

Tree height prediction models for *Nauclea diderrichii* (De Wild. & Th.Dur.) Merrill Plantation in Area J4, Ogun State, Nigeria

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ABSTRACT

Predicting total tree height based on observed diameter at breast height is routinely required in practical management and silvicultural research work for efficient management of forest. Six nonlinear growth functions were fitted to tree height-diameter data of *Nauclea diderrichii* stands established in the years 1971, 1974 and 1975 in Ogun State Forestry Plantation Project (Area J4) Ijebu-Ode. A total of 30 temporary sample plots of size 20m x 20m were randomly selected from all the three age series with total enumeration carried out. The number of trees per age ranged from 122 to 214 with total of 619 trees. The models' goodness of fits was evaluated using coefficient of determination (R^2), Root Mean Square Error (RMSE) and significant difference at 0.05 level of probability. The coefficients of determinations (R^2) for the best models in the three stands were 77.93%, 78.74% and 97.57% for 1971, 1974 and 1975 stands respectively. All the nonlinear models fitted were significant at $p < 0.05$ for each of the stand. According to the model performance criteria, the six nonlinear growth functions were able to capture the height-diameter relationship and fitted the data while only Weibull model was adjudged the best in terms of its predictive ability across the stands. The results of slenderness coefficient SLC which measures the ratio of the tree total height to its diameter gave values ranging from 29.278 to 127.394, 21.750 to 141.390 and 18.815 to 502.72 and Mean SLC values are 53.17, 60.21 and 63.41 for the stand 1971, 1974 and 1975 respectively. The result showed that all the stands have low SLC (< 70), which implies that most of the trees species were not prone to wind throw.

Key words: Nonlinear models; growth variable; tree height-diameter.

INTRODUCTION

The individual tree height and diameter at breast height (Dbh) are essential forest inventory growth characteristics for estimating timber volume, site index, stand description, damage appraisals and other important variables in forest growth and

yield, succession, and carbon budget models (Peng *et al.*, 2001; Sharma and Zhang, 2004; Castedo-Dorado *et al.*, 2005). The relationship between tree diameter at breast height (Dbh) and total height is a structural characteristic of a tree that describes key elements of stem form, and thus the volume of the harvestable stem (El Mamoun, *et al.*,

2013). They are also the commonly measured variables in forest inventories as they are frequently required for both routine forest management activities and for research purposes. Estimating individual tree volume and site index, and describing stand growth dynamics and succession overtime, requires accurate height-diameter models (Curtis, 1967; Zhang, 1997; Colbert *et al.*, 2002; Peng *et al.*, 2004; Castedo-Dorado *et al.*, 2005). Predicting total tree height based on observed diameter at breast height outside bark is routinely required in practical management and silvicultural research work (Meyer, 1940).

Height-diameter modelling had been discovered for predicting height for a given diameter at breast height of species. These height-diameter models are primarily useful in estimating other tree parameters that are variously important in forest growth modelling and many sustainable forest management options (Larsen and Hann, 1987). Numerous of these models have been developed and postulated to predict tree heights from diameter at breast height (Dbh) (Meyer 1940, Monserud 1975, Ek *et al.*, 1984, Parresol 1992, Oyebade and Onyambo 2011). Lei and Bernard (2001) however, reported that many of these models are limited by not reflecting the pertinent characteristics of models that would give height-diameter relationship curve with monotonic increment, inflection point and asymptote with a S-shaped which is significantly appropriate in describing realistic height-diameter relationship with many forest biological growth pattern. A non-linear model of wider applicability for predicting and estimating the stand height is currently lacking for *Nauclea diderrichii* plantation at Area J4, Ijebu-Ode, Ogun stae, Nigeria. Without these models, it might be difficult to estimate the timber volume, site index, stand description, damage appraisals, and other important variables in forest

growth and yield, succession and carbon budget models.

The study therefore aims to develop predictive models for height-diameter relationship for *Nauclea diderrichii* in the study area for sustainable management.

