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Development of Height Equations for Teak (*Tectona grandis* L.f.) Plantation in Ketou Commune, Ketou, Republic of Benin

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: To develop Height equation for a seven years old Teak (*Tectona grandis*) plantation in Ketou commune, Republic of Benin.
Study Design: Simple random sampling technique was adopted for this study, in which, 25 plots of 20 x 20 m in size. Information was collected on the species tree height (TH) and Diameter at breast height (Dbh) at 1.3 m above the ground level on a randomly laid 25 plots of 20 x 20 m in size in the entire plantation.
Place and Duration: The study was carried out in a private Teak plantation in Ketou commune, Republic of Benin from October to December. 2021.
Methodology: The collected data was splitted into two parts: 1,552 trees were used for model development while the remaining 754 was used for data validation. Linear, semi-log, double and exponential equations were fitted to the calibrated tree height data, using stepwise regression method procedures in Statistical Package for Social Scientist (SPSS, version 20).
Results: The result revealed that, TH, Dbh and basal area (BA) of ranges between 2.4 – 16.3 m, 5.0 – 16.0 cm and 1.6 x 10^{-3} to 5.9 x 10^{-3} m^2 respectively for both the calibrated and validated data set. Out of the total number of trees enumerated, only two diameter (dbh) class of 5 – 10 and 11 -15

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cm was observed in the plantation. 270 trees (11.7 %) of the trees fell into lower diameter class of 5 to 10 cm, while 2,036 trees (88.3 %) fell into 11 to 15 cm class indicating that the most the tree species are still in pole stage. Correlation analysis between the dependent and independent variables were evaluated. A moderately negative correlation was exhibited with the weighted diameter at breast height. Considerable differences were found among the predictive ability of the selected models. The adjusted coefficient of determination values ranges between 55.5 and 96.7%, while the root mean square error and bias ranges between 0.026 to 1.638 and 1.2 x 10^{-3} to 5.6 x 10^{-3} respectively. Judging by the regression analysis criteria's, Model III gave the highest R^2_{Adj} and lowest RMSE value among the competing models. The findings clearly shows that, Model III was the appropriate function to fits the data and was selected as the best equation for describing total height growth of *Tectona grandis* in Ketou commune, Republic of Benin.

Keywords: Plantation; ketou commune; equations; calibrated; validated; residual.

1. INTRODUCTION

The potential for growing and managing teak (*Tectona grandis*) in different ecological zones and under different objectives is being increasingly recognized, which has lead to intensive domestication and cultivation of the species in countries or regions beyond its natural habitat. Despite the value of teak timber and its increasing demand, its full potential for providing direct revenue as well as value-added down-stream processing and for contributing to the national income has not been fully utilized. Despite all the efforts invested in reforestation, i.e. 5.7 million hectares planted worldwide in year 2000 according to the [1], the currently available *Tectona grandis* (teak) timber resources are far below the needs of the huge worldwide market demand [2].

Teak is being recognized as one of the most valuable timbers in the world on account of its outstanding properties. The sapwood is white to pale yellow-brown, narrow to moderately wide. The heartwood is a dark golden-yellow when fresh, turning to a dark golden-brown, sometimes with darker markings. On prolonged exposure to the weather, the colour becomes lighter. The grain is generally straight, but may occasionally be figured. Texture is moderately coarse and uneven, due to the presence of growth rings. It is moderately hard and moderately heavy, weighing approximately 1.5 cubic metres for seasoned sawn timber. Density is about 670 kilograms per cubic metre at 12% moisture content. The timber has a distinct oily feel and this, with other properties, make the wood highly resistant to acids and fire [3]. In its natural state, teak grows on a variety of geological formations, but the quality of growth depends on the depth, structure, porosity, drainage and moisture holding capacity of the soil. Teak thrives best on soils that are neutral, or slightly alkaline, so the most favourable soils for growth and development usually have a pH of between 6.5 – 7.5.

