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NON-LINEAR HEIGHT–DIAMETER RELATIONSHIP MODELS FOR FOUR ACCESSIONS OF *Parkia biglobosa* (Jacq. Benth) PLANTATION IN WASANGARE, OYO STATE, NIGERIA

P.O. Ige[1], O.O. Adeoti[2] and Z.T. Animashaun[2]

[1]Department of Social and Environmental Forestry, University of Ibadan, Ibadan
[2]Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho, Ibadan, Oyo State, Nigeria

ABSTRACT

Height–diameter relationships are significantly modulated by microsite (elevation, aspect and slope), climate and competition. Traditionally, tree height–diameter relationships are modelled or examined using linear or nonlinear regression models, in which the microsite influences or species–habitat relationships are largely ignored. The study on height-diameter modelling was carried out on 24years old Wasangare Parkia Plantation, Nigeria. Total enumeration of four accessions (Senegal, Cameroon, Ghana, and Mali) selected were carried out. Data on tree height and diameter at breast height (dbh) were subjected to ten (10) nonlinear models to predict the height-diameter relationships. Harmonic Decline model was observed to give the best fit for Senegal ($H = {}^{4.452}\big/\left(1 + {}^{dbh}/_{-58.032}\right)$, RMSE = 2.329 and AIC = 83.239) and Ghana ($H = {}^{4.141}\big/\left(1 + {}^{dbh}/_{-17.000}\right)$, RMSE = 0.989 and AIC = 1.190) accessions while Ratkowsky and Modified Exponential models were observed to be the best for Cameroon ($H = {}^{11.814}/_{(1 + e^{(3.958 - 0.275dbh)})}$, RMSE = 3.441 and AIC = 140.126) and Mali ($H = 11.161 * e^{-3.682/_{dbh}}$, RMSE = 3.605 and AIC = 152.391), respectively. Due to the availability of other accessions stands in the study area, the method and the best models developed for height-diameter relationships in this study can be further used for predictions.

Keyword: Accessions; height-diameter; model; climate; plantation.

INTRODUCTION

Measurements of tree heights and diameters are essential in forest assessment, modelling and management (Ige *et al.*, 2013). The relationship between height and diameter is also related to species, climatic, soil characteristics, region and tree species diversity (Feldpausch *et al.*, 2011). Tree heights are used for estimating timber volume, site index and other important variables related to forest growth and yield, succession and carbon budget models (Peng *et al*., 2001, Ige *et al.*, 2013). Tree height is difficult, time consuming and expensive to obtain most especially in dense stands (Moore *et al.,* 1996; Hasenauer and Monserud, 1997; Uzoh and Oliver, 2006; Uzoh, 2017). As a result, instead of measuring the heights of all the trees in a stand, it is more preferable in inventory studies traditionally to measure the diameter at breast height (dbh) of all the trees in the stand and height is measured on a sub-sample of trees. For diameter measurements, there are several diameter measurements that can be obtained from a tree stand such as diameter at the base (db), diameter at breast height (dbh), diameter at the middle (dm), and diameter at the top (dt). Diameter at breast height (dbh) measurement can be considered to be more accurately obtained and most widely used because trees exhibit their growth at this point and can be obtained at low cost than total tree height. It is usually measured at 1.3 meters above ground level. The effective correlations between tree height and diameter is thus used to formulate models to estimate the heights of the remaining trees in the stand, reducing the costs associated to forest inventory (Paulo *et al.*, 2011). Finding accurate and easy to apply height-diameter relations are therefore important tools in inventory design and monitoring and in forest growth simulators, where individual tree diameter or stand level growth is estimated based on site productivity and stand characteristics (e.g. Palahí *et al*., 2003; Adame *et al.*, 2008; Ahmadi *et al.*, 2013). Previous studies have shown that, a number of height–diameter equations have been developed using only DBH as the predictor variable for estimating total height (e.g. Huang *et al.*, 1992; Moore *et al*., 1996; Zhang 1997; Peng 1999; Fang and Bailey 1998; Fekedulengn *et al*., 1999; Shamaki *et al.*, 2016). However, the height–diameter relationship is neither constant between stands nor over time (Curtis, 1967; Ferraz Filho *et al.*, 2018), which it is often addressed by creating models including additional variables to account for the stand dynamics.