MATERIALS AND METHODS

THE STUDY AREA

This study was carried out on three age series of *Nauclea diderrichii* plantations established in 1975, 1974 and 1971 (39, 40 and 43 years) at Area J4, which falls within latitude 6° 35' to 7° 05' N and longitude 4° 19' to 4° 10' E in the Ijebu area of Ogun State, Nigeria. The climate of Ogun State Forestry Plantation Project, Area J4 has been extensively described by Ola-Adams (1999). The reserve falls within the tropical wet – and – dry climate characterized by two rainfall peaks separated by a relatively less humid period usually in the month of August. The mean daily temperature is about 1750mm and mean relative humidity is 80%. The mean daily temperature is 26.4°C.

DATA COLLECTION

Data used in this study were obtained from the total number of 30 plots sampled randomly by stratification within the three age series (39, 40 and 43 years old) of *Nauclea diderrichii* plantations. Ten temporary sample plots of size 20m x 20m were randomly selected in each age series making a total of 30 sample plots. Total enumeration of all the trees in each plot was done. The following tree growth variables were measured; Total height (m), Height with clear bole (m) and Diameter at breast height (Dbh (m)) with the aid of Spiegel relascope and Diameter tape respectively.

DATA ANALYSIS

Data analysed in this study were generated using Curve Expert Software. In analyzing the data, scatter plots were first examined to show the relationship between the tree height (Ht) and Diameter at breast height (Dbh). Basal Area (BA) of individual trees was estimated using the formula according to Husch *et al.*, (2003) and Slenderness coefficient (SLC) was also estimated. The volume of individual trees was calculated using the equation developed for tree volume estimation in the lowland rainforests by FORMECU (1999).

$$BA = \frac{\pi}{4} D^2 \quad \text{.....eqn. 1}$$

$$SLC = \frac{THT}{D} \quad \text{.....eqn. 2}$$

$$V = e^{-8.433 \pm 2.331 \log D} \quad \text{.....eqn. 3}$$

Where: BA = Basal area (m²), D = Dbh (cm), THT = Total height and V = volume of trees (m³)

FITTING AND EVALUATION OF THE MODELS

Six non-linear growth functions (Table 1) were tested as candidate functions for the height–diameter relationship. These models were considered and selected based on their appropriate mathematical properties (typical sigmoid shape, number of parameters, flexibility), possible biological interpretation of parameters (upper asymptote, maximum or minimum growth rate), and satisfactory prediction for tree height-diameter relationship in the literature (Arabatzis and Burkhardt, 1992; Huang and Titus, 1992; Zeide, 1989; Zhang, 1997; Fang and Bailey, 1998). The models were evaluated and ranked using three statistical criteria: root mean square error (RMSE), which analyses the precision of the estimates; coefficient of determination (R²) and significance different at 5% α -level.

Table 1: The Growth Candidate Functions Fitted and Evaluated

S/N	NAME OF MODEL	EQUATIONS	REFERENCE
1.	Chapman-Richards	$h = 1.3 + a \cdot [1 - \exp(-b \cdot dbh)]^c$	Huang and Titus, 1992
2.	Weibull	$h = 1.3 + a \cdot [1 - \exp(-b \cdot dbh^c)]$	Huang and Titus, 1992
3.	Exponential	$h = 1.3 + a \cdot \exp\left[\frac{b}{(dbh + c)}\right]$	Ratkowsky, 1990
4.	Modified Logistic	$h = 1.3 + \frac{a}{(1 + b^{-1} \cdot dbh^{-c})}$	Huang <i>et al.</i> , 2000
5.	Korf/Lundgvist	$h = 1.3 + a \cdot \exp[-b \cdot dbh^{-c}]$	Zeide, 1989
6.	Gompertz	$h = 1.3 + a \cdot \exp[-b \cdot \exp(-c \cdot dbh)]$	Huang and Titus, 1992