In Republic of Benin, Teak is often planted by individual or small others on marginal land for the production of timber especially poles with diameter ranging from 5 to 15 cm. In commercial forestry, the important management decisions on different activities such as fertilizing, thinning and harvesting are taken long before the trees achieve the required end dimensions. [4]. Individual tree height and diameter are essential forest inventory measures for estimating timber volume, site index, and other important variables in forest growth and yield, succession, and carbon budget models [5]. It is therefore important to make good predictions of required tree variables from height, so that the change of growth with time can readily be determined. Hence; looking at the importance of growth modeling in forestry, it helps the forest researchers and managers to provide an efficient way to prepare resource forecasts, formulate prescription, and forest policy decision making. Individual tree height and diameter are essential forest inventory measures for estimating timber volume, site index, and other important variables in forest growth and yield, succession, and carbon budget models [6-8].

Height is a variable considered to be difficult to measure when compared to tree diameter [9] since it can be obtained directly or indirectly and, in certain cases, mainly in stands whose individuals are at more advanced ages, due to canopy closing and lack of visibility at the top, the measurement can result in error and high cost as described by [10].

Tree diameters can be easily measured at little cost. Tree height data, however, are relatively more difficult and costly to collect. Often total tree heights are estimated from observed tree diameter at breast height (DBH) outside bark. Estimation of individual tree volume and site index, and description of stand growth dynamics and succession over time, require accurate height and diameter models [6,10]. Many growth and yield models require height-diameter as basic input variables, with all or part of the tree height predicted from measured diameters [11-13]. When actual height measurements are not available, height-diameter functions can also be used to indirectly predict height growth [14]. These equations do not include additional variables that may influence the height-diameter relation in different stands [15]. Height function estimates the specific relationship between individual tree heights and diameters, using stand variables such as basal area per hectare, quadratic mean diameter, dominant height and dominant diameter, mean height and number of trees. Thus, height can be estimated by means of only a function, although in Europe, generalized height-diameter functions have been used since 1930's [15,16].

Several authors have worked on different area of research on teak in the Republic of Benin, but are yet to research on the growth and yield of the specie. This study focused on the development of height equations for *Tectona grandis* in one of the community (Ketou commune) in the Republic of Benin.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out in a private Teak plantation established in Ketou commune. Kétou is a Yoruba town, located in the Plateau Department of the Republic of Benin [17]. The commune covers an area of 2,183 square kilometres and as of 2013 had a population of 156,497 people, making it the 13th largest settlement in Benin. Ketou town is located at the extreme northern part of the department of plateau within latitudes $7^{o}10\ 00'$ and $7^{0}41'17''$ N and longitudes $2^{0}\ 24'\ 24''$ and $2^{0}\ 47'40''$ E [17].

It covers a land mass of about 1,775Km^2 [17] and bounded to the North by Save, to the south by Pobe and to the West and East by Ouinhi and Federal Republic of Nigeria respectively.

In Ketou commune, two climatic zones may be distinguished—a southern and a northern. The southern zone has an equatorial type of climate with four seasons—two wet and two dry. The principal rainy season occurs between mid-March and mid-July; the shorter dry season lasts to mid-September; the shorter rainy season lasts to mid-November; and the principal dry season lasts until the rains begin again in March. The amount of rain increases toward the east. Grand-Popo receives only about 812 mm per year, whereas, Cotonou and Porto-Novo both receive approximately 1,270 mm. Temperatures are fairly constant, varying between about 22° and 34°C and the relative humidity is often uncomfortably high [18].

In the Northern climatic zone, there are only two seasons, one dry and one rainy. The rainy season lasts from May to September, with most of the rainfall occurring in August. Rainfall amounts to about 53 inches a year in the Atakora Mountains and in central Benin; farther north it diminishes to about 38 inches. In the dry season the harmattan, a hot, dry wind, blows from the northeast from December to March. Temperatures average about 27°C, but the temperature range varies considerably from day to night. In March, the hottest month, diurnal temperatures may rise to 43°. The topography is more or less undulating with an altitude ranging from 100 m to 200 m above sea level. The natural forests in this area composed of indigenous tree species such as *Triplochiton scleroxylon, Irvingia garbonensis, Daniella oliveri, Lophira lanceolata and Parkia biglobosa.*

2.2 Materials Used

i. 50 m Measuring tape
ii. Spigel Relaskop
iii. Diameter tape,
iv. Ranging pole
v. Recording sheet

2.3 Data Collection and Measurement of Growth Variables

In the three (3) hectare Teak plantation, 25 plots of 20 m x 20 m sample plot were randomly laid in the entire plantation. Complete enumeration was carried out in each of the sampled plots, adopting [19] methods where all sampled trees were measured for diameter at breast height (DBH) outside bark, and total height (HT). Forked trees or those with damaged tops were excluded from the analysis. The available tree height diameter data were split into two sets: the majority (70%) was used for model development; and 30% of trees in each diameter class were randomly selected and reserved for model validation as described by [20].