Nevertheless, the relation between the diameter of a tree and its height varies amongst given forest structures (Calama and Montero, 2004) and depends on the growing environment and stand conditions (Sharma and Zhang, 2004). For a particular height, trees that grow in high density stands will have smaller diameters than those growing in less dense stands, because of greater competition between individuals (Lopez Sanchez *et al*., 2003; Calama and Montero, 2004; Ige, *et al.*, 2013).

Parkia biglobosa, also called the African Locust Bean tree is a multipurpose tree indigenous to the tropical regions of West Africa. *Parkia biglobosa* belongs to the family Mimosaceae (Leguminosae-Mimosoideae) (Alinde *et al.*, 2014). The matured tree can grow up to 30m in height with a crown large of low branches. *Parkia biglobosa* occurs in a diversity of agro-ecological zones, ranging from tropical forests with high and well-distributed rainfall to arid zones where mean annual rainfall maybe less than 400 mm. It has a capacity to withstand drought conditions because of its deep taproot system and an ability to restrict transpiration (Orwa, *et al.*, 2009). Aside from its ecological role in cycling of nutrients (Gbadamosi, 2005; Udobi *et al.*, 2010), it is a valuable source of food especially the seeds which serves as a source of useful spices for cooking (Campbell-Platt, 1980) reported that it is a very important tree crop in the Africa Savannah where the natives use it as medicine, glaze for ceramic pots, fodder, firewood, and charcoal production. *Parkia* tree is also used as timber for making pestles, mortars, bows, hoe handles, and seats (Irwine, 1961) while the husks and pods are good food for livestock (Hagos, 1972). Therefore, the objective of this study is to develop and compare selected nonlinear models fitted for *P. biglobosa* tree height–diameter relationship in the study area for sustainable management.

MATERIALS AND METHODS

Study Area

Wasangare Parkia Plantation is located in the Savannah zone of Oyo state, Nigeria. The accessions of *Parkia biglobosa* were from eleven (11) African countries and span across 10 hectares. This study is based on four (4) accessions from Senegal, Cameroon, Ghana and Mali. The area lies between Lat. 8.8558ºN to 8.8573ºN and Long 3.42353ºN to 3.42519ºE (Fig 1). The plantation was established in 1995 through Commission of the European Communities Directorate General for Science, Research and Development Programme. The project was aimed at Germplasm conservation and improvement of Parkia for multipurpose use. The climate is of tropical savanna or tropical wet and dry climate where it exerts enormous influence on the area. This climate, exhibits a well-marked rainy season and a dry season with a single peak known as the summer maximum due to its distance from the equator. The average monthly temperature of the site is 26.18ºC with highest value recorded in March (28.1ºC) and minimum in June and July (24.5ºC each) and an annual rainfall of about 1,500 mm with a single rainfall maxima in September. Generally, the soil is sandy loam and slightly acidic with outcrop of rocks (FRIN, 2018).

