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TREE HEIGHT – DIAMETER MODEL FOR THE INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE (IITA) FOREST, IBADAN NIGERIA

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Abstract

Tree height is one of the basic growth variables in forestry through which several other variables essential to forest management and decision-making and stand development over time are dependent. To this end, a study was conducted to develop models for estimating tree height- diameter relationship for IITA forest, Ibadan, Nigeria. Systematic sampling design was used to lay three straight line transects, four temporary plots of 0.25ha (50 m x 50 m) were laid in alternating position along each transect at 100 m interval to make up a total of 12 plots for the study, total height and Diameter at breast height (Dbh) were measured for all trees with Dbh ≥ 10cm in every plot. A total of 299 trees, 46 species from 25 families were encountered. Mean Basal Area (Ba) ranged from 0.01 m^2 *to 0.54*m^2*, mean volume ranged from 0.02* m^3 *to 11.93* m^3*, mean Dbh ranged from 10.00cm to 110 cm and mean total height ranged from 3.0 m to 34.40 m The Height- diameter relationship was modeled using R statistics. The data collected were split into two sets; the first set was the calibration set which was used for models' construction and the second was the validation set. and Akaike's Information Criterion (AIC), Bayesian Information Criterion (BIC) and Root Mean Square Error (RMSE) were the criteria used to select the best model. Based on these criteria, the power function (*$H = 1.3 + 29.275BH^{0.724}$*) was adjudged to be the most suitable model that best predict tree height for IITA forest because it has the lowest AIC and RMSE of 1387.598 and 5.616 respectively followed by Gompertz. Logistics and Ratkowsky has the same AIC and RMSE of 1394.859 and 5.697 respectively. T-test carried out to validate the best model at 95% probability level revealed that there was no significant difference (P>0.05) between the mean of predicted height (12.402m) and mean of the observed height (12.378m) with p-value of 0.976. However, close and low values of AIC and RMSE for all models tested suggest that all the models can adequately predict tree height for IITA forest and an indication that the models' estimators are efficient.*

Keyword: *Tree height, Diameter at Breast Height, Models, IITA, AIC*

Introduction

Tree height is one of the most important variables crucial for quantitative assessment of forest stocks, however, it is difficult to measure, more time consuming, and expensive. In addition, the closed canopy nature of dense stands hinders visibility (Nguyen *et al*., 2019, Sharma, Parton 2007; Colbert *et al*., 2002; Staudhammer and Lemay, 2000) and others sources of errors and challenges to measuring tree height, especially in natural forest include visual obstructions, rounded crown forms, leaning trees and terrain (Mugasha *et al*., 2013). Several other variables essential to forest management decision-making, such as tree scrolling and volume, stand dominant height and station quality index are derived from tree height, and the projection of stand development over time is based on precise height-diameter functions (Achille *et al*., 2022; Baumeister, 2017; Calama and Montero, 2004).

Tree height measuring exercise is a tedious task and even more difficult in natural and complex tropical forests, where trees of various ages, species, sizes, vigor classes, crowns and shade tolerance levels coexist, than under uniform planting conditions and this could cause measurement errors (Calama and Montero, (2004); Fortin *et al*., (2009); Zhang *et al*., (2014), Temesgen *et al*. (2014) Maiti *et al*., 2016) and Salami *et al*. (2021). Tree height-diameter models effectively describe the relationship between both tree characteristics at the stand level, and are frequently used in forest inventories for forest management and planning when sufficiently representative sample of diameter and height measurements are used (Ayoola and Silas, 2023). Information on tree height and diameter is important for efficient management of trees in various ways such as to estimate the volume, the height of the trees in the forest which is also a pointer to evaluate site productivity and provides information on the competition of trees for nutrient, light and space within a stand (West, 2015, Ige *et al*., 2019, Ayoola and Silas, 2023). Hence to save time and effort in forest inventory, it is important to develop tree height – diameter relationship models to predict height instead of direct measurement of height (Ahmadi *et al*., 2013).

