Ayankanmi Mary Oluwamayowa

The Federal University of Technology,
Akure,
Ondo State,
Nigeria.

10th October, 2023.

Dear Sir/ Ma,

I wish to submit an original research article titled "Diameter distribution of teak stands in University of Ilorin plantation, Ilorin Nigeria." for consideration by African Journal of Wood Science and Forestry.

I confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere. We have no conflicts of interest to disclose. Please

address all correspondence concerning this manuscript to me at ayankanmioluwamayowamary@ gmail.comand telephone number +2347035671212

Thank you for your consideration of this manuscript.

Sincerely,

Ayankanmi, Mary Oluwamayowa

DIAMETER DISTRIBUTION OF TEAK STANDS IN UNIVERSITY OF ILORIN PLANTATION, ILORIN NIGERIA

Ayankanmi, M. O.[1],Adekunle, V.A.J.[2]

[1]Department of Forestry and Wood Technology, Federal University of Technology Akure.

Email: ayankanmioluwamayowamary@gmail.com, vajadekunle@futa.edu.ng

ABSTRACT

Teak a tropical hardwood tree species, is widely cultivated in Nigeria due to its high durability, stability, and aesthetic qualities. However, local knowledge of the growth and yield characteristics of the species is still lacking at many sites. Monitoring the growth and yield dynamics of planted forests is essential for adequate management responses. This study aims to develop diameter distribution models for teak stands at the University of Ilorin, Nigeria. The study was conducted using systematic line transects and 30 temporary plots of 25 by 25 m in the five-age series was sampled. The data collected was analysed using EASY FIT 5.5®. The tree growth variable was used to compute basal area, volume, diameter distribution models for the forest. The diameter distribution model was fitted using Kolmogorov-Smirnov and Chi–Square goodness of fit. The results revealed that the trees within the plantation had a diameter at breast height (DBH) that ranged from 10.9 cm to 27.50 cm, with an average value of 15.05 cm. The heights exhibited a range of 4 m to 21.50 m, with an average height of 10.87 m. The basal area exhibited a range of values between 0.01 m^2 and 0.06 m^2, whilst the volume encompassed a range from 0.02 m^3 to 0.53 m^3, with an average value of 0.13 m^3.The diameter distribution models indicated that Johnson SB had the best fit while Weibull (3P) had the least desired fit.

In summary, this research study offers significant contributions by providing useful insights into the features of teak plantation trees and presenting effective models for diameter estimation. The aforementioned findings possess the potential to contribute valuable insights to the implementation of forest management practices inside the University of Ilorin plantation.

Keywords: Growth, yield, diameter

Introduction

Teak is a fast-growing tropical hardwood tree species. It belongs to the family Verbenaceae. Teak a high-quality deciduous species, is among the important timber species in the world that are used for commercial purposes (Palanisamy*et al.,* 2009). It is one of the most widely cultivated exotic species in Nigeria because of its good anatomical and physical properties (Miranda *et al.* 2011). Its high durability, good dimensional stability, and aesthetic qualities make it a very valuable timber species to be considered when establishing forestry plantations (Shamaki and Akindele, 2011).

It occurs naturally in Myanmar (formerly Burma), India, the Lao People's Democratic Republic, and Thailand (Hansen *et al.*, 2017). It is also multipurpose tree species and as such, there is continuous demand for its products (Miranda *et al.* 2011). It is used as a source of electric transmission poles for rural electrification projects. Its utilization in building construction, furniture making, and carpentry works among others, makes it a very profitable option for both public and private forestry schemes. The aim of this study is to determine the diameter distribution of teak stands in university of Ilorin teak plantation.

Methodology

Study area

The study was conducted at the University of Ilorin Teak Plantation, which is geographically located at longitude 4^0 38' and 4^0 39'E and latitude $8^0$28' and $8^0$29'N within the campus of the University of Ilorin, Ilorin South Local Government Area of Kwara State, North Central Nigeria (Amusa and Adedapo, 2020). The Teak Plantation was initiated in 2008 and spanned a 5-year planting period (2008–2012). It covers a total land area of 616 ha in five age series (10-14 years).

There sizes are, 57ha(2008), 130ha(2009),150ha|(2010), 157ha(2011) and 122ha(2012) respectively.

Climate

The study area falls within the Southern Guinea Savanna ecological zone of the country. It has a tropical climate with distinct wet and dry seasons. The rainfall pattern exhibits a double maxima, with an annual range of 1000 to 1500 mm. The temperature ranges between 25^0C and 30^0C during the wet season and between 33^0C and 37^0C during the dry season. The relative humidity is between 75% and 80% during the wet season and between 35% and 80% during the dry season (Olanrewaju, 2009). The land surface is gently to strongly undulating, with an average elevation that varies from 273 m to 333 m above sea level. The soil is underlain by Precambrian basement complex rock and composed of loamy soil with medium-to-low fertility (Ajibade and Ojelola, 2004).

Method of Data Collections

The laying of the plot was carried out using the systematic line transects. Two parallel transects 100m apart were laid in each age series after a 10m offset had been measured out. Thereafter, three sample plots of equal size (25 x 25m) will alternatively laid on each transect. A total of 30 temporary sample plots of 25 by 25 m were laid in the five age series. These age series were treated as compartments. A complete enumeration of all trees in each plot was carried out. Thereafter, the diameter at the base, middle, top, and breast height (DBH; 1.3 m above ground)and total height of all trees were measured using measuring tape,Haga altimeter and Spiegel Relascope.

Data Analysis: The data collected was organized and screened for analysis. EASY FIT 5.5® was used to generate the diameter distribution model. The tree growth variable measured was used to compute basal area, volume, develop volume and diameter distribution models for the forest.