2.4 Data Analysis

The data collected from tree measurement were estimated and processed into a suitable form for the estimation of variables used in model development for this study.

2.4.1 Tree height estimation

(i) Stand Mean Height: The stand mean height per plot was estimated by summing up the individual tree plot height and divided by the number of plots.

$$H = \frac{\sum_{i=1}^{n} h_p}{n} \qquad 1$$

where:
H = Stand mean height (m)
h_p = Plot mean height (m)
n = Number of plots in each stand.
i == 1, 2 ...., 4.

2.4.2 Basal area estimation

(i) Individual Plot Basal Area: The individual plot basal area was obtained by multiplying the square of the diameter with a constant pie (π) and divided by 4.

$$\mathrm{b_i} = \frac{\pi \mathrm{d}^2}{4} \qquad 2$$

where:
b_i = individual tree basal area (m)
d = diameter at breast height (cm)
π = constant (3.142)

2.5 Model Verification, Development and Validation

The collected data was divided into two sets: two-third (17 plots) of the dataset was used for model development, while the remaining one-third (8 plots) of the data set were reserved for model validation. Both model development and validation data sets covered the same range of variable examined and were screened to remove any possible outliers that may distort the models. A system of equations (Linear, Logarithm, semi-Logarithm and Exponential) were developed for this study based on the functional form of independent height growth models, being currently used in growth and yield prediction system for even-aged forest [19]. The models were fitted to the tree height data for the species. Parameters of the corresponding equation for the species were estimated, using stepwise regression method procedure in Statistical Package for Social Sciences.

Eight plots were randomly selected out of the twenty five plots laid in the teak plantation and used for validating the developed model. This data set was used to build an acceptable level of confidence that an inference about the simulated process is a valid inference about the actual processes. Normality test was also performed to check the adequacy of fit for the selected models by plotting normal probability plot (NPP).

The first thin in model development was to define those factors which would characterized the best model. For this study, the best model was defined as that which minimizes the residual mean squared error, came closest to meeting the assumption of regression analysis and characterized the relationship between the tree height and the independent variables biological meaningful way.

2.6 Model Comparison and Selection Criteria

Selected model was evaluated quantitatively by examining the magnitude and distribution of residuals to detect any obvious patterns and systematic discrepancies and by testing for bias and precision to determine the accuracy of model predictions [8,22,23]. On the other hands, after parameter estimates were obtained, the predictive abilities of the selected height functions were evaluated using equation 3 and 4, while equation 5 was used to estimate the biasness (E) of the best model. Goodness of fit with high adjusted coefficient of determination (R^2_{Adj}), low Root Mean Square Error (*RMSE*) was selected as the best equation for predicting total tree height of teak in Ketou commune. The model efficiency was judged by ranking in terms of High R^2_{Adj} and low RMSE value.

i. $$R^2{}_{Adj} = 1 - \left\{\left(\frac{SSE}{SST}\right)\left(\frac{n-1}{n-p}\right)\right\} \qquad (3)$$

ii. $$RMSE = \sqrt{\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(H_{ij} - \hat{H}_{ij}\right)^2}{n-p}} \qquad (4)$$

iii. $$E(\%) = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(H_{ij} - \hat{H}_{ij}\right)}{n} X\ 100 \qquad (5)$$

where:
H = Actual value
$\hat{H}$ = Predicted value
n = Number of observation
p = Number of parameters
SSE = Sum of Square Error
SST = Sum of Square Total