RESULTS

The summary of the stand growth variables is shown in Table 2. The number of trees per hectare are 825/ha, 875/ha and 900/ha for the 1975, 1974 and 1971 years' stand respectively. The basal area per hectare for age 39, 40 and 43 years are 0.147m², 0.124m² and 0.047m² respectively while the maximum basal area per hectare are 0.517m², 0.325m² and 0.315m² and the minimum basal area per hectare also are 0.007m², 0.005m² and 0.001m² for the three stands age (1975, 1974 and 1971 years) respectively. The dominant volume per hectare for the stands (1975, 1974 and 1971 years) are 3.952m³, 3.315 m³ and 3.278 m³ respectively while the maximum volume per hectare are 7814m³, 5.900m³ and 5.554m³ and the minimum volume per hectare are 1.065m³, 1.030m³ and 0.487m³ for the three stands (1975, 1974 and 1971 years) respectively.

The results show that all the stands at mean and minimum SLC values have low SLC (<70). The most dominant basal area and volume was found in the 39 years old plantation (0.147m² & 3.952m³) and the least dominant was found in the forty-three years old stand (0.047m² & 3.278m³).

The result of the correlation analysis indicates a positive correlation between DBH and Height (0.588); similar trend was found between DBH and Basal area (0.976). However negative relationship was recorded for DBH and SLC, Basal area and SLC (Table 3). Knowledge of tree heights such as total height is fundamental for predicting growth and yield models in forest stands. Based on their appropriate mathematical properties, six non-linear growth functions were evaluated for estimating total tree-height using diameter at breast height (dbh) as their independent variable. These are Chapman-Richards, Weibull, Exponential, Modified Logistics, Korf/Lundqvist and

Gompertz models. The results obtained in fitting the selected models for tree height prediction for *Nauclea diderrichii*, Weibull model had the highest value of coefficient of determination (R²) accounted for 67%, with RMSE of 0.0006 for the combined data irrespective of the age (Table 4). Weibull model yielded the minimum Root Mean Square Error (RMSE), which is an indication that the estimator is efficient compared with other growth curves. Hence, Weibull model was chosen as the best model having the least value of 0.0006 at 5% α -level (Table 4). Comparing the mean of residual of the models fitted, Weibull model has the least value of -1.99×10^{-09} . The standard deviation of residual and the sum of square of residual for all the models are similar. Out of the entire model fitted, Weibull has the lowest standard deviation of residual and the sum of square of residual value of 0.2254 and 0.7114 respectively. Weibull model also yielded the least coefficient of variation of residual value of -113457652.00 when compared to other models.

Furthermore, it was observed that Weibull model gave the best fit across the three age series (1975, 1974 and 1971) used in this study as presented in Tables (5, 6 and 7). Weibull model has the highest values of coefficient of determination (R²) accounted for 97.59%, 78.74% and 71.93% with RMSE of 0.6018, 0.1315 and 0.9620 respectively. All regression models tested were significant at 5% α -level for each of the stand.

The values range from 29.278 to 127.394, 21.750 to 141.390 and 18.815 to 502.72 for the stand 1971, 1974 and 1975 respectively, with the dominant SLC value of 62.84 for the three plantations.

Diameter Class Distribution

Diameter class distribution for all the stands (1975, 1974 and 1971) followed inverse – j distribution as presented in Figure 2. The highest density was found in class 20 – 29cm; 79.75 for stand 1971, followed by class 30 – 39cm; 63.70 and 70 for stand 1974 and 1975 respectively. The lowest density was found in class 60 and above; 2, 8 and 3 for stands 1975, 1974 and 1971 respectively. Low class diameters was highest in 1971 (43years) stand. All the classes have values for each of the stands.

Hieght Class Distribution

Height class distribution for the entire stand 1975, 1974 and 1971 followed normal distribution as presented in Figure 3. The chart rose from < 5m up to class 16m – 20m and began to fall again. The highest density was found in class 16m – 20m; 98.22 and 108.50 for stand 1971 and 1974 respectively followed by class 21m – 25m; 85.80 for stand 1975. However, there are few numbers of trees in stand 1975 in class <5m, 6m – 10m, 11m – 15m and >25m. Stand forty-three and forty years (1974 and 1971) have no density in class >25m. However, only stand 1975 has values for class >25 tree height (m) size class.