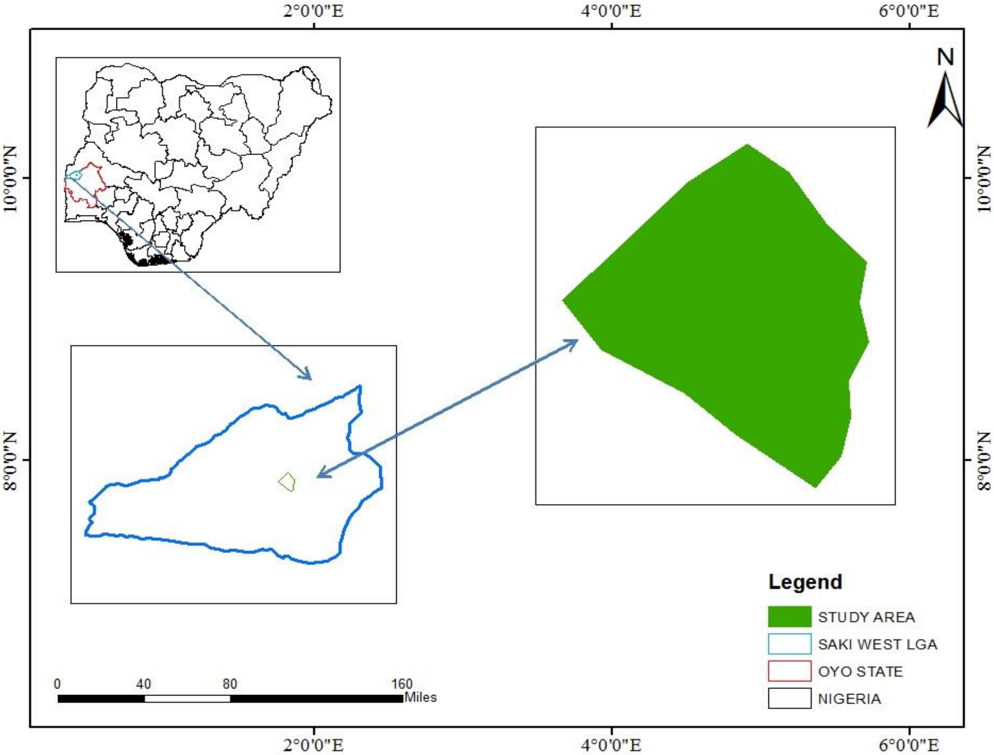

Figure 1: The Study Area

Sampling Technique and Data Collection

Total enumeration of the plantation for each accession were done for Parkia that have their dbh above 10 cm using 20 x 20 m sample plots in the plantation for data collection. The following data were collected for enumeration and further analysis:

- Diameter at breast height (dbh) usually measured at 1.3m above ground.
- Diameter over back at the base, middle, and top.
- Stem height and merchantable height were also measured using a Spiegel Relaskop

Basal Area Estimation

The Basal Area (BA) of individual trees was estimated using the formula in equation 1 (Husch *et al.*, 2003)

$$BA = \frac{\pi}{4} D^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where BA = Basal area (m^2), D = dbh (cm).

Slenderness Coefficient Estimation

The slenderness coefficient (SC) is the ratio of tree height to its DBH. It shows the firmness of a tree to withstand wind throw.

$$SLC = \frac{THT}{Dbh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 2$$

Where,
THT = total height and Dbh = diameter at breast height
The values obtained from the analysis of the data were classified into three categories (Navratil *et al*., 1994) as stated below:
SLC values > 99 = high slenderness coefficient
70 < SLC > 99 = moderate slenderness coefficient
SLC < 70 = low slenderness coefficient.

Data Analysis

The data collected were summarised using descriptive statistics and non-linear regression models were further developed using R Statistical Package, version 3.5.0.

Fitting of Height-diameter Models

Prior to model calibration, scattered plot of height against dbh of the data from the field was plotted for each of the accession so as to know the relationship between the two variables and plots appeared to be nonlinear (Figures 2-5). Hence, the choice of using nonlinear modelling was considered.

Ten (10) non-linear model forms were used for height-diameter relationship model fitting as presented in Table 1. The data set was divided into two, 70% of the data set (calibrating set) were used to fit the 10 height-diameter models, while the remaining 30% was used for model validation as described by Akindele (1990).