3. RESULTS AND DISCUSSION

3.1 Summary Statistics of Tree Height and Diameter at Breast Height of *Tectona grandis* Species in Ketou Commune

A total number (N) of 2,306 trees was enumerated in the seven (7) years old teak plantation. Presented in Table 1 is the summary statistics of the calibrated and validated data set for the tree variables. The tree height (TH), Diameter at breast height (Dbh) and basal area (BA) of the studied species ranges between 2.4 - 16.3 m, 5.0 - 16.0 cm and 1.6 x 10^{-3} to 5.9 x 10^{-3} m^2 respectively for both the calibrated and validated data set. Out of the total number of trees enumerated, only two diameter (Dbh) classes of 5 - 10 and 11 - 15 cm are represented in the entire plantation. 270 trees (11.7 %) of the trees fell into lower diameter class of 5 to10 cm, while 2,036 trees (88.3 %) fell into 11 to 15 cm class indicating that the most the tree species are still in pole stage (Fig. 1).

3.2 Correlation Analysis of the Tree Variables

The result of correlation analysis revealed that a low correlation coefficient between the tree total height, Dbh and Basal area, while a moderately negative correlation was exhibited with the weighted diameter (Dbh-TH ratio). (Table 2). The relationship between the tree height and diameter at breast height is depicted in Fig. 2.

Table 1. Summary statistics of *Tectona grandis* species in Ketou commune

Variable	Calibrated data (No. of Plot: 17; No. of Trees: 1552)				Validated data (No. of Plot: 8; No. of Trees: 754)			
	Min	Max	Mean	Std	Min	Max	Mean	Std
TH (m)	2.4	16.3	8.7	1.97	4.0	15.3	9.25	2.09
DBH (cm)	5.0	15.0	8.52	1.86	5.0	13.2	8.16	1.82
BA (m^2)	0.0016	0.0176	0.0059	0.0026	0.0016	0.0136	0.0055	0.0024

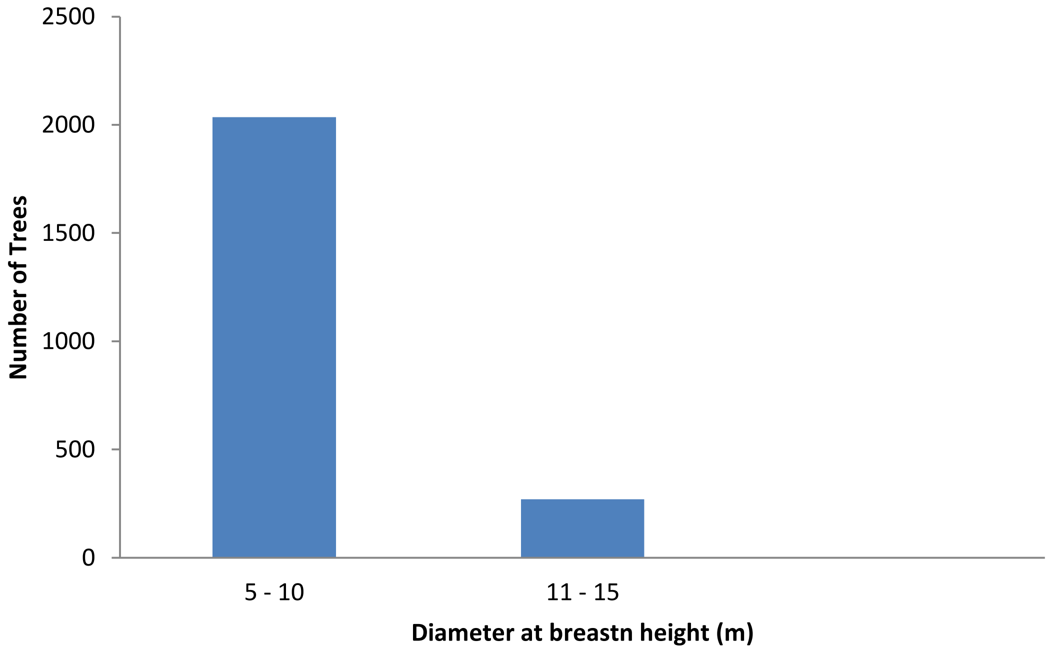

Fig. 1. Diameter distribution of *Tectona grandis* in Ketou commune

Table 2: Correlation of validated tree variables

	TH	Dbh	BA	LOGBA	Dbh/HT
TH	1				
Dbh	0.156**	1			
BA	0.153**	0.992**	1		
LOGBA	0.157**	0.991**	0.965**	1	
Dbh/HT	-0.665**	0.576**	0.569**	0.573**	1
N	754	754	754	754	754