Table 2: Growth Characteristics

Variables	Parameters	1971	1974	1975
DBH (cm)	Mean	29.00	33.57	34.90
	Maximum	63.34	64.29	81.16
	Minimum	10.00	10.00	10.00
	Standard Error	0.73	0.936	0.815
Height (m)	Mean	15.83	17.06	19.08
	Maximum	24.70	24.20	29.60
	Minimum	10.00	10.00	10.00
	Standard Error	0.28	0.267	0.366
BA (m²/ha)	Mean	0.075	0.099	0.110
	Maximum	0.315	0.325	0.517
	Minimum	0.001	0.005	0.007
	Standard Error	0.004	0.006	0.005
Volume (m³/ha)	Mean	2.658	2.696	3.049
	Maximum	5.554	5.900	7.814
	Minimum	0.487	1.030	1.065
	Standard Error	0.061	0.074	0.063
SLC	Mean	53.17	60.21	63.41

	Maximum	127.394	141.390	502.72
	Minimum	29.278	21.750	18.815
	Standard Error	1.280	2.898	1.361
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No of trees/ha	Mean	36	35	33
	Total	900	875	825

Table 3: Correlation Analysis

	Dbh (cm)	BA (m²)	Vol (m³)	HT(m)	SLC
Dbh (cm)	1				
BA(m2)	0.9764	1			
Vol (m³)	0.9670	0.8918	1		
Ht (m)	0.5880	0.5144	0.6500	1	
SLC	-0.5229	-0.5243	0.4670	0.3079	1

Dbh= Diameter at breast height, BA= Basal area, Vol=Volume, HT=Height and SLC=Slenderness coefficient