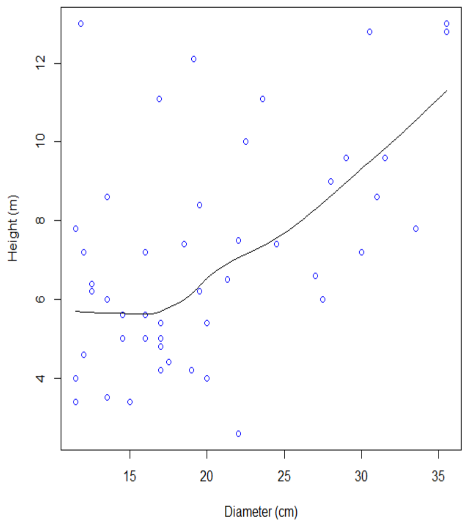

Fig 2: Scattered plot for Senegal accession

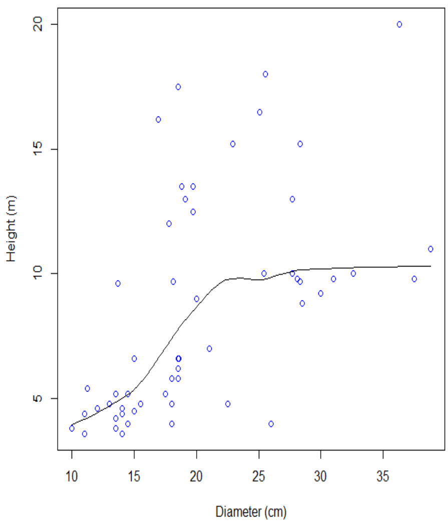

Fig 3: Scattered plot for Cameroon accession

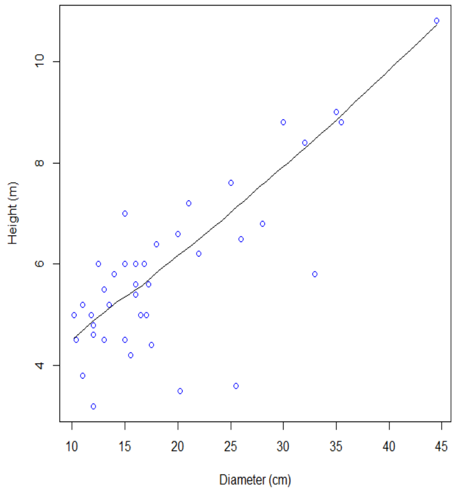

Fig 4: Scattered plot for Ghana accession

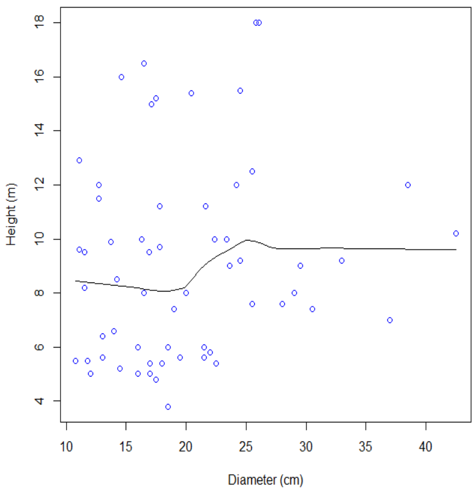

Fig 5: Scattered plot for Mali accession

Table 1: Model forms adopted for height-diameter relationship modelling

S/N		Function	Equtn No	Reference
1	Exponential	$H = ae^{b*dbh}$	3	Banin, *et al.*, (2012)
2	Hyperbolic decline	$H = \left(a\left(1+\frac{b*dbh}{c}\right)\right)^{-\frac{1}{b}}$	4	Philip (1994), Ige, *et al.*, (2013)
3	Exponential association 2	$H = a(1-exp(-b*dbh))$	5	Tsoularis and Wallace (2012)
4	Gompertz	$H = a*e^{(-e^{(b-c*dbh)})}$	6	Winsor (1932), Mensah, *et al.*, (2018)
5	Richards	$H = {}^{a}/_{(1+e^{(b-c*dbh)})^{1/d}}$	7	Winsor (1932), Mensah, *et a*l., (2018)
6	Power	$H = a*dbh^{b}$	8	Mensah, *et al.*, (2018)
7	Saturation Growth Rate	$H = {}^{a*dbh}/_{(b+dbh)}$	9	Tsoularis and Wallace (2012), Ige, *et al.*, (2013)
8	Ratkowsky	$H = {}^{a}/_{(1+e^{(b-c*dbh)})}$	10	Ratkowsky (1990), Mensah *et al.*, (2018)
9	Harmonic Decline	$H = {}^{a}/_{\left(1+{}^{dbh}/_{b}\right)}$	11	Khamis and Ismail (2004)
10	Modified Exponential	$H = a*e^{b/dbh}$	12	Khamis and Ismail (2004), Ige, *et al.*, (2013)

H = Height (m), a,b,c, and d = model parameters

The model predictions functions for each accession were compared using the root mean square errors and biases/residuals of stand diameter class. The absolute root mean square error (RMSE) was calculated as:

$$RMSE = \sqrt{\sum_{i=1}^{n}(Vi-\lambda i)^2}\,/n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

Where: n = number of sample stands, Vi = diameter/height class of growing stock in stand i, λi = the diameter/height of stand i estimated from the predicted distribution. The bias of the predictions was calculated as:

$$Bias = \sum_{i=1}^{n}(Vi-\lambda i)^2\,/n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

Also, Akaike Information Criterion (AIC) was used for criteria selection and the models were ranked based on the AIC value. The lower the AIC value the better the model. The AIC is of the form:

$$AIC = 2k - 2\log(L) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

Where:
K = number of estimated parameters in the model
log = logarithm
L = the maximized value of the likelihood function for the model

The plausibility and suitability of the models were further assessed using paired sample student T-test as described by Adekunle, *et.al.* (2013). This was done by comparing the observed value for the dependent variable (height) with their predicted values. The decision rule for the test is to accept the null hypothesis (H_o: mean value observed = mean value predicted) if the p–value < 0.05.

