HEIGHT-DIAMETER RELATIONSHIP MODELS FOR TEAK (*Tectona grandis*) PLANTATION IN NIMBIA FOREST RESERVE, NIGERIA

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ABSTRACT

The study on height-diameter modelling was carried out on Teak (*Tectona grandis*) plantation in Nimbia Forest Reserve. Two fit methods (Chapman-Richards and Weibull) were used to model height-diameter relationship. The teak plantation is divided into four forest beats as management unit, therefore, stratified random sampling was employed to select five plots of 20 x 20 m from each forest beat (as stratum), thereby having a total of 20 plots. Stump diameter (Dst), diameter at breast height (Dbh), diameter at middle and top positions (Dm and Dt) of trees, and tree height for all the selected trees were measured. Average Dbh measured 15.00cm and the mean tree height was 6.77m. Pseudo coefficient of determination (Pseudo R^2) and residual mean square error (RMSE), goodness-of-fit statistics were considered as model selection criteria. Chapman-Richards function produced the best goodness-of-fit statistics for Teak height-diameter modelling. The height-diameter models require additional site factors for better models; hence the need for establishing permanent sample plots (PSP) in order to get additional information from re-measurements of the plots.

INTRODUCTION

Growth and yield models are generally used to predict temporal and future growth of forest stands. In forestry, it is important to be able to make accurate future predictions of the

mean values of growth variables based on repeated measurements through time made on units grouped hierarchically. In many forest management practices, decisions are based on yield projections that crucially depend on projections of plot level averages of tree height, basal area, and other morphometric variables [1].

Knowledge of diameter at breast height (Dbh) and tree height is fundamental to both developing and applying many growth and yield models. One of the greatest challenges in model development is measuring tree variables and data gathering. In forest measurement, Dbh of a tree can be measured quickly, easily, and accurately, but the measurement of total tree height is relatively complex, time consuming and expensive [2]. Furthermore, some site conditions and tree composition especially in tropical forests may prevent accurate height measurements on all trees measured for Dbh as it may not be possible to unambiguously observe a given tree, or reach an appropriate vantage point. Therefore, with many permanent and temporary sample plot systems, Dbh is conventionally measured for all trees sampled, but height is measured for only a sub-sample of trees selected across the range of diameters observed [3]. Height-diameter relationship models are then used to estimate the heights of trees measured only for diameter. A number of height-diameter models have been developed using only Dbh as a predictor variable for estimating total or merchantable tree height (e.g. [4]; [2]; [5]; [6]; [7]). However, the relationship between the diameter and its height varies among stands [8] and depends on the growing environment and stand conditions [9].

Teak, though native of India, Myanmar (Burma), Thailand and Laos, grows nowadays in the whole inter-tropical region (excluding deserts area s of Africa) [10]. In the international market, Teak has been recognized for its high quality timber. Its high durability, good dimensional stability and aesthetic qualities make it a very profitable option for both public and private forestry schemes [11]. As a sustainable supply of timber from natural forests shrinks and the demand continues to increase, the general trend in the future of teak growing

will be towards increasing production and utilizing more plantation grown teak [12]. This suggests a need for enhanced knowledge ranging from diverse aspects of teak plantations establishment as well as silviculture, management, utilization and the ecological aspects of both plantations and natural stands [13].

MATERIALS AND METHOD

Study Area

Nimbia forest reserve is located in the Northern Guinea Savanna zone of Nigeria but in the derived savanna zone at the eastern part of Jema'a Local Government Area of Kaduna state, 70km south east of Jos, along Jos-Kafanchan road. It lies between latitudes $9^0$29' and $9^0$32'N and longitudes $8^0$30' and $8^0$36'E with an elevation of about 594m above sea level [14].

Nimbia forest reserve has an undulating topography. The eastern end of Nimbia forest reserve is the last part of Assop escarpment. It descends in a series of steps with long level stretches interrupted by steep boulder-strewn descents. It descends more gently west wards to Jama'a-Jagindi plains. The forest reserve drains south-west into the Gimi River and west towards the stream that forms the western boundary. There is no permanent stream that flows through the reserve. The northern and southern parts of the reserve are bounded by Lioc stream and Gimi River respectively.