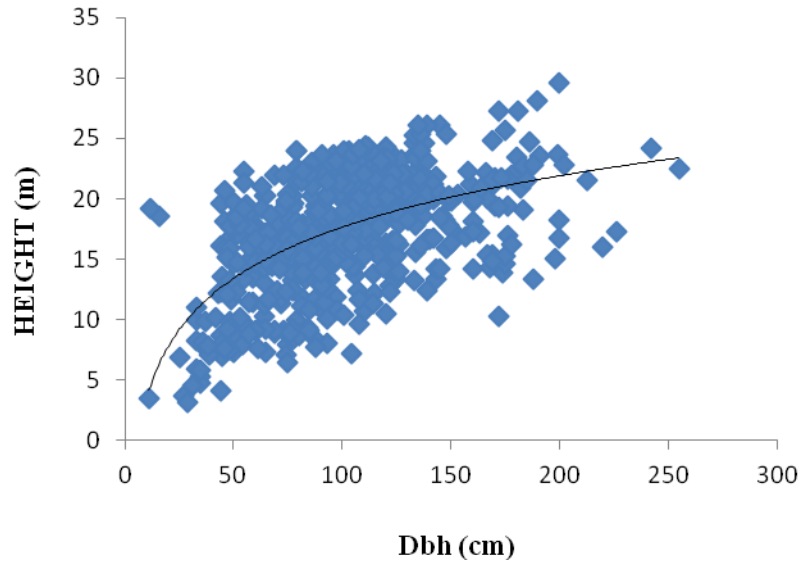


Figure 1: Relationship Between Dbh (Cm) and Height (M) for the Three Age Series

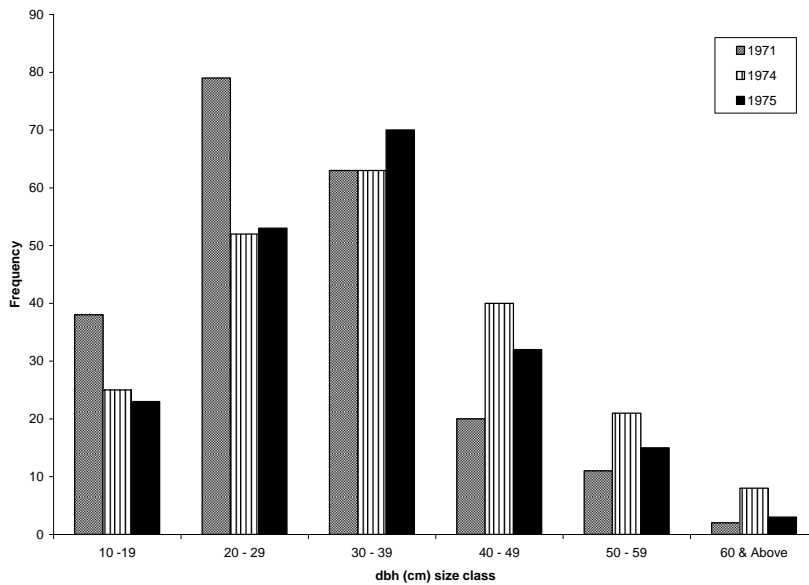


Figure 2: Diameter Distribution – Size Class Distribution for Stands in the Study Area

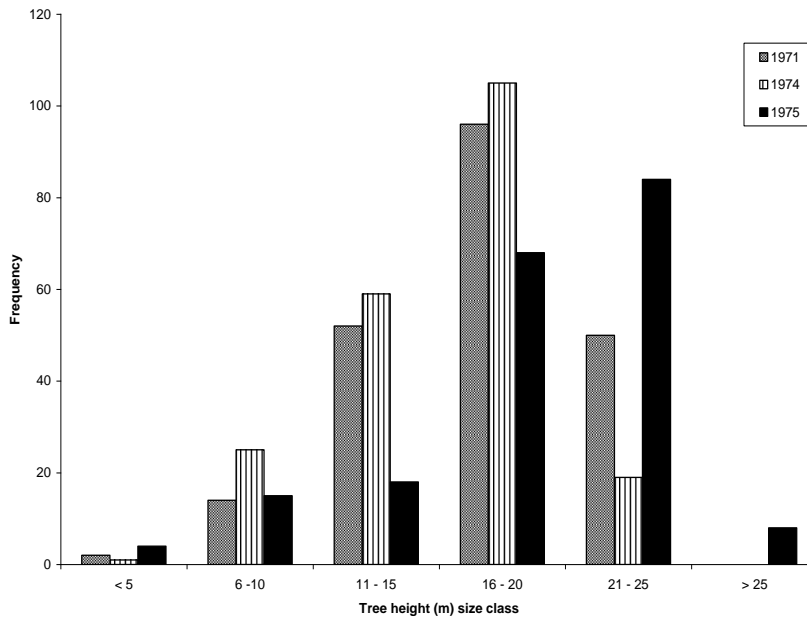


Figure 3: Height Class Distribution – Size Class Distribution for Stands in the Study Area.

Table 4: Combined Summary for Fitted Models in the Study Area

S/N	Model	Parameters			Model statistics							
		A	B	C	P-level	RMSE	R ² (%)	MR	SD	SSR	CVR	R
1	Chapman-Richards	2.232	-1.685	1.072	0.0022*	3.857	66.40	7.95×10^{-09}	0.2480	0.8608	31201002.51	3
2	Weibull	2.436	2.690	6.261	0.0006*	3.804	67.59	-1.99×10^{-09}	0.2254	0.7114	-113457652.00	1
3	Exponential	1.256	1.221	2.108	0.0118*	4.252	56.05	1.59×10^{-08}	0.2599	0.9457	16351461.41	6
4	Modified Logistic	2.219	6.092	1.260	0.0031*	3.870	65.95	7.95×10^{-09}	0.2540	0.9031	31958127.91	4
5	Korf/Lundgvist	2.289	5.080	3.293	0.0052*	3.979	63.45	-6.36×10^{-08}	1.2674	22.49	-19934035.48	5
6	Gompertz	2.232	1.182	1.059	0.0017*	3.845	66.50	-1.99×10^{-09}	0.2432	0.8282	-122417808.00	2