The International Institute of Tropical Agriculture (IITA) forest, Ibadan, Nigeria has been under protection since 1965 shortly after the whole area was acquired and has served as reservoir of numerous plant and animal species. A number of studies on regeneration dynamics Ariyo (2020), Salami and Akinyele (2018), Oladoye *et al.* (2014), Ariyo *et al.* (2013), socio-economics (Ariyo *et al*., 2018,), yield models (Aghimien *et al*., 2016), Wildlife (Osunsina *et al*., 2012), there is no known or documented studies on tree height–diameter distribution model for IITA forest. Hence the objective of this study was to develop tree height–diameter relationship models for tree species in the IITA forest to promote easy estimation of tree heights.

Materials and Methods

Study Area

The study area is located on the one thousand hectares out of which 350 hectares IITA Forest Reserve has been under active protection since 1965 in the International Institute of Tropical Agriculture (I.I.T.A) campus at Idi-Ose, North of Ibadan, Nigeria on longitude 7° 30′N and latitude 3° 55′ E and 243m above sea level. The site is within the humid tropical lowland and has two distinct weather seasons: the longer wet season and shorter dry season. Wet season last for eight months and it extends from March to October while dry season last for four months from November to February. The rainfall pattern has bimodal peak with an annual total range between 1,300-1,500mm most of which falls between May and September. The average daily temperature ranges between 21°C-23°C while the maximum is between 28°C and 34°C. Mean relative humidity is in the range of 64-84% (Ariyo, 2020, Aghiemien, *et al*., 2016, Oladoye and Aduradola, 2015, Osunsina *et al.,* 2012, Tenkouano and Baiyeri, 2007).

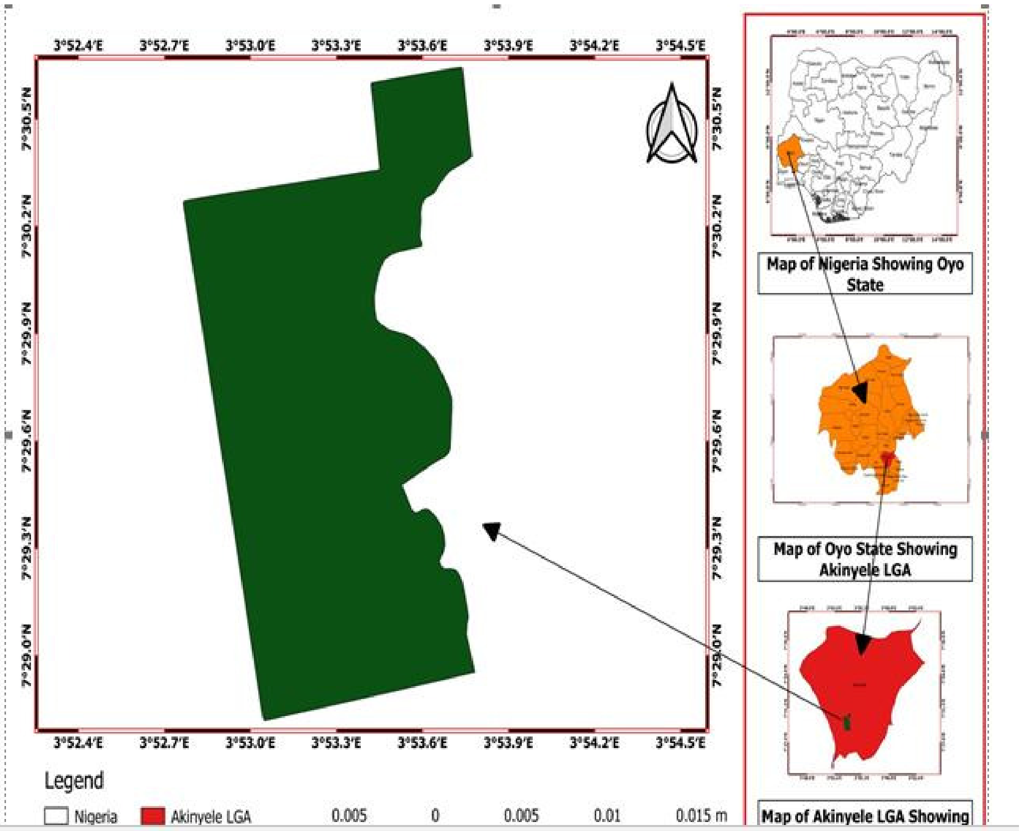

Fig. 1: Map of the study Area

Study Design

Systematic sampling (line transect) technique was adopted for plot location in the reserve following Adekunle *et al* (2004), Oladoye *et al.,* (2020). A distance of 20 m from the forest boundary was measured to locate the first transect. The starting point of each transect was determined with the aid of Geographic Positioning System (GPS) receiver. Three transects were laid within the location and four 0.25ha (50 m x 50 m) plots were laid in alternate position along each transect at 100 m interval to make a total of 12 plots for the study.