Nimbia forest reserve is within the Jema'a platform and is underlain predominantly by igneous and metamorphic rocks. The greater part of the reserve is underlain by the Newer Basalt of the late Tertiary and Quaternary periods which is composed of olivine, amygdales and zeolites.

There are different soil types within the plantation, but most commonly found are the red deep freely draining loams and dark-brown loamy soils. According to [15] soils of Nimbia area as indicated on the soil map of Nigeria as belonging to the unit 15F and are

classified as Typical Dystrusteps (USDA)/ Dystric Cambisols (FAO). The soils also belong to the Nimbia series which developed from weathered olivine basalt and classified as Eutrophic Brown soil by [16].

The climate is determined by altitude and its location in relation to the seasonal migration of the inter-tropical convergence zone. The position of Nimbia with respect to altitude (594m above sea level) induces orographic rain and has an annual rainfall of between 1500mm – 2000mm spread over a period of seven months (April - October) while the dry months are five months (November - March). Minimum temperatures range between 17^0C and 22^0C (December - March) and the maximum ranges from 28^0C to 35^0C (August - March). Relative humidity is between 30 and 36% in the dry season and 95% in the rainy season.

The natural vegetation of Nimbia ranges from the Southern Guinea Savanna to a dry type of rain forest, which consists mostly of savannah woodland with tall grasses and broadleaved trees usually with short boles (e.g. *Milicia excelsa, Guira senegalensis, Parkia biglobosa, Daniela olivera* and *Vitex doniana*). Over the years the reserve has been over exploited which resulted in the introduction of fast growing exotic species specifically *Tectona grandis* and *Gmelina arborea.* The trees were planted in rows of 3 x 3m, both inter and intra row spacing attaining a height of about 13.6m and diameter of about 41cm averagely at the age of 20years [14].

Sampling and Data Collection

A reconnaissance survey of the Teak plantation was carried out with an attempt to locate the boundaries of the plantations and get acquainted with the general conditions of the forest reserve. With the assistance of the forest officers and forest guards in the reserve, the selected plots and stands were located by the use of prismatic compass, GPS, 50-meter tape, cutlass, and ranging poles. Nimbia forest reserve is divided into four different forest bits and

each bit is divided into compartments as management units. Stratified Random Sampling Technique was employed (in order to group the stands into a more homogenous sets), considering each forest beat as a stratum. Each stratum was further divided into 20 x 20 m sampling units out of which five plots were randomly selected, thereby having a total of 20 plots for the study.

Within each randomly selected sample plot, preference was given to the enumeration of healthy trees with more typical growth forms; dead trees and trees with abnormal form were avoided. This is because in developing growth and yield models for effective management of forest plantations, only such trees that meet grade, soundness and size requirements for commercial logs or poles are considered relevant. While this sampling guideline appeared to introduce a bias in favor of better-formed trees, it is justified because only healthy trees with good form are of commercial value and therefore, require volume computation. The following measurements were carried out on each selected tree:

1. Stump diameter (35 cm above ground level) and diameter at breast height (at 1.3 m above ground) using the girth-diameter tape (in cm);
2. Stem diameter at the middle and upper positions of the tree using the Spiegel relaskop (in cm)
3. Merchantable height of selected trees using the Spiegel relaskop up to 7 cm upper diameter limit (in meters);
4. Total height of dominants and co-dominant trees using the Spiegel relaskop (in meters).

Data Analysis

Data collected were organized and screened (removing the outliers) for analysis. Descriptive statistical analysis was further carried out in order to summarize the data. All

analysis carried out were conducted using SAS statistical package version 9.3, licensed to the University of British Columbia, Vancouver, Canada.