*Significant at 5% probability level, R² (%) = Coefficient of determination, MR = Mean of residual, SD= Std.dev. of residual, SSR= Sum of square of residual, CVR= Coeff of variation of residual and R= Ranking

Table 5: Summary Models Estimates for 1971 Stand

S/N	Model	Parameters			Model statistics							
		A	B	C	P-level	RMSE	R ² (%)	MR	SD	SSR	CVR	R
1	Chapman-Richards	1.703	-0.913	1.112	0.0031*	2.737	66.60	1.75×10^{-09}	0.2480	0.8608	141714286	3
2	Weibull	2.003	3.901	6.092	0.0008*	0.962	71.93	-1.03×10^{-09}	0.2254	0.7114	-2.19×10^{08}	1
3	Exponential	0.913	1.119	3.110	0.0108*	5.723	55.29	1.59×10^{-08}	0.2599	0.9457	16345912	6
4	Modified Logistic	2.311	4.582	0.632	0.0031*	3.009	60.93	3.78×10^{-09}	0.2540	0.9031	67195767	4
5	Korf/Lundgvist	1.230	5.013	2.917	0.0063*	4.391	59.36	-6.36×10^{-08}	1.2674	22.49	-19927673	5
6	Gompertz	2.222	0.893	2.000	0.0019*	1.335	68.93	-1.99×10^{-09}	0.2432	0.8282	-1.22×10^{08}	2

*Significant at 5% probability level, R² (%) = Coefficient of determination, MR = Mean of residual, SD= Std.dev. of residual, SSR= Sum of square of residual, CVR= Coeff of variation of residual and R= Ranking

Table 6: Summary Models Estimate for 1974 Stand

S/N	Model	Parameters			Model statistics							
		A	B	C	P-level	RMSE	R ² (%)	MR	SD	SSR	CVR	R
1	Chapman-Richards	1.062	-0.932	0.229	0.0003*	1.4329	61.31	-7.63 x 10 ⁻⁰⁷	23.8797	7983.3529	-31299583.92	3
2	Weibull	3.441	1.094	6.781	0.0038*	0.1315	78.74	-2.54 x 10 ⁻⁰⁷	28.5257	11391.9972	-112167509.00	1
3	Exponential	0.739	1.198	3.110	0.0038*	0.2697	48.69	-1.27 x 10 ⁻⁰⁶	28.5327	11397.6382	-22439055.85	6
4	Modified Logistic	2.192	4.552	3.492	0.0003*	0.2573	54.06	7.63 x 10 ⁻⁰⁷	23.8817	7984.7263	31302276.24	4
5	Korf/Lundgvist	2.110	5.821	7.402	0.0216*	0.2636	51.37	3.58 x 10 ⁻⁰⁸	0.6558	6.0219	18338765.83	5
6	Gompertz	1.734	2.999	3.339	0.0338*	0.2524	70.21	7.95 x 10 ⁻⁰⁹	0.6763	6.4035	85099148.00	2

*Significant at 5% probability level, R² (%) = Coefficient of determination, MR = Mean of residual, SD= Std.dev. of residual, SSR= Sum of square of residual, CVR= Coeff of variation of residual and R= Ranking

Table 7: Summary Models Estimate for 1975 Stand

S/N	Model	Parameters			Model statistics							
		A	B	C	P-level	RMSE	R ² (%)	MR	SD	SSR	CVR	R
1	Chapman-Richards	2.232	-1.685	1.072	0.0174*	0.6806	76.40	-6.36 x 10 ⁻⁰⁸	1.3808	26.69	-21718443.01	3
2	Weibull	2.436	2.690	6.261	0.0052*	0.6018	97.59	-6.36 x 10 ⁻⁰⁸	1.2674	22.49	-19934035.48	1
3	Exponential	1.256	1.221	2.108	0.0118*	0.6343	56.05	1.59 x 10 ⁻⁰⁸	0.2599	0.9457	16351461.41	6
4	Modified Logistic	2.219	6.092	1.260	0.0022*	0.6479	65.95	7.95 x 10 ⁻⁰⁹	0.2480	0.8608	31201002.51	4
5	Korf/Lundgvist	2.289	5.080	3.293	0.0031*	3.979	63.45	7.95 x 10 ⁻⁰⁹	0.2540	0.9031	31958127.91	5
6	Gompertz	2.232	1.182	1.059	0.0017*	0.625	86.50	-1.99 x 10 ⁻⁰⁹	0.2432	0.8282	-122417808.00	2