Data Collection

The data used for this study comprises tree height (H) and diameter at breast height (Dbh) for 299 trees from 46 species collected from twelve (12) temporary sample plots of 0.25 ha. Measurement and information collected are diameter at breast height (Dbh) of diameter girth and tape Spiegel Relascope respectively. Also, trees were identified to species level.

Data Analysis

Tree height-diameter models that were used for this study as presented in table 1, are power, exponential, logistic, Gompertz, Ratkwosky and Modified Exponential, their consideration was based on their appropriate mathematical features such as (typical sigmoid shape, flexibility) and possible biological integration of parameters (eg. Upper asymptote, maximum or minimum growth rate as described by Huang (1999), Peng *et al*. (2001), Temesgen *et al*., 2014; Mehtätalo *et al*., 2015; Mensah *et al*., 2018). The models selected were fitted by nonlinear least-squares (nls) estimations using the 'nls' function of the R Stats Package version 3.6.4 while the selection of the best fit model was based on the lowest RSE, mean bias, AIC and BIC values. Prior to model calibration, scattered plot of height against dbh of the data from the collected was plotted to know the relationship between the two variables across plots and appeared to be nonlinear (Figure 2). Hence, the choice of nonlinear modelling. Residual analysis was conducted to identify the error structure. A weighting factor was found to be appropriate for achieving the equal error variance assumption to deal with heteroscedasticity of the data set.

Model validation is important before inferences deduced from them can be used with confidence. Validation involves the process of testing and comparing the models output with what is observed in the real world (Ige *et al.,* 2014.The data collected was randomly split into fitting (70%) and validation (30%) dataset following Akindele (1990), Ige et al., (2019) Summary statistics of stand variables from sample plots used for model fitting and model validation are presented in table 2.

Fitting of Height-diameter Models

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

Table 1: Tree Height–diameter models

Non-Linear Height-Diameter Equations Selected	
Model	Equation
Exponential	$1.3 + ae^{bDbh}$ ……………………………………………1
Modified Exponential	$1.3 + ae^{b/Dbh}$……………………………………………2
Logistic	$H = 1.3 + a(1 + b\ (-cDBH))exp$(Zeide,1993)………...3
Gompertz	$H = 1.3 + a\ \exp(\frac{b}{DBH} + c))$(Ratkowsky,1990)………….4
Power	$H = 1.3 + aDBH^{b}$(Arabatzis and Burkhart, 1992)……....5
Ratkwosky	$1.3 + \frac{a}{(1+e^{(b-C*Dbh)})}$………………………………………..6

Where H = Total Height (m), exp =Exponential, DBH = Diameter at Breast Height (cm), a, b, c = Parameter Estimates

Table 2: Descriptive statistics summary of the group data

Variables	Fitting data (N trees = 220)				Validation data (N trees = 79)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
DBH (cm)	30.13	23.21	1.00	134.00	27.34	16.75	10.00	110.00
THT (m)	13.06	8.29	3.00	85.00	12.38	5.11	3.00	25.00
VOL(m^3)	1.57	4.83	0.02	50.46	0.84	1.58	0.02	10.97

