



NONLINEAR HEIGHT-DIAMETER RELATIONSHIP MODELS FOR *Gmelina arborea* PLANTATION IN NIMBIA FOREST RESERVE, NIGERIA

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ABSTRACT: Height-diameter modelling was carried out on *Gmelina* (*Gmelina arborea*) plantation in Nimbia Forest Reserve in North-western Nigeria with the aim of establishing relationship between tree height and diameter, thereby avoiding the difficulties of height (difficult to measure variable) measurement in an inventory work. Stratified random sampling was used to select 20 plots of 20 x 20 m. Stump diameter (Dst), diameter at breast height (Dbh), middle (Dm) and top (Dt) positions, and merchantable height of selected trees were measured. Both Chapman-Richards and Weibull models were used to predict the goodness-of-fit of the parameters measured. Average Dbh measured was 16.33 cm, and the mean tree height was 6.85m. Pseudo coefficient of determination (Pseudo R^2) and residual mean square error (RMSE) goodness-of-fit statistics were considered as model selection criteria. Weibull function appears a better height-diameter fit method for *Gmelina* stands. 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.

Keywords: *Gmelina* stands; Nimbia forest; Chapman-Richards; Weibull; Modelling

1. 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 (Hall and Bailey 2001).

Knowledge of diameter at breast height (Dbh) and tree height is fundamental to both development and application of many growth and yield models. One of the greatest challenges in model development is measurement of 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 (Sharma and Parton 2007). 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, in 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 (Huang *et al.* 1994). 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 (Fang

and Bailey 1998; Sharma and Parton 2007; Jiang and Li 2010; Ahmadi *et al.* 2013; Oyamakin *et al.* 2013). However, the relationship between tree diameter and its height varies among stands (Calama and Montero 2004) and depends on the growing environment and stand conditions (Sharma and Zhang 2004).

Gmelina like many other tropical hardwood species is reasonably strong for its weight. Its timber is highly esteemed for door and window panels, joinery and furniture especially for drawers, wardrobes, cupboards, kitchen and camp furniture, and musical instruments because of its lightweight, stability and durability. *Gmelina* is easy to cultivate and grow at the smallholder level. It has been widely grown in plantations in south and Southeast Asia. Experience indicates that marketable small-diameter *Gmelina* timbers can be produced in 7 to 10 years (Roshetko *et al.* 2003). In a reasonably good site with freely drained, fertile soils, with no hardpan or other impediment to root development and in moist tropical regions, it takes only three years to attain a merchantable timber size from 5.8 - 8.3 m with a diameter from 10 – 15 cm. It grows to a height of 30 meters, a diameter of 60 – 100 cm and lives up to 40 years (Roshetko *et al.* 2003).

2. MATERIALS AND METHODS

2.1 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°29' and 9°32'N and longitudes 8°30' and 8°36'E with an elevation of about 594m above mean sea level.

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, amygdals 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 Federal Department of Agricultural Land Resources (1990) soils of Nimbia area as indicated on the soil map of Nigeria as belonging to the unit 15F and are classified as Typic Dystrusteps (US Department of Agriculture)/ Dystric Cambisols. The soils also belong to the Nimbia series which developed from weathered olivine basalt and classified as Eutrophic Brown soil by D'Hoore (1964).

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°C – 22°C (December - March) and the maximum ranges from 28°C – 35°C (August - March). Relative humidity is between 30 – 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*, *Vitex doniana et cetra*). 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 20 years (Adegbehin, 2002).

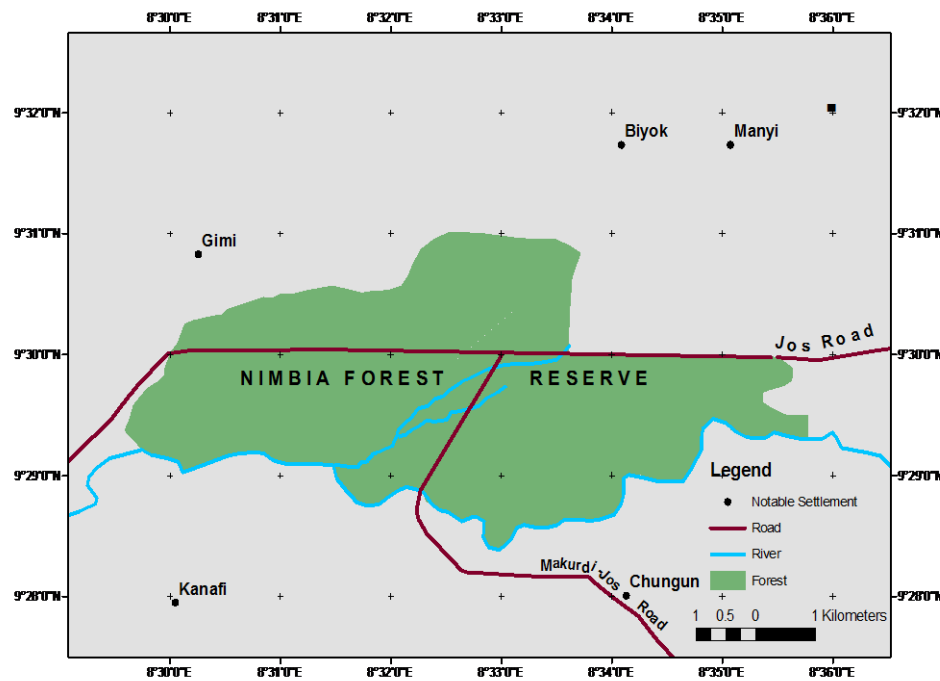


Figure 1: Map of Nimbia Forest Reserve

3. RESULTS AND DISCUSSION

3.1 Summary Statistics

For efficient and accurate growth and yield modelling, field data must be biologically and statistically valid before using it 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 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 Adegbehin (2002); Shamaki *et al.* (2011); Shamaki and Akindele (2013); and Shamaki and Ibrahim (2013).

