 17.840m (for stands in plot 10) and 20.958m for stands in plot 2 (Table-2). Height variability differs from one plot to another and falls between 3.635 (for stands in plot 2) and 11.689 (for stands in plot 5). No specific relationship could be established between mean and the variance of the tree height based on this result. Mean Dbh ranged between 0.304m/stand for stands in plot 15 and 0.424m/stand. The variance on the other hand ranged between 0.005 (for stand in plot 2 and 6) and 0.028 for stands in plot 14. From this result, it is noteworthy that there exists homoscedasticity condition among the stand dbh. Also, it is glaring that the height and diameter at breast height followed disparate trends. Similarly, mean basal area of the trees encountered ranged between 17.840m^3 (for stands in plot 11) and 21.250m^3 (for stands in plot 3 – Table-3). The variance was between 3.635 for plot 2's stands and 11.689 for stands in plot 11.

Table-1: The General summary of Tree Growth Variables of *Nauclea diderrichii* Plantation.

Variables	Values
No of Stem/hectare	235
Mean Dbh (cm)	35
Mean Total Height (m)	19.32
Basal Area (m^2/ha)	23.78
Volume (m^3/ha)	241.60
Confidence Limit of Volume Estimate/ha (Lower limit)	241.66
Confidence Limit of Volume Estimate/ha (Upper limit)	246.86

Table-2: Summary Statistics of the Height and DBH of *Nauclea diderrichii* plantation in Omo forest Reserve.

Plot	N	Height			DBH		
		Mean ± SE	Variance	Sum	Mean±SE	Variance	Sum
1	24	20.296 ± 0.571	7.832	487.100	0.355 ± 0.019	0.009	8.509
2	12	20.958 ± 0.5504	3.635	251.500	0.338 ± 0.020	0.005	4.061
3	18	21.250 ± 0.647	7.539	382.500	0.370 ± 0.027	0.013	6.654
4	18	18.633 ± 0.649	7.588	335.400	0.323 ± 0.028	0.014	5.821
5	17	18.594 ± 0.829	11.689	316.100	0.321 ± 0.027	0.012	5.449
6	10	19.480 ± 0.884	7.815	194.800	0.389 ± 0.022	0.005	3.892
7	16	19.531 ± 0.767	9.42	312.500	0.350 ± 0.021	0.007	5.597
8	18	20.044 ± 0.547	5.391	360.800	0.377 ± 0.026	0.012	6.781
9	12	18.333 ± 0.600	4.324	220.000	0.328 ± 0.025	0.007	3.935
10	15	18.393 ± 0.786	9.262	275.900	0.304 ± 0.028	0.012	4.561
11	10	17.840 ± 0.865	7.487	178.400	0.329 ± 0.048	0.023	3.288
12	14	18.143 ± 0.539	4.07	254.000	0.311 ± 0.021	0.006	4.358
13	19	20.653 ± 0.494	4.637	392.400	0.401 ± 0.020	0.007	7.626
14	14	19.443 ± 0.795	8.852	272.200	0.424 ± 0.045	0.028	5.930
15	19	18.484 ± 0.545	5.641	351.200	0.365 ± 0.030	0.017	6.937

Mean volume of the tree stands fall between 0.304m^3 for stands in plot 10 and 0.424m^3 for stands in plot 14. It was also observed that some of the plots are homoscedastic (having equal variance) and the variance ranged between 0.005 (for both plot 2 and plot 6's stands) and 0.028 (for plot 14 st and Table-3).

The correlation analysis result consistently returned positive pearson correlation values ranging between 0.763 (relationship between height and basal area) and 0.975 (relationship between Dbh and Basal area Table-4). All the correlation values are greater than 0.5 (Table-4) hence can be said to be highly correlated. Volume is directly correlated with all other parameter in the following order;

$$volume\ \alpha\ height(0.934) > dbh(0.878) > Basal\ area(0.872)$$

Table-3: Summary Statistics of the Basal Area and Volume of *Nauclea diderrichii* plantation in Omo forest Reserve.