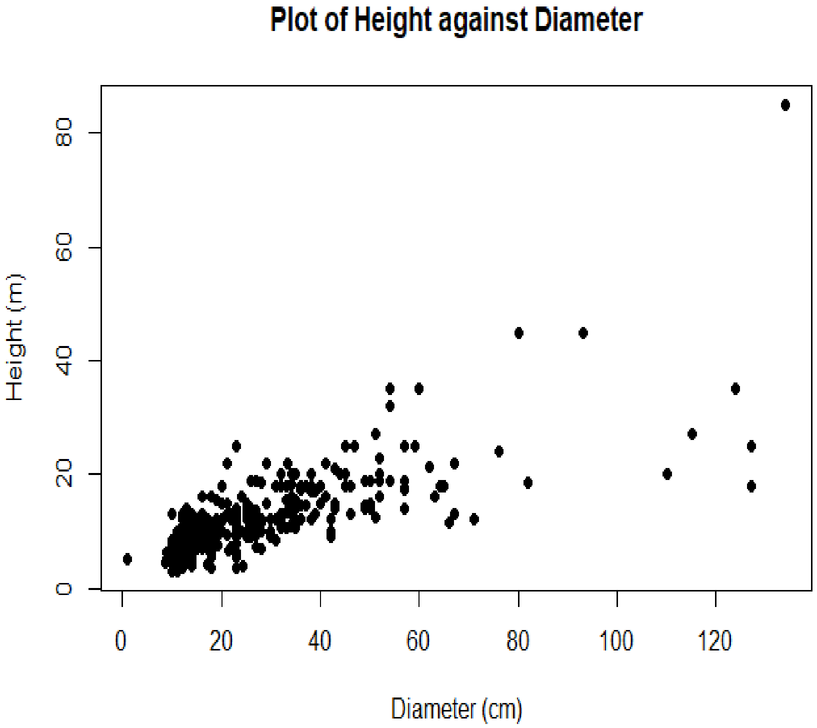

Fig. 2: Relationship between Height and Diameter for IITA Forest, Nigeria

Assessment of Models

Models assessment was carried out to estimate recommendation of models with good fit for further uses: models' examination at all stages of model design, fitting and implementation is important. T-test as described by Adekunle *et al.* (2013), Ige *et al.* (2019) was carried out to assessed the validity and suitability of the selected model 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 (Ho: mean value observed = mean value predicted) if the p–value < 0.05.

The following statistical criteria were used.

Akaike's Information Criterion (AIC)

This was computed using

$$AIC = n \times \ln\left(\frac{RSS}{n}\right) + 2 \times k \quad ......7$$

Bayesian Information Criterion (BIC)

$$BIC = \ln\left(\frac{RSS}{n}\right) + \frac{k}{n}\ln(n) \quad ......8$$

k = number of parameters in the model

n = number of regression coefficient

RSS being the residual sum of squares of the regression

Root Mean Square Error (RMSE)

$$RMSE = \sum \frac{(y_{i-y})^2}{n-p} ....9$$

Yi=observed value of the dependent variable Y=predicted value of the dependent variable n=number of observations p=number of parameters

Significance of Regression (F-ratio)

This was used to test the overall significance of the regression equation. The critical value of F (F-Tabulated) at equals 0.05 was compared with variance ratio F (F-calculated). When F-calculated is greater than the critical value (F-tabulated), such equation was considered significant and therefore adopted for prediction.

Results

A total, 299 trees were encountered representing 46 species from 25 families. *Elaeis guineensis* had the highest no of stem (30) followed by *Trilepisium madagascariense* (27), *Funtumia elastica, Holarrhena floribunda, Trichilia monadelpha had* a total of 18 stems each. Mean Dbh ranged from 10.00cm to 110 cm and mean total height ranged from 3.0 m to 34.40 m Moraceae family had the highest number of species (6) while Sterculiaceae and Apocynaceae had four species each (table 3). Height-diameter relationship model for IITA forest was developed using six non-linear models and the parameter estimates and fit statistics presented in table 4. Total tree height and Diameter at breast height were used as dependent and independent variable respectively. Gompertz, logistics, power exponential, modified exponential and Ratkowsky were the models selected for developing the relationship. RMSE AIC and BIC values ranged from 5.616 to 6.091, 1387.598 to 1423.346 and 1397.779 to 1433.527 respectively. Based on the AIC value and after evaluation and validation, power model produced the best fit for H-D for IITA forest. Power model also has the least RMSE (5.616) and BIC (1397.779). Modified exponential is adjudged to be the least model for developing H-D for IITA forest. Gompertz model is ranked second after power model with RMSE, AIC and BIC of 5.661, 1392.132, and 1405.706 respectively.