RESULTS

Total number of *P. biglobosa* stands encountered in this study for the four (4) accessions selected are 306 tree stands. These data were randomly split in to two datasets for model development (80%) and for model validation (20%). All the three models selected were found to fit the dataset adequately at p=0.05. The student t–test between the observed and predicted values for the dependent variable (height) was conducted to ascertain the predictive ability of the models considered. The predicted height values from the best fit models were not statistically different from the height observations (Table 4). However, the slenderness coefficient value obtained for the selected accessions were moderate, the values ranges from 11.82 to 110.68, 15.38 to 98.33, 14.12 to 71.82, 18.54 to 115.81 for Senegal, Cameroon, Ghana, and Mali, respectively. From Table 2, it was observed that the mean dbh (cm) were 20.30, 20.77, 19.15, and 19.66 for Senegal, Cameroon, Ghana, and Mali, respectively. In the same vein, mean stem height (m) were 8.77, 9.23, 6.86 and 8.42 for Senegal, Cameroon, Ghana, and Mali, respectively.

Table 2: Summary statistics of growth characteristics

Accession Country	Variables	Mean	Minimum	Maximum	Standard Error
Senegal	DBH (cm)	20.30	10.50	42.01	0.89
	Height (m)	8.77	2.60	17.00	0.44
	Basal area (m^2)	0.04	0.01	0.14	0.00
	SLC	46.39	11.82	110.68	2.57
Cameroon	DBH (cm)	20.77	10.00	40.00	0.81
	Height (m)	9.23	3.60	20.00	0.47
	Basal area (m^2)	0.04	0.01	0.13	0.00
	SLC	45.69	15.38	98.33	2.09
Ghana	DBH (cm)	19.15	10.00	44.50	1.02
	Height (m)	6.86	3.20	13.00	0.32
	Basal area (m^2)	0.03	0.01	0.16	0.00
	SLC	38.19	14.12	71.82	1.51
Mali	DBH (cm)	19.66	6.50	42.50	0.74
	Height (m)	8.42	3.80	18.00	0.37
	Basal area (m^2)	0.03	0.00	0.14	0.00
	SLC	46.99	18.54	115.81	2.50

Table 3 shows the summary of the best three fitted models and ranked according to their suitability. It was observed that, the model that performed better was not the same across the accessions. The Harmonic Decline model performed better for Senegal and Ghana accessions in the plantation while Ratkowsky and Modified Exponential models performed better for Cameroon and Mali respectively. Figures 6-9 further revealed graphical plot of correlation between height and dbh for the models selected in each accession. Table 4 revealed the validation of models for predicting the height with student's t-test. It was observed that the best three models selected for accession were suitable for use base on the fact that the mean predicted and observed values of the dependable variables were not significantly different at 5% probability level.

Table 3: Summary of the fitted Models ranked according to their suitability

		Model parameters				Selection Criteria	
Accessions	Models	A	b	C	d	RMSE	AIC
	Harmonic Decline	4.452	-58.032			2.329	83.239
	Hyperbolic Fit	-121.824	3.225			2.303	84.310
Senegal	Exponential	3.899	0.028			2.356	84.331
	Ratkowsky	11.814	3.958	0.275		3.441	140.126
	Gompertz	12.178	2.3284	0.187		3.453	140.531
Cameroun	Chapman Richards	11.357	20.342	1.015	8.206	3.424	141.811
	Harmonic Decline	4.141	-17.000			0.989	1.190
	Exponential	3.646	0.023			0.990	1.274
Ghana	Hyperbolic Fit	-57.223	-0.552			0.986	3.127
	Modified Exponential	11.161	-3.682			3.605	152.391
	Exponential Association	9.983	0.139			3.608	152.498
Mali	Exponential	7.636	0.008			3.609	152.627

Table 4: Validation results of models for predicting the height with student's t-test