		Basal Area			Volume		
PLOT	N	Mean ± SE	Variance	SUM	MEAN±SE	Variance	SUM
1	24.000	20.296 ± 0.571	7.832	487.100	0.355 ± 0.019	0.009	8.509
2	12.000	20.958 ± 0.550	3.635	251.500	0.338 ± 0.020	0.005	4.061
3	18.000	21.250 ± 0.647	7.539	382.500	0.370 ± 0.027	0.013	6.654
4	18.000	18.633 ± 0.649	7.588	335.400	0.323 ± 0.028	0.014	5.821
5	17.000	18.594 ± 0.829	11.689	316.100	0.321 ± 0.0269	0.012	5.449
6	10.000	19.480 ± 0.884	7.815	194.800	0.389 ± 0.022	0.005	3.892
7	16.000	19.531 ± 0.767	9.420	312.500	0.350 ± 0.021	0.007	5.597
8	18.000	20.044 ± 0.547	5.391	360.800	0.377 ± 0.026	0.012	6.781
9	12.000	18.333 ± 0.600	4.324	220.000	0.328 ± 0.025	0.007	3.935
10	15.000	18.393 ± 0.786	9.262	275.900	0.304 ± 0.028	0.012	4.561
11	10.000	17.840 ± 0.865	7.487	178.400	0.329 ± 0.048	0.023	3.288
12	14.000	18.143 ± 0.539	4.070	254.000	0.311 ± 0.021	0.006	4.358
13	19.000	20.653 ± 0.494	4.637	392.400	0.401 ± 0.020	0.007	7.626
14	14.000	19.443 ± 0.795	8.852	272.200	0.424 ± 0.045	0.028	5.930
15	19.000	18.484 ± 0.545	5.641	351.200	0.365 ± 0.030	0.017	6.937

Table-4: Correlation Analysis of the tree Variables measured/considered.

	Ht	Dbh	BA	Vol
Ht	1			
Dbh	0.805**	1		
BA	0.763**	0.975**	1	
Vol	0.934**	0.878**	0.872**	1

Regression models of the relationships: The Simple linear regression model of the relationships between volume and any of either height or dbh and basal area indicated that volume - height model is the most plausible model. The model coefficient of determination (adjusted R^2) obtained for the models were 0.872 (volume - height), 0.77 (volume – dbh) and 0.759 (volume – basal area). Also the F- statistics of the regression model is of the trend; 1596.00 (volume – height) > 785.657 (volume – dbh) > 740.789 (volume – base area) and these were all significant (P<0.05 – Table-4). The analysis of the variability of the estimation indicated that height is the best estimator of the volume since it gave the least variance of 0.520. This was followed by dbh (0.932) and the highest was the basal area with the variance of estimates of 3.499. Similar trend was obtained for the polynomial regression model. Volume – height model gave the highest adjusted coefficient of determination R2 of 0.887 while the polynomial model of volume based area gave the least coefficient of determination (0.772–Table-4). The $F_{(1,234,:0.05)}$ = 266.894 was obtained for volume basal area relationship and they (the values) are all significant ($p < 0.05$). The volume height relationship model retrieved the most efficient model because of the least variance obtained for volume-basal area relationship and they (the values) are all significant ($p<0.05$). The volume-height relationship model was the most efficient model because of the least variance (0.457) obtained (Table-5). The volume – dbh relationship model retuned higher variance of 0.919 while the highest variance (0.921) was obtained for volume-basal area relationship model. The power model generally returned the best model statistics irrespective of the predictors (height, dbh and basal area). The adjusted coefficient of determination-R^2 obtained for the power model ranged between 0.829 (Volume –basal area relationship model) and 0.902 (for volume – height relationship model). Similar trend was obtained for the analysis of variance for the power models. $F_{(1,234:0.05)}$= 2165.147 obtained for the volume – height model was greater than that obtained for volume –dbh relationship model (1145.029). Also, the variance of the model estimates which falls between 0.022 (for volume – height relationship model) and 0.038 (for both volume – basal area and volume – dbh relationship model) were the least among the model types investigated (Table-5). It is also noticeable that homoscedasticity exist in the estimates of 2 of the model types (volume – dbh and volume – basal area relationship models). Homoscedasticity is defined as the property of having equal statistical variance[16].

The adjusted coefficient of determination, R^2 for the exponential models ranged from 0.680 for volume-basal area relationship model to 0.884 which was obtained for volume-height relationship model. High values of F-statistics obtained for the models were all significant ($p<0.05$ – Table-5). The regression analysis of variance has $F_{(1,234:0.05)}$ = 1806.145, 805.495 and 513.524 for volume –height, volume – dbh and volume basal area relationship model respectively.