The result of T-test carried out to validate the best model at 95% probability level revealed that there was no significant difference (P>0.05) between the mean of predicted height (12.402m) and mean of the observed height (12.378m) with p-value of 0.976. Figure 2 presented the scatter relationship between total height and Dbh at breast height very the actual field data with majority of the trees in the diameter range of 10-60cm. Figure 3 a-f presented the residual plot of the predicted height obtained from Gompertz, logistic, power, exponential, and modified exponential and Ratkowsky respectively. The figure indicated that a homogenous distribution of residuals and suggests that the assumption of regression was not violated by the models and is independent of experimental error. Figure 4 presented a graphically visualization of the fitted models comparison of all the six-nonlinear models which reveals that all the models have similar tendency to relatively estimate total height.

Table 3: Checklist of tree species, families and growth parameters of trees Encountered

Species		**No of Stem**	**Mean DBH/cm**	**mean THT/m**
Aidia genipiflora	Rubiaceae	5	23.60	9.66
Albizia ferruginea	Mimosaceae	4	37.05	16.05
Albizia zygia	Mimosaceae	4	36.00	13.68
Alchornea laxiflora	Euphorbiaceae	1	12.00	5.50
Alstonia boonei	Apocynaceae	5	35.20	16.86
Antiaris africana	Moraceae	3	30.67	16.17
Antiaris toxicaria	Moraceae	6	55.00	13.47
Ceiba pentandra	Bombacaceae	10	65.90	25.49
Celtis philippensis	Cannabaceae	5	14.86	8.18
Celtis toka	Ulmaceae	6	15.67	7.42
Celtis zenkeri	Ulmaceae	10	23.00	13.92
Chrysophyllum albidum	Sapotaceae	7	17.14	9.36
Cleistopholis patens		13	41.62	14.89
Cleistopholis philippensis	Annonaceae	2	26.00	12.00
Cola millenii	Sterculiaceae	5	16.20	9.58
Dialium guineensis	Caesalpiniaceae	1	12.00	11.00
Diospyros monbutensis	Ebenaceae	1	10.30	6.00
Elaeis guineensis	Arecaceae	30	36.00	13.95
Erythrina senegalensis	Fabaceae	3	19.67	12.67
Ficus exasperata	Moraceae	1	10.00	5.00
Ficus mucoso	Moraceae	1	110.00	20.00
Funtumia elastica	Apocynaceae	18	19.56	11.47
Holarrhena floribunda	Apocynaceae	19	30.44	15.28
lecaniodiscus cupanioides	Sapindaceae	16	16.91	8.01
Lonchocarpus sericeus	Papilionaceae	2	26.67	11.27
Maesopsis emini	Rhamnaceae	7	43.14	20.31
Milicia excelsa	Moraceae	2	36.00	19.10
Millettia griffoniana	Papilionaceae	7	37.43	13.29
Myrianthus arboreus	Moraceae	1	28.00	7.00
Newbouldia laevis	Boraginaceae	3	22.75	5.25
Olax subscorpioidea	Olacaceae	1	10.00	6.00
Pouteria alnifolia	Sapotaceae	3	14.67	7.33
Ptercapous soyausii	Fabaceae	4	34.33	15.83
Pycnanthus angolensis	Myristicaceae	0	14.60	9.00
Ricinodendron heudelotii	Euphorbiaceae	1	54.00	19.00
Spathodea campanulata		2	24.50	9.60
Spondias mombin	Bignoniaceae	15	21.25	11.18
Sterculia setigera	Sterculiaceae	8	23.38	14.46
Sterculia tragacantha	Sterculiaceae	9	16.51	9.81
Trichilia megalantha	Meliaceae	2	57.00	16.00
Trichilia monadelpha	Meliaceae	19	17.14	6.75
Trilepisium madagascariense		27	36.36	13.76
Triplochiton scleroxylon	Sterculiaceae	3	65.33	34.40
Voacanga africana	Apocynaceae	1	18.00	3.70
Zanthoxylum leprieurii	Rutaceae	1	32.00	13.00
Zanthoxylum zantoloides	Rutaceae	5	19.67	14.95
		299		