*Significant at 5% probability level, R² (%) = Coefficient of determination, MR = Mean of residual, SD= Std.dev. of residual, SSR= Sum of square of residual, CVR= Coeff of variation of residual and R= Ranking

DISCUSSION

The distribution of Dbh ranged from 11cm to 255cm and Height ranged from 3.2m to 29.6m in all the sampled plots. The basal area of the three plantations throughout the period of assessment followed almost the same trend with the number of stem per hectare. This can be explained by the number of trees per hectare that varies within the three years (Husch *et al.*, 2003). Also, the result shows that the trees have high basal areas correlated to the tree escapement. According to Husch *et al.*, (2003), dbh and height are functions of basal area and volume. It is evident that all the selected trees in the data set tend to follow similar trend of tapering from bottom to the top which confirms the biological validity of the data set.

The tree height prediction models used for this study include: Chapman-Richards, Weibull, Exponential, Modified Logistics, Korf/Lundqvist and Gompertz. In predicting the best model for height of *Nauclea diderrichii* plantation using diameter at breast height as independent variable in Ogun State Forest reserve, the best model was selected based on significant of the model using the α -level at 5%; the model with lowest value of Root Mean Square Error (RMSE) and model with the highest Coefficient of Determination (R^2).

Using the above criteria, it was observed (Tables 4, 5, 6 and 7) that Weibull model satisfies the requirement and therefore, was chosen as the best model for this study. The model has its Coefficient of Determination (R^2) value being the highest in all the three stands, 97.59%, 78.74% and 71.93% for 1975, 1974 and 1971 (39year, 40years and 43years) respectively. Similarly, there was a great variation in the R^2 values of the same models across the age series of the plantation. This conforms to the findings

of Ige *et al.*, (2013) and El Mamoun *et al.*, (2013).

The predicted values followed the same non-linear pattern and formed close to the line of the best fit without much outlier. The Weibull model fit also yielded the minimum Root Mean Square Error (RMSE), which is an indication that the estimator is efficient compared with other growth curves used in this study. According to Gregoire *et al.*, (1995) and Ige *et al.*, (2013), the determination of fixed and random effects parameters in a model is a flexible decision subject to debate. It was also shown in Tables 4, 5, 6 and 7 that the entire model tested were significant at $p < 0.05$.

In order of ranking, Gompertz, Chapman-Richard and Modified logistics were found to be among the models that perform better after Weibull for the three stands occupying the 2nd, 3rd and 4th position. Their respective R^2 values are 66.50%, 66.40% and 65.95% (Table 4, 5, 6 and 7). Also the RMSE value of the models is 3.845, 3.857 and 3.870 in order of the ranking. Occupying the 5th and 6th position in the order of ranking are Korf/Lundqvist and Exponential model (Table 4, 5, 6 and 7)

CONCLUSION AND RECOMMENDATION

The result of this study has evidently revealed that non-linear model can be used to predict tree height. The Weibull model was observed to give the best fit for both the combined data and three stands out of the six models considered. The study also suggests that prediction outside the range of fitting data might give misleading or unsatisfactory results. Since it has been established that diameter at breast height (dbh) and height are among pertinent tree characteristics for quantitative tree measurements and reasonable prediction, based on the result of this study, Weibull model is recommended for evaluating or

predicting the height and growth of *Nauclea diderrichii*.

In future studies, other parameters like crown cover, nearness to the neighboring tree and soil fertility should be included for examining the quality of fit better to cast any doubts concerning the quality of tested models for reasonable decision making.

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