Table-5: The models and their statistics for the volume Estimation of *Nauclea diderrichii* plantation in Omo forest Reserve.

Types	Parameters	Models	Adj. R^2	F-statistics	Variance Estimation	D-W sts
Linear	Height Dbh BA	$-8.536+0.674x$ $-1.109+16.034x$ $1.695+26.594x$	0.872 0.770 0.759	1596.00 785.651 740.789	0.520 0.932 0.975	1.661 1.394 1.404
Polynomial	Height Dbh BA	$1.306-0.386x+0.03x^2-0.000084x^3$ $0.342+5.912x+19.667x^2-9.894x^3$ $1.032+40.086x-59.892x^2+53.607x^3$	0.887 0.773 0 .772	616.755 267.473 266.894	0.457 0.919 0.921	1.641 1.379 1.384
Power	Height Dbh BA	$0.0005x^{3.061}$ $16.485x^{1.27}$ $19.235x^{0.635}$	0.902 0.830 0.829	2165.147 1145.029 1143.832	0.022 0.038 0.038	1.804 1.330 1.329
Exponential	Height Dbh BA	$0.187\lambda^{0.159x}$ $1.073\lambda^{3.802x}$ $2.18\lambda^{5.902x}$	0.884 0.788 0.680	1806.145 805.495 513.524	0.583 1.398 3.499	1.652 1.482 1.724
Reciprocal	Height Dbh BA	$16.272-222.796x^{-1}$ $8.422-1.218x^{-1}$ $5.899-0.091x^{-1}$	0.777 0.565 0.403	820.023 306.490 159.927	0.902 1.759 2.413	1.743 1.623 1.6532