Fitting of Height-diameter Models

For the construction of height-diameter models, the first step was to plot the data from field measurements of height against the Dbh in a scatter form. This gives an outlook of the relationship which appears to be nonlinear hence the choice of nonlinear modelling. Different height-diameter models (Exponential, Chapman-Richards, Gompertz, and Modified logistic) were reviewed before choosing the two functions used for this study and out of them the Chapman-Richards was found to be the most widely used, but the decision to add another model was to enable selection of the better one. Considering the model flexibility; region and species of this study, the Chapman-Richards and Weibull functions were selected for the height-diameter modelling due to their simplicity, accuracy, and precision. PROC NLIN statistical analysis method in SAS package was used to fit the two functions and the model form was presented in Table 1.

Table 1: Models selected for height-diameter

Model	Expression	References
Chapman-Richards	$H = 1.3 + \alpha\,(1 - exp^{-\beta Dbh})^{\gamma}$	[17]; [18]
Weibull	$H = 1.3 + asym.\,(1 - exp[(-b * Dbh)^{c}])$	[19]

H = tree height; Dbh = Diameter at breast height; α, β, γ = fitting parameters of Chapman-Richards function; b, c = shape and scale parameters of Weibull function

RESULTS AND DISCUSSION

Summary Statistics of Measured Parameters

For efficient and accurate growth and yield modelling, field data must be biologically and statistically valid before using them to develop models. In this study the data used were

carefully obtained from the field and subjected to biological validation and the results indicated a normal distribution pattern as tree tapers from bottom to the top, so does the diameter decreases from bottom to the top as indicated in Table 2. This shows that the environmental factors are favorable for the normal growth and development of the species over time. Trees that are bigger in size also produce more volume compared with those with smaller diameters and this further confirms the biological validity of the data. The results of the descriptive statistics (Table 2) were found compatible with the works of [14]; [20]; [21]; and [22].

Table 2: Summary statistics of measured parameters

Statistics	Dst(cm)	Dbh(cm)	Dm(cm)	Dt(cm)	Height(m)	BA(m^2)	Volume(m^3)
Mean	19.1	15.0	11.7	8.2	6.8	0.019	0.0963
Min	11.1	8.6	7.5	5.0	3.4	0.006	0.0178
Max	42.7	31.8	27.5	15.0	12.5	0.080	0.6968
SD	4.41	3.61	2.98	1.93	1.22	0.01	0.07
SE	0.16	0.13	0.11	0.07	0.05	0.00	0.00

Height-diameter Relationship

Different approaches were adopted by numerous researchers in developing height-diameter models. Chapman-Richards and Weibull functions are flexible and easier to work with, as such were considered for this study. Figure 1 shows the scatter relationship between height and Dbh using the actual field data before model fitting. From the scatter plot it shows non-uniformity of the height distribution especially as the trees grow taller, this is as a result of less competition at the upper level of the stands. Consistent increment in height with the increase in diameter was noted up to the 20 cm in diameter. Similar relationships were observed by [23] and [24]. They all believe the changes to be as a result of genetic materials and environmental factors that influence growth and development of the trees.

Both Chapman-Richards and Weibull have three parameters in the fit models and the iterative search of the parameter estimates in SAS software revealed a relatively higher Standard Error (SE) for Weibull estimates compared with the Chapman-Richards (Table 3) and this could be as a result of using asymptote in Weibull function for estimating height from diameter. The two functions used for modelling the relationship between height and diameter are nonlinear in nature, as such the R^2 value from ordinary least squares (OLS) cannot be used in comparison of the better model, therefore, Pseudo R^2 was used together with Residual Mean Square Error (RMSE) as the basis for selecting the better model. From the goodness-of-fit statistics (Table 4) it is evident that, the Pseudo R^2 values are low for both Chapman-Richards and Weibull functions. This is a confirmation that height-diameter relationship may be influenced by other factors and the height-diameter modelling will yield more convincing result if such factors as; stand level density, spacing, age, and some climatic variation are added to the model. However, such information cannot be obtained in a single measurement, there is a need for a permanent sample plots that will be used for re-measurements over time. [23] developed height-diameter models with the inclusion of covariates and reported a better goodness-of-fit statistics compared with the models that exclude covariates. [5] developed mixed-effects models for estimating height from diameter; they first derived the models from each stand data as fixed effect before combining the stand attributes as mixed-effects. The resulting statistics revealed that mixed-effects models performed better in terms of goodness-of-fit than the fixed-effect models. Similar results were obtained by [2].