*** Correlation is significant at the 0.01 level (2-tailed)*

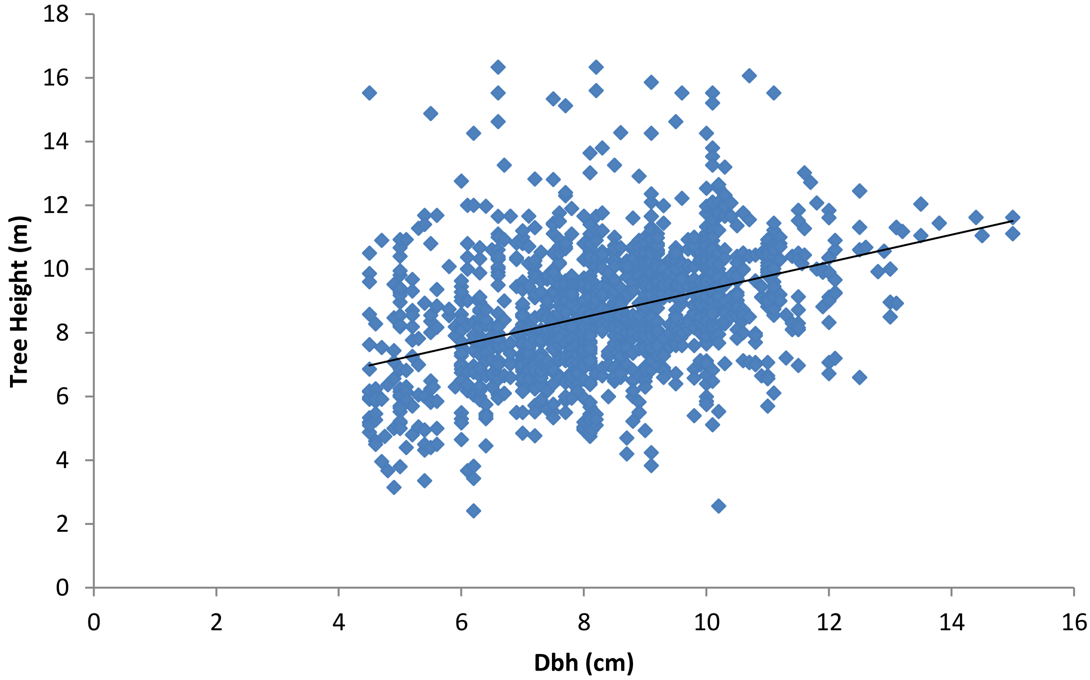

Fig. 2. Tree height and diameter at breast height distribution of *Tectona grandis* in Ketou Commune, Republic of Benin

3.3 Developed Tree Height Equations for *Tectona grandis* in Keotu Commune

Presented in Table 3 were the developed tree height equations for *Tectonal grandis* in Ketou Commune. There are considerable differences among the predictive ability of the selected model, the adjusted coefficient of determination values of all the developed equations ranges between 55.5 and 96.7, while the root mean square error and bias ranges between 0.026 to 1.638 and 1.2 x10^{-3} to 5.6x 10^{-3} respectively. The R^2_{Adj} value obtained in this study was higher than that reported by [22] in their study on height equation of *Tectona grandis* in Alta Floresta which is a little bit lower, indicating good performance of the selected model for this study. Also, the RMSE value obtained in this study is lower than the one reported by [23] in his study on height growth of *Populus tremula* stands which ranges between 1.226 to 1.832.