Accessions	Models	t-value	df	p-value	Remark
	Harmonic Decline	0.041	47.000	0.967	Ns
Senegal	Hyperbolic Fit	-0.002	47.000	0.999	Ns
	Exponential	0.028	47.000	0.978	Ns
	Ratkowsky	0.035	54.000	0.972	Ns
Cameroon	Gompertz	0.027	54.000	0.979	Ns
	Chapman Richards	0.014	54.000	0.989	Ns
	Harmonic Decline	-0.026	41.000	0.980	Ns
Ghana	Exponential	0.013	41.000	0.990	Ns
	Hyperbolic Fit	0.000	41.000	1.000	Ns
	Modified Exponential	0.006	57.000	0.995	Ns
Mali	Exponential Association	0.003	57.000	0.997	Ns
	Exponential	0.042	57.000	0.967	Ns

*ns= no significance difference, df= degree of freedom

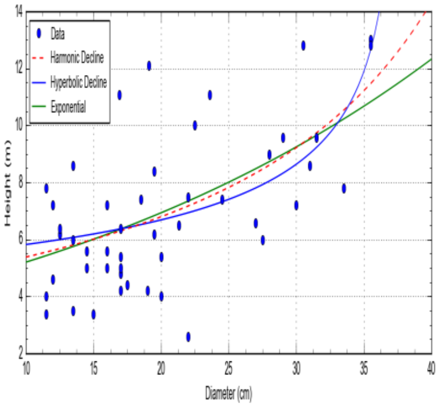

Fig 6: Height-Diameter relationship for Senegal

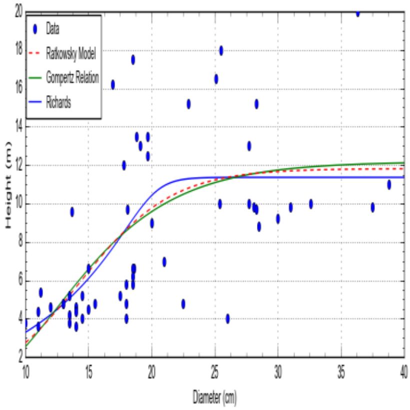

Fig 7: Height-Diameter relationship for Cameroon

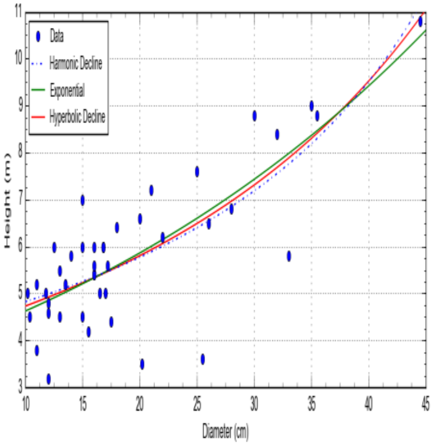

Fig 8: Height-Diameter relationship for Ghana

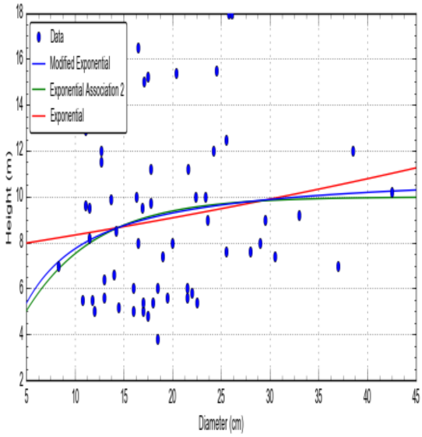

Fig 9: Height-Diameter relationship for Mali

DISCUSSION

It was deduced that growth variables observed in this study area compared favourably well with what is obtainable in tropical Plantation forests (Husch *et al*., 2003; Ige, 2018; Ige and Akinyemi, 2015; Ige and Adesoye 2017; Akindele, 1990). This study shows that Cameroun accession in terms of height performed very well in the plantation with the value of 20m followed by Mali, Senegal, and Ghana with 18m, 17m, and 13m respectively. In this study, ten non-linear growth functions model forms were adopted for Height-diameter relationship and the best three were selected for each accession as a result of performing very well with small AIC value of 83.239, 140.126, 1.190, and 152.391, for accessions of Senegal, Cameroun, Ghana and Mali respectively. It was also observed in this study that Harmonic decline model performed very well for two of the accessions (Senegal and Ghana) while Ratkowsky and Modified Exponential performed very well for Cameroun and Mali respectively.