Table 4: Regression Parameter estimates and fit statistics of Height-diameter relationship for IITA Forest

S/N	Model Name	Model Parameter			Selection Criteria		
		a	b	c	RMSE	AIC	BIC
1	Gompertz	43.906	2.289	1.822	5.661	1392.132	1405.706
2	Logistic	37.538	6.260	3.370	5.697	1394.859	1408.433
3	Power	29.275	0.724	-	5.616	1387.598	1397.779
4	Exponential	7.552	1.315	-	5.955	1413.374	1423.555
5	Modified Exponential	30.445	-0.235	-	6.091	1423.346	1433.527
6	Ratkowsky	37.538	1.834	3.370	5.697	1394.859	1408.433

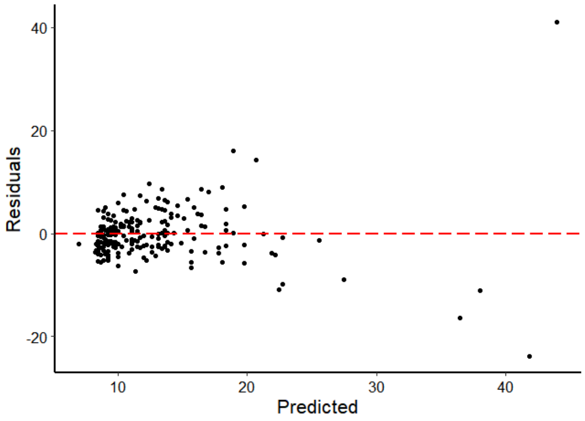

Fig. 3(a)

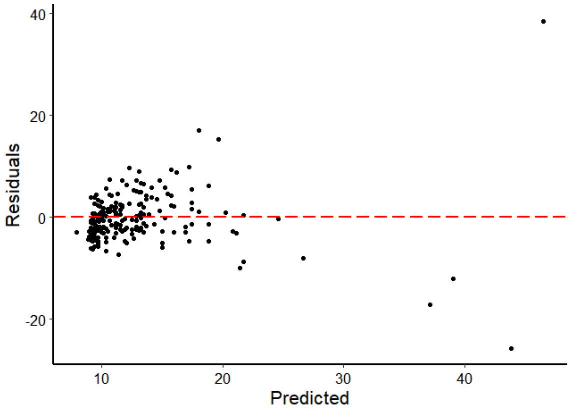

Fig. 3(b)

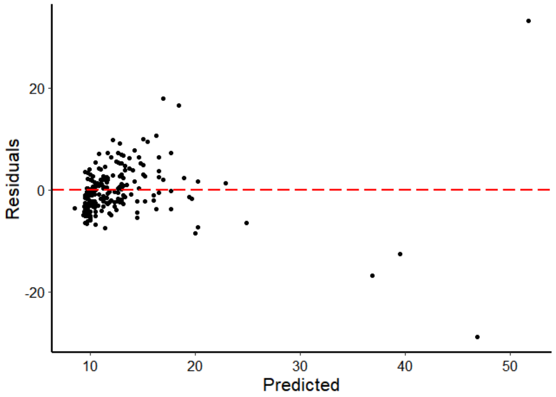

Fig. 3(c)

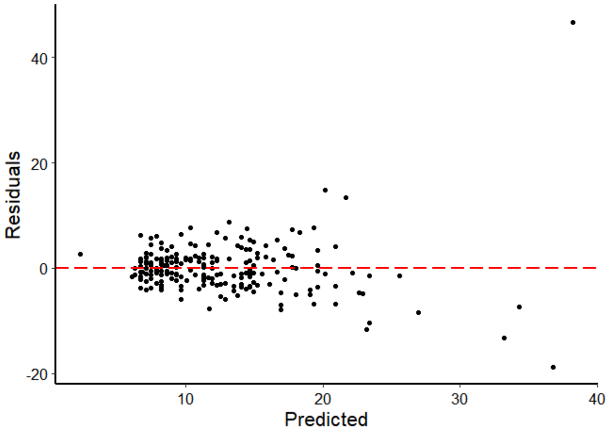

Fig. 3(d)