Model III and VI gave a very similar fitting statistics with similar R^2_{Adj} value of 96.7, and different RMSE value of 0.0263 and 0.0607 respectively. This was followed by model II and V, with similar R^2_{Adj} value of 96.6 and different RMSE value of 0.0267 and 0.0616 respectively, while model VII had the least R^2_{Adj} value of 55.5 with RMSE value of 1.6382. Model III (Log TH) with high R^2_{Adj} and low RMSE value was selected as the best equation for describing the total tree height of *Tectona grandis* in Ketou commune. This result corroborate with [24], which highlighted an approximately homogenous variances over the full range of predicted values, indicating equal variance and reasonable model specification and non systematic pattern in the variation of the residuals. The lower residual obtained in this study is also in line with that reported by [25] in their work on Juvenile height equation of *Phoenix dactylifera* in Nigeria. The graphical analysis (FigS. 4 and 5) of the residuals makes it possible to verify the adjustment of the equation over data amplitude for the detection of possible biases in the estimates. In order to meet this assumption, the residuals were plotted, as a percentage, of the estimates of the variables of interest on the observed and predicted tree variables, which allowed the visualization of the behaviour of these residuals along the axis. The formation of cumulative probability of the observed and predicted tree height data along a straight line pattern of the Normal probability plot also indicated the goodness of fit of the selected model (Fig. 6).