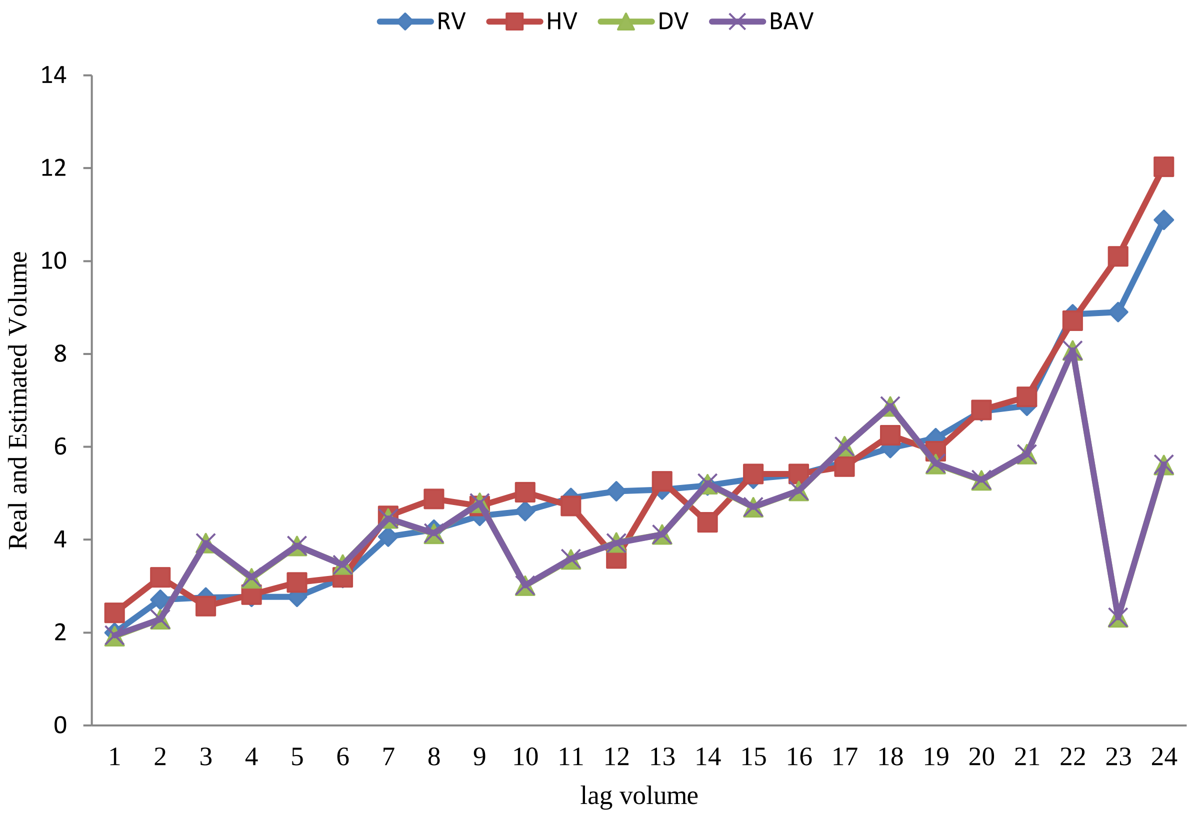

Figure-2: Visual Analysis of the Volume and the Predicted Volume. (RV=real Volume: HV = volume-Height model: DV=Volume – DBH model and BAV= Volume – Basal area model).

The variance of the estimates also falls between 0.583 (volume-height relationship model) and 3.499 (for volume – basal area relationship model). The reciprocal model of the volume – height relationship model had the highest adjusted coefficient of determination (R^2) of 0.777 while the adjusted R^2 obtained for volume – basal area relationship model had the least 0.403 (Table-5). The regression analysis of variance for the reciprocal models returned $F_{(1,234,:0.05)}$ = 820.023, 306.490 and 159.927 for volume-height, volume – dbh and volume – basal area relationship models and were all significant. The variance of the estimates were 0.902 (volume – height relationship model), 1.759 (volume – dbh relationship model) and 2.413 (volume – basal area relationship model). Lastly the sum of the error of the predictions obtained for the models were, -3.049, 17.380 and 17.241 for volume-height, volume – diameter at height breast and volume –basal area relationship models. The visual analysis of the model prediction (Figure-2) indicated that the prediction of the volume-height relationship model was the most parsimonious.

From these results and using all the model statistics, the power model gave the most parsimonious model to predict volume of *Nauclea didderichi* in a plantation. The Durbin-Watson statistics returned for the power model were also about the highest (1.804 – 1.329). The volume – height relationship model of the power form was equally the best among others of the power form.

Conclusion

Existence of stories is a peculiarity of tropical forest and this was established for the *Nauclea diderichi* plantation in our study through the disparate tree heights. This might not be unconnected with the fact that the species is one of the famous candidate of the tropical forest and also that the plantation is located within the tropical forest region. High correlation values obtained in our current study conform to Adekunle[17]. The value for basal area encountered for the stand in our study is an indication of a well-stocked forest as established by Alder and Abayomi[18]. The trend exhibited by dbh and height distributions is an indication that the plantation has not reached its climax thus still growing. Higher coefficient of determination (R^2) obtained in our present work is similar to that reported by Mugasha *et al*[19] for lowland forest of Tanzania. The homoscedasticity of the power model established in our study is in contrast with Kelly and Beltz[5]. It was maintained that heteroscedasticity occurs when samples include a range of tree sizes, from small trees to large ones as contained in the present study[5].

The probable reason for the nature of the error variance could be hinged on the model type since both Heteroscedasticity and homoscedasticity could be found in the present study. Also, it was obtained that all the investigated models were plausible for tree volume estimation and it is similar to those used by Adegbehin[20] for *Pinus caribea*, *Eucalyptus cloeziana* and *E.tereticomis* stands and Nokoe[21] for some plantation species. High adjusted coefficient of determination (R^2) obtained in our work is similar to Adekunle[17] who reported that index of fit, R and R^2 values were high for non-linear models for volume estimation in natural forest.

Height determination in practical forestry though might be said not to be meaningful[21,22], tree height was still found to be most valuable estimators of tree volume from the present study. The essence of the prediction range of the model is to provide objective basis for the adoptability of the model. Meanwhile a statistical model (Cox, 2006) was defined as a set of probability distribution P_θ on $\wp$ (that is probability distribution on sample space). So, it is not out of place establishing validity range for the most parsimonious model in the present work. Prediction range of $x \leq 65cm$ was also established by Mugasha *et al* [2] for Miombo woodland model. The range of the validity of the model might not be unconnected with the range of the original data used in the study.

Volume – height relationship model in conclusion remain the most reliable of all the models investigated in the present study. It is therefore recommended that the future study should be expanded to cover the effects of height and diameter classes on model validity range.

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