The result of tree slenderness coefficient in this study implies that the stands can withstand wind throw at the moment (Navratil *et al*., 1994). The relationship between tree height and diameter is one of the most important elements of forest structure (Zhang *et al*., 2014). In this study, it was observed that there is no significance difference between the observed mean height and predicted values. It was discovered in previous studies that the inclusion of stand characteristics as independent variables in height-diameter models improved the prediction accuracy of tree height estimation (Newton and Amponsah, 2007). According to Huang *et al*. (1992) and Mengasha *et al*. (2018) for any appropriate height-diameter model, the asymptotic statistics for each coefficient has to be significant, the AIC has to be small and the model RMSE has to be small. The result of this study is in line with Ige *et al.* (2013) who developed five nonlinear growth functions for Tree height–diameter of a 21-year-old *Gmelina arborea* plantation in Ibadan, Nigeria. According to the model statistics, the five growth functions fitted the data equally well, but resulted in different asymptote estimates. Modified exponential fit was observed to give the best fit for the three data sets based on least square error and AIC. Also**,** Özçelik *et al.* (2014) developed Seven different nonlinear height (*h*)–diameter (*d*) models for brutian pine (*Pinus brutia*), black pine (*Pinus nigra* Arnold), and Taurus cedar (*Cedrus libani* A. Rich.) in southern Turkey. Residual analysis was conducted to identify the error structure. A weighting factor of $wi = 1/d$ was found to be appropriate for achieving the equal error variance assumption.

The performance of the models was compared and evaluated based on 6 statistical criteria and residual analysis. Results suggested that the Gompertz model was superior to the other models in terms of its predictive ability which supports this study. Sharma *et al*., (2007) investigated the Height–diameter relationships based on stand characteristics (trees/ha, basal area, and dominant stand height) for balsam fir, balsam poplar, black spruce, jack pine, red pine, trembling aspen, white birch, and white spruce using data from permanent growth study plots in northern Ontario, Canada. Approximately half of the data were used to estimate model parameters with the rest used for model evaluation. Multiple Chapman–Richards functions with parameters expressed in terms of various stand characteristics were fit to determine the best models for predicting height. Shamaki *et al.* (2016) carried out a study on height-diameter modelling on Teak (*Tectona grandis*) plantation in Nimbia Forest Reserve; two fit methods (Chapman-Richards and Weibull) were used to model height-diameter relationship. Pseudo coefficient of determination (Pseudo R^2) and residual mean square error (RMSE), goodness-of-fit statistics were considered as model selection criteria.

The authors concluded that Chapman-Richards function produced the best goodness-of-fit statistics for Teak. Mensah *et al.* (2018) Height-diameter equations are essential to understand forest dynamics and estimate forest biomass and carbon stocks. Using a dataset of 1130 trees measured for their diameter and height from four forest sites with varying environmental characteristics across South Africa, they evaluated the deviations in height estimated from existing generalized height-diameter equations, compared the predictive ability of eight function forms applied to develop height diameter models, tested for sites and species effects on tree height-diameter allometries and developed country scale and site-specific height-diameter models in South Africa natural forests. The existing continental height-diameter equations significantly overestimated tree height in South Africa. The deviations associated with these equations, though varied with sites, remained substantially large and increased with increasing tree diameter. The power function outperformed the other theoretical functions forms and proved to be the most suitable for height-diameter allometry at country scale. Mengesha *et al.* (2018) conducted a study to fit and evaluate ten existing nonlinear height diameter functions for *Cupressus lusitanica* in Gergeda forest Ethiopia. A total of 260 trees were measured for their dbh and height using destructive sampling methods. Considering hetroscadasticity of variance, all functions were fitted using weighted nonlinear least square regression. To evaluate the performance of each model, five fit statistics-such as Coefficient of determination (R^2), root mean square error (RMSE), bias (E), absolute mean deviation (AMD), and coefficient of variation (CV%) were used. Among all the models tested, the Weibull type function of the form was observed to give the best fit based on the model's goodness of fit and predictive ability which does not support this study because Weibull type function failed in pre-selection test in this study.

CONCLUSION

The relationship between height and diameter for *Parkia biglobosa* stands in the plantation was observed to follow a nonlinear pattern based on the preliminary scatter plots, hence the decision to carryout nonlinear modelling. Based on the different performance evaluation of the models, the Harmonic Decline, Ratkowsky, and Modified Exponential models of this study provides more satisfactory result based on the AIC value than the other models. It can also be suggested that for the remaining accessions of other African countries in the plantation the models developed can be adopted to know the height-diameter relationships.

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