3.2 Height-diameter Models

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 2 shows the scatter relationships between height and Dbh for the *Gmelina* stands using the actual field data before model fitting. From the scatter plot it shows that as the trees increase in size (Dbh), they tend to be less concentrated at their height level which is an indication of non-uniformity of the height classes as trees grow taller, this could be 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, but variation at the intercept and inclination of the curves were noticed which is believed to be as a result of more competition (as environmental influence) at the lower level of stands with less competition at the upper level. Similar relationships were observed by Guimaraes *et al.* (2009) and Krisnawati *et al.* (2010). They all believe the changes to be as a result of genetic materials and environmental factors that influence growth and development of the trees.

Table 2: Summary statistics of measured parameters

Statistic	Dst(cm)	Dbh(cm)	Dm(cm)	Dt(cm)	Height(m)	BA(m ²)	Volume(m ³)
Mean	20.9	16.3	12.2	8.1	6.9	0.023	0.1130
Min	10.8	8.3	7.5	3.0	2.8	0.005	0.0156
Max	54.7	40.4	30.0	17.5	12.5	0.128	0.3237
SD	5.81	4.68	3.65	2.20	1.50	0.01	0.09
SE	0.25	0.20	0.15	0.09	0.06	0.00	0.00

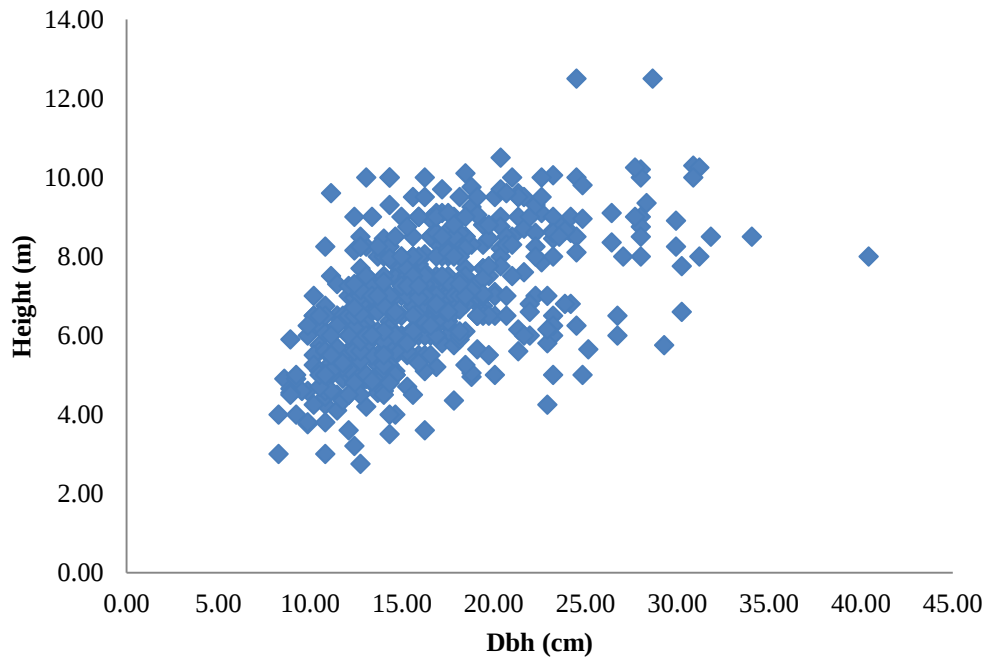
Figure 2: Height-diameter relationship for *Gmelina*

Table 3: Height-diameter models parameter estimates

Model	Parameters	Estimates	SE
Chapman-Richards	β_1	0.4024	0.146
	β_2	1.1664	0.190
	β_3	0.9658	0.100
Weibull	Asymptote	8.9959	0.54
	B	11.3216	0.97
	C	1.1514	0.17

Table 4: Goodness of fit statistics

Model	Pseudo R ²	RMSE
Chapman-Richards	0.3269	1.2579
Weibull	0.3274	1.2574

*RMSE = Residual Mean Square Error

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). The two functions used for modelling the relationship between height and diameter are nonlinear in nature, as such the R² 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 as adopted by Staudhammer and LeMay (2000); Sharma and Zhang (2004); and Jiang and Li (2010). 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. Guimaraes *et al* (2009) developed height-diameter models with the inclusion of covariates and reported a better goodness-of-fit statistics compared with the models that exclude covariates. Jiang and Li (2010) 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 Sharma and Parton (2007).

In this study, it is difficult to select a single model since the goodness-of-fit statistics are very close to each other. Unlike many studies (Liu and Li, 2003; Sharma and Parton, 2007; Jiang and Li, 2010; and Krisnawati *et al.*, 2010) that suggest the use of Chapman-Richards over other functions for height-diameter modelling. However, results of this study revealed that Weibull function has a better goodness-of-fit because of its lower RMSE and higher Pseudo R^2 . To account for the variation between different stand conditions, Krisnawati *et al.* (2010) adopted the methods of incorporating stand variables into base height-diameter model as described by Staudhammer and LeMay (2000).

4. CONCLUSION

1. 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.
2. 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.
3. Height growth tend to decline as the trees grows bigger in size, which is as a result of lesser

competition at the upper level of the stand distribution.

4. Weibull function appears to be a better model for *Gmelina* 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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