It is difficult to select a single model for all the species since they possess different attributes and the goodness-of-fit statistics are very close to each other for all the species. Like many studies ([25]; [2]; [5]; and [24]) that suggest the use of Chapman-Richards over other functions for height-diameter modelling, results of this study also revealed Chapman-

Richards as being a better model for modelling Teak species height-diameter relationship considering the lower SE values. To account for the variation between different stand conditions, [24] adopted the methods of incorporating stand variables into height-diameter model as described by [26].

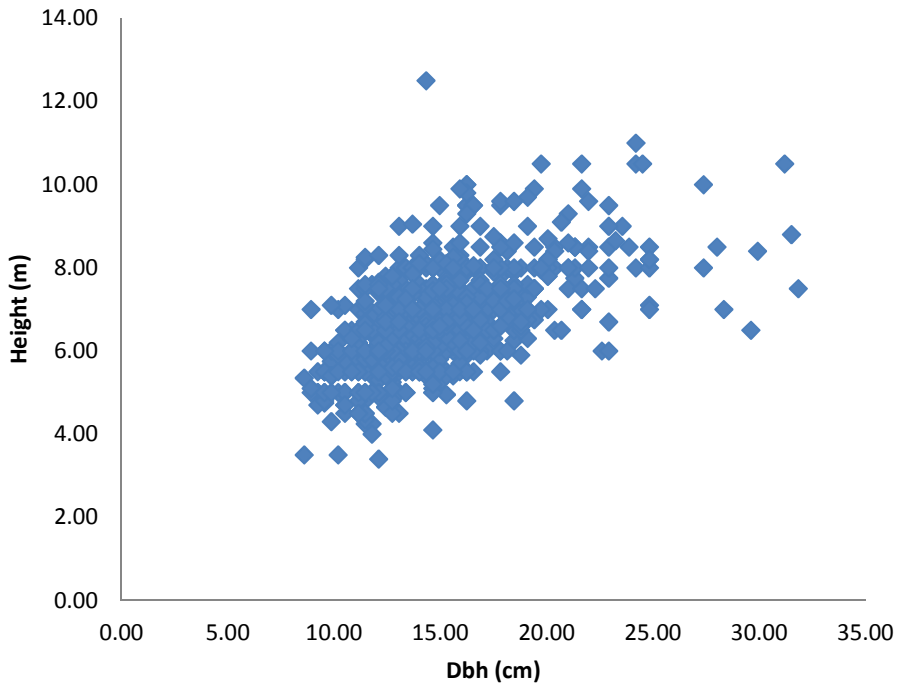

Figure 1: Height-diameter relationship for teak

Table 3: Height-diameter parameter estimates

Model	Parameters	Estimates	SE
Chapman-Richards	β_1	0.4729	0.15
	β_2	1.0624	0.18
	β_3	0.9706	0.01
Weibull	asymptote	9.6740	1.05
	b	11.912	2.37
	c	0.9303	0.17

β_1, β_2 and β_3 are asymptote; rate and shape parameters, *b* and *c* are scale and shape parameters

Table 4: Goodness of fit statistics

Model	Pseudo R^2	RMSE

Chapman-Richards	0.3359	0.9946
Weibull	0.3353	0.9950

*RMSE = Residual Mean Square Error

CONCLUSION

This study revealed that the growth performance of trees in terms of tree taper has followed a normal distribution pattern, with diameter being reduced from bottom to the top of the trees. Goodness-of-fit test for height-diameter relationship shows lower Pseudo R^2 value which indicates weaker relationship between height and diameter without inclusion of other site factors. Height growth tends to decline as the trees grow bigger in size, which is as a result of lesser competition at the upper level of the stand distribution. Chapman-Richards function appears to be a better model for Teak height-diameter modelling. Other stand variables like density, spacing, age and management practices should be incorporated in order to improve the accuracy and reliability of height-diameter models.

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