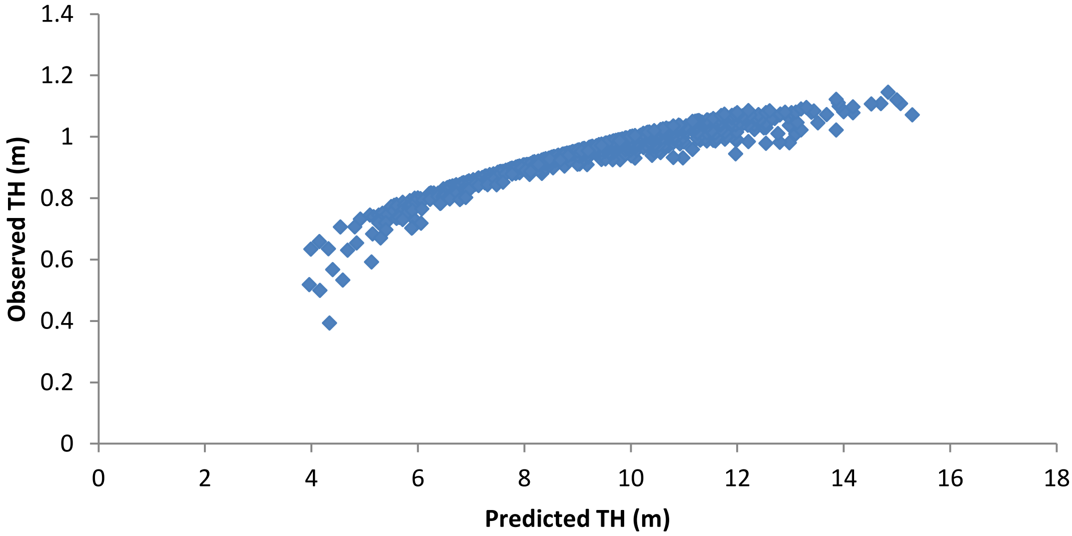

Fig. 3. Graphical relationship between observed and predicted tree height

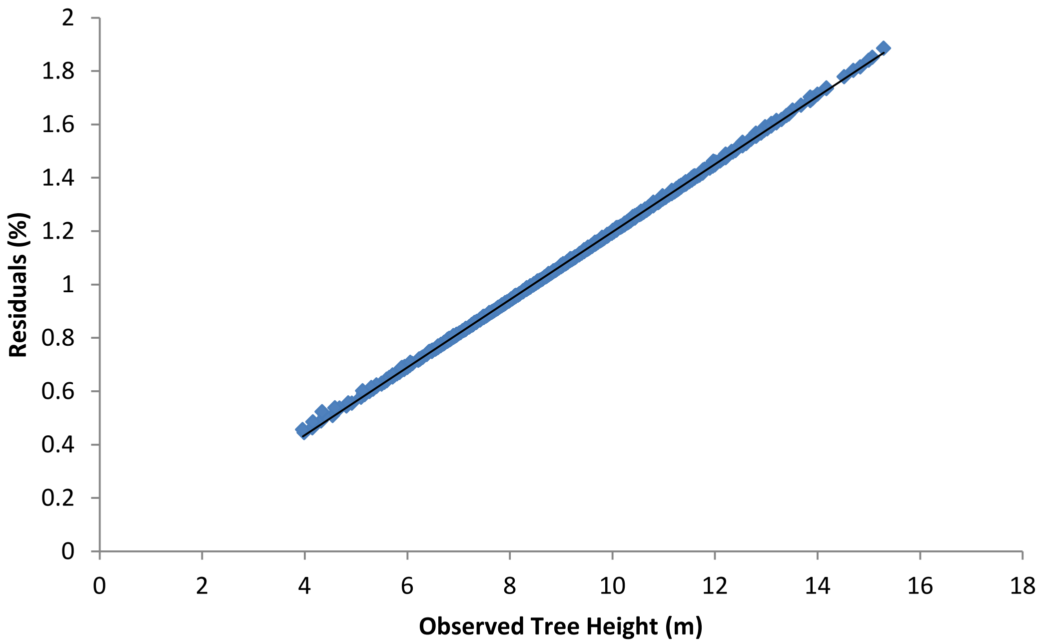

Fig. 4. Relationship between residuals and observed tree height data

Table 3. Developed equations for *Tectona grandis* in Ketou commune

Model	Equations	Parameters							
		β_0	B_1	β_2	β_3	Adj R^2	RMSE	Bias	Efficiency Rank
I	$Log\ TH = \beta_0 + \beta_1 Dbh/Ht$	1.162	0.231	-	-	57.9	0.0842	0.0129	8
II	$Log\ TH = \beta_0 + \beta_1 Dbh/Ht + \beta_2 Log\ BA$	2.340	0.437	0.450		96.6	0.0267	0.0130	3
III	$Log\ TH = \beta_0 + \beta_1 Dbh/Ht + \beta_2 Log\ BA + \beta_3 Dbh$	1.888	0.388	0.309	0.015	96.7	0.0263	0.0130	1
IV	$Ln\ TH = \beta_0 + \beta_1 Dbh/Ht$	2.675	0.532	-	-	57.9	0.1939	0.0056	7
V	$Ln\ TH = \beta_0 + \beta_1\ Dbh/Ht + \beta_2 Dbh$	5.389	0.892	1.030	-	96.6	0.0616	0.0056	4
VI	$Ln\ TH = \beta_0 + \beta_1 Dbh/Ht + \beta_2 LogBA + \beta_3 Dbh$	4.348	0.894	0.710	0.036	96.7	0.0607	0.0056	2
VII	$TH = \beta_0 + \beta_1 Dbh/Ht$	12.980	4.226	-	-	55.5	1.6382	0.0013	9
VIII	$TH = \beta_0 + \beta_1 Dbh/Ht + \beta_2 Dbh$	8.383	7.074	0.877	-	95.4	0.7553	0.0013	6
IX	$HT = \beta_0 + \beta_1 Dbh/Ht + \beta_2 Dbh + \beta_3 Dbh^3$	7.383	7.093	1.062	0.001	92.5	0.7477	0.0012	5