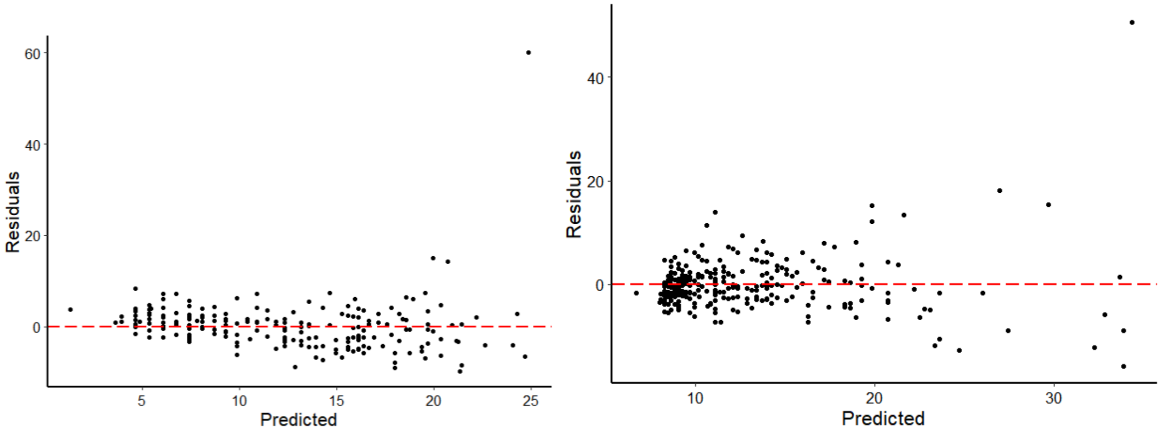

Fig. 3(e) Fig. 3(f)

Figure 3: Residual plot using (a). Gompertz, (b). Logistic (c). Power, (d). Exponential, (e). Modified Exponential and (f). Ratkowsky for Height-Diameter Relationship in IITA Forest

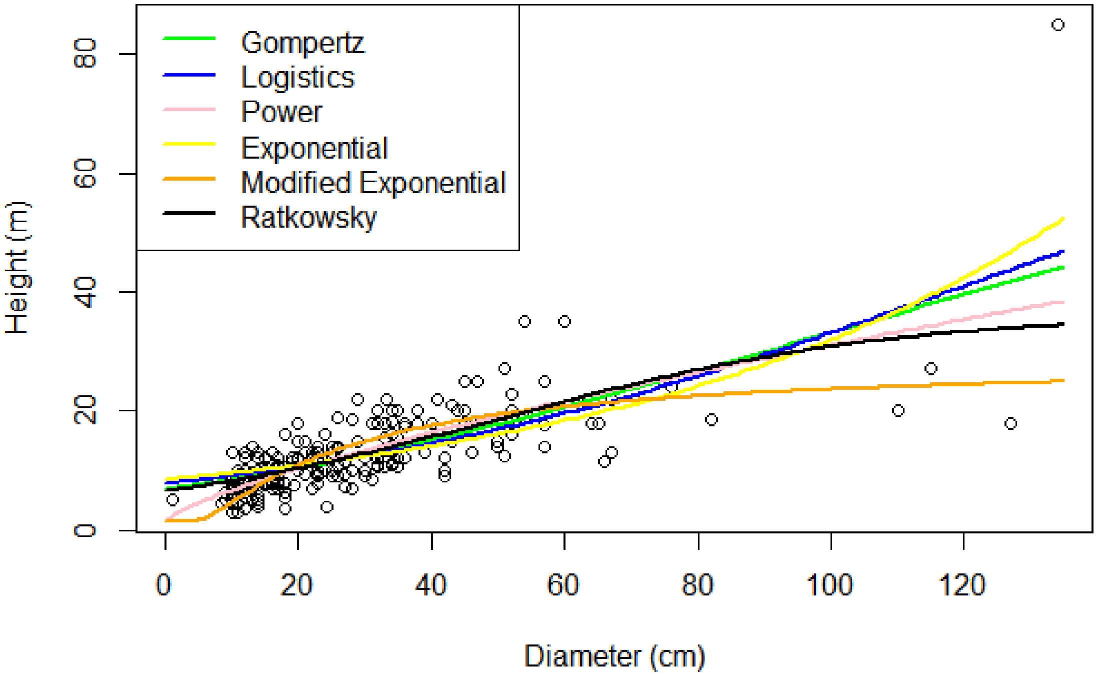

Fig. 4: Graphical visualization of the fitted models comparison of all the six-nonlinear models

Discussion

Tree height and diameter at breast height, height of individual trees and stand are the two most commonly measures used variables in forest inventories for understanding the dynamics of forest ecosystems describing forest structures, estimating stand, volume, biomass, Carbon and incorporating ecological characteristics of species constituting the canopy (Zhang *et al*., 2014; Tsega *et al*., 2018; Mensah *et al*., 2018; Ng'andwe *et al.,* 2019; de Lima *et al.,* 2021)

Tree height diameter relationship for IITA forest was tested and evaluated with six nonlinear height diameter model functions in order to predict the height of trees using AIC, BIC and RMSE as the criteria to select the best models. Based on these criteria, the power function was adjudged to be the most suitable model that best predict tree height for IITA forest because it has the lowest AIC and RMSE of 1387.598 and 5.616 respectively followed by Gompertz. Logistics and Ratkowsky has the same AIC and RMSE of 1394.859 and 5.697 respectively. However, close and low values of AIC and RMSE for all models tested suggest that all the models can adequately predict tree height for IITA forest and an indication that the models estimators are efficient. This is similar to the findings of Ige *et al.* (2013) who reported low RMSE for Modified exponential, Oladoye *et al.,* (2015) Weibull model for *Nauclea diderrichii,* in Nigeria.

The power function has always been found suitable for predicting tree height in some tropical forest. Chenge, (2021) in Omo Strict nature reserve, Mensah *et al.* (2017) and (2018) in South African Misbelt forests and South Africa's indigenous forests respectively. Similar findings have been recorded by Imani *et al.*, (2017). The decision to use a model function to predict tree height using diameter at breast height as variable in natural forests may be a function of differences in tree height and diameter relationship in different forest sites, this is evidence in the findings of Banin *et al.*; (2012), Fayolle *et al.* (2016); Imani *et al.* (2017) and Chenge (2021).

The result of model validation showed that there was no significant difference between mean of observed height (12.378) and mean of predicted height (12.402) with p – value of 0.97. This suggests the capability of the power model and other evaluated models in this study to effectively predict tree height and further validated the positive relationship between diameter at breast height and total tree height and the possibility of predicting tree height using diameter at breast height as predictor within the same location**.** (Moore *et al*., 1996; Sharma, 2009; Avsar, 2004 and Osman *et al*., 2013).

Residual plot for the six models selected showed a randomly distributed residuals with a zero mean and relatively homogenous variances except for exponential and modified exponential, respectively. The height diameter curve of power models indicates no violation of assumptions of non – linear regression similar to the finding of Chenge, (2021). The findings from this study further revealed the potentials of diameter at breast height to predict tree height based on the models statistics and the models' ability for predictive purposes. The results of these height curves in IITA forest revealed that the successful models will continue to perform very well within the range observed field data, prediction outside these range may produce different response by the same successful models.

Tree height diameter relationship can be influenced by a number of factors which can make the models to yield better convincing results and this include but no limited to stand density, climatic variations (Zheng *et al*. (2025), Salami *et al*. (2021); Kearsley *et al*. (2017), Shamaki, *et al.,* 2016) and this may explain the rationale behind the different model been adjudged for different forest reserves.

Conclusion

The relationship between height and diameter for trees in IITA forest 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 power function, amongst all other tested functions, was considered most adequate for modeling height–diameter relationship of trees in IITA forest based on the AIC, BIC and RMSE value. Local height-diameter function which are only dependent on diameter at breast height can normally be applied to the location or locations with similar ecological conditions to where the data were collected. Hence the model developed and validated are adequate to provide more reliable estimate of height in the respective study area of area with similar ecological condition. Tree height diameter model developed in this study efficient and suitable for tree height estimation and could play a significant role in estimating tree biomass in IITA forest.

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