TH = Tree Height; Dbh = Diameter at breast height; BA = Basal area

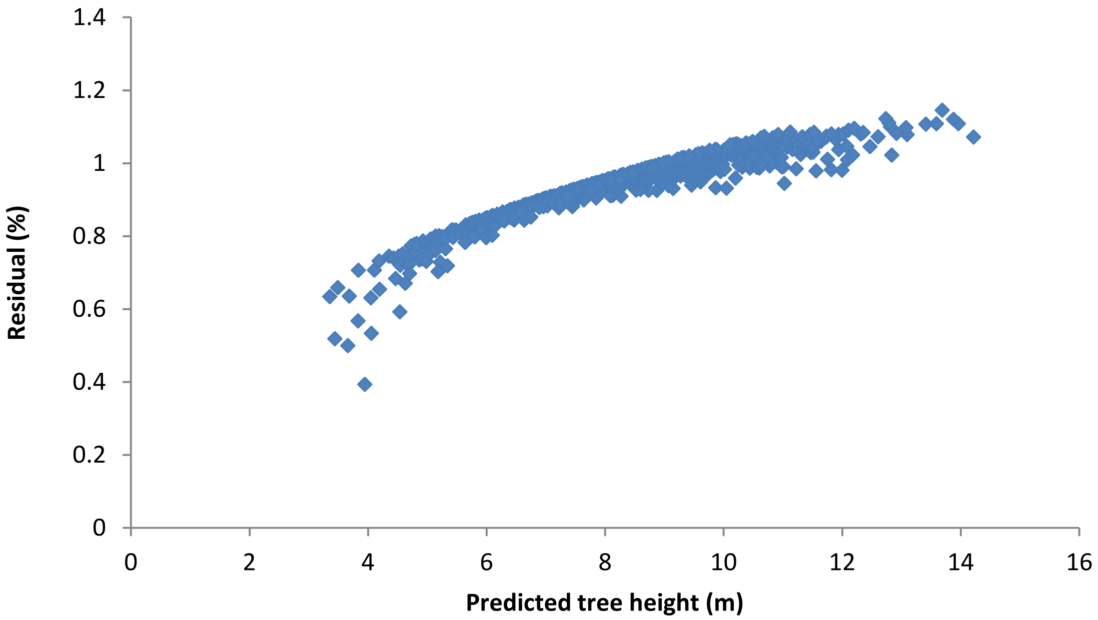

Fig. 5. Graph of residuals versus predicted tree height

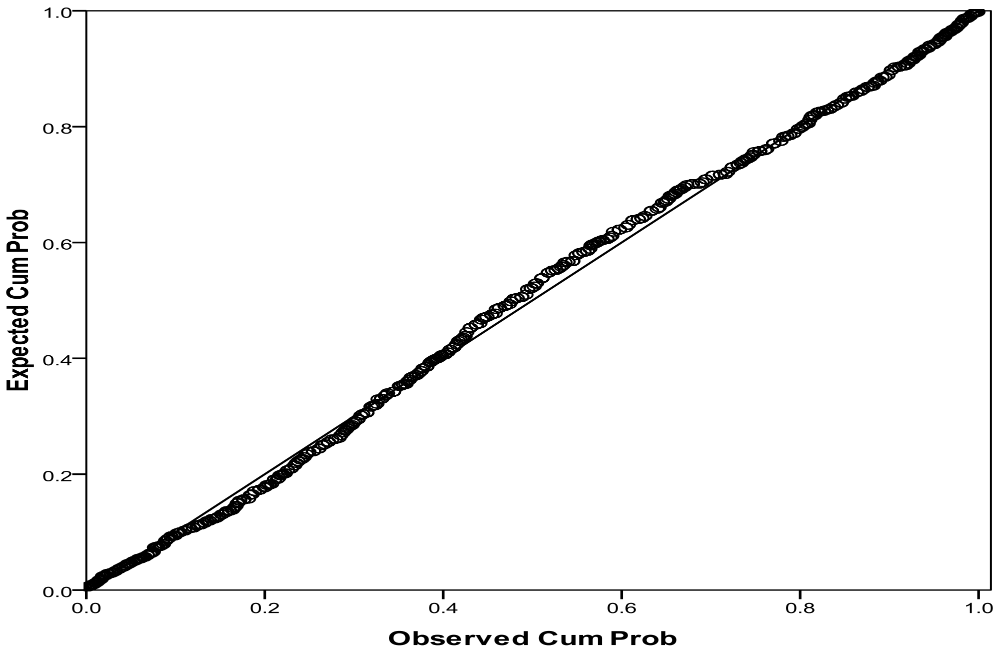

Fig. 6. Normal probability plot for *Tectonal grandis* in Ketou commune

4. CONCLUSION

Equations are very essential for quantifying the potential of tree species stand. Teak being the most commonly planted species in Republic of Benin by both individuals and smallholder farmers cannot be excluded due to its economic and environmental benefits. Out of the various equations developed for this study. Model III was ranked as the best equation for predicting the tree total height equation for *Tectona grandis* in Ketou commune, Republic of Benin, due to its convergences of data set and high predictive ability among the competing models.

The selected equation will accurately predict the total tree height (TH) when fitted to stands with diameter at breast height (dbh) within the range of 5 to 15 cm class. In stands, where diameter of the trees is greater than 15 cm, the recommended model should be reevaluated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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