Basal area

Basal Area Computation The basal area for each sampled tree was determined using the following formula:

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

Where, BA = Basal area (m^2),

D = Diameter at breast height (cm) (Philip, 1983).

Volume

Individual tree volume was computed using Newton's formula (Husch*et. al.*, 2003).

$$V = \frac{\pi H}{24}(Db^2 + 4(Dm)^2 + Dt^2)$$

Db= Diameter at the base, Dt= Diameter at the top, Dm= Diameter at the middle, H= Height

Tree height

$$H = \frac{(Rt - Rb) \times HD}{100}$$

Where Rt = Reading at the top

Rb = Reading at the base

HD =Horizontal Distance from the base of the tree

Diameter Distribution Model

Fitting of Diameter Distribution Model

For this study, Kolmogorov-Smirnov and Chi–Square goodness of fit was used to rank them accordingly. The distributions used for fitting the diameter at breast height data were Weibull's (3-parameter) distribution, Beta distribution (2-parameter), Johnson S_B distribution, Gamma distribution, and Burr distribution.

Estimating Parameters for Diameter Distribution Models

The parameters for the diameter distribution model were estimated using EASYFIT 5.5® software. The probability density function (pdf) and cumulative distribution function were equally analyzed by the easy fit 5.5® software. The statistical distribution models considered are represented below:

a. Weibull distribution function

The probability density function for the Three-Parameter Weibull was used in this study. Three-parameter (3P) Weibull distribution (Weibull, 1951) is expressed as:

$$f\,(x) = \frac{c}{b}\left\{\left(\frac{x-a}{b}\right)^{c-1} \exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]\right\} \text{ ---------------(1)}$$

with x > α, b > 0, c > 0.

where: x= tree diameter (Dbh), a= location parameter, b= scale parameter, c= shape parameter.

The Weibull cumulative distribution was obtained by the integration of its density function in equation (1).

$$f\text{ (x)} = \int_0^x \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} exp\left[-\left(\frac{x-a}{b}\right)^c\right] dx = 1 - \exp\left[-\left(\frac{x-a}{b}\right)^c\right] \text{-----------(2)}$$

with x > α, b > 0, c > 0.

Where: F(x) is the cumulative distribution function.

b. Johnson S_B distribution function

The probability density function of Johnson S_B will be used in this study. The frequency of diameters was described by Hafley and Schreuder (1977). The Johnson S_B density function is given by the formula:

$$f\text{ (x)} = \left(\frac{\delta}{\sqrt{2\pi}}\right)\left[\frac{\lambda}{(\xi+\lambda-x)(x-\xi)}\right] exp\left\{-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\xi}{\xi+\lambda-x}\right)\right]^2\right\} \text{----------(3)}$$

The cumulative distribution function (CDF) takes the form:

$$f\text{ (x)} = \Phi\left(\gamma + \delta \ln\left(\frac{z}{1-z}\right)\right), z \equiv \frac{x-\xi}{\lambda}, \text{-------------(4)}$$

Where x is dbh (cm), $\gamma(-\infty < \gamma < +\infty)$ and $\delta(\delta > 0)$ are shape parameters denoting asymmetry and kurtosis, respectively, $\lambda(\lambda>0)$ is a scale parameter, ξ $(-\infty < \xi < +\infty)$ is location parameter, and Φ is Laplace integral.

The parameters of the J_B function will be estimated from detailed diameter records using the maximum likelihood method (MLE).

c. The Beta Function

The general expression of the beta distribution for a random variable x is given by (Loetsch*et al.*, 1973):

$$f\text{(x)} = \frac{y^{\alpha-1}.1-y^{\beta-1}}{B.\ (\alpha,\beta)} \text{------------(5)}$$

αandβ are parameters of the beta function

$x = \frac{x-a}{b-a}$-------------(6)

where x is the variable (dbh), and **a** and **b** are the lower and upper bound of the distribution, respectively.

$B(a,b) = \frac{\Gamma(\alpha).\Gamma(\beta)}{\Gamma(\alpha+\beta)}$----------------(7)

where Γ(·) is the gamma function.

d. The Gamma Function

The model of the gamma PDF has the following expression for a continuous random variable x (Podlaski, 2006; Nelson, 1964):

$f(\mathrm{x}) = \frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\propto)} \cdot e^{\left[-\left(\frac{x-\gamma}{\beta}\right)\right]}$---------------(8)

with x >γ, α > 0 and β> 0, where α is the shape parameter, β is an inverse scale parameter, γ is the location parameter (γ= 0 for the two-parameter gamma distribution) and Γ(·) is the gamma function.

e. The Burr Function

The Burr distribution (Zimmer and Burr 1963) has a flexible shape, and controllable scale and location, which makes it appealing for data fitting. For a random variable, x, such as dbh, with the boundary $\gamma \leq$ x < +∞, the PDF of the Burr 4-parameter distribution is;

$f(\mathrm{x}) = \frac{\propto k\left(\frac{x-\gamma}{\beta}\right)^{\propto-1}}{\beta\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$ -------------(9)

where k and α > 0 are the 2 shape parameters, β> 0 is the scale parameter, and γ is the location parameter. If γ = 0, then the distribution can be simplified to a 3-parameter one. The CDF of the Burr 4-parameter distribution of the random variable, x, is:

$f(\mathrm{x}) = 1 - \left(1 + \left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{-k}$---------(10)

RESULTS AND DISCUSSION

Results

Table 1: Summary of the measured variables of *T. grandis* plantation atthe University of Ilorin

Variable	Minimum	Maximum	Mean	Std. Dev	Skewness	Kurtosis
DBH (cm)	10.9	27.50	15.05	2.69	1.28	2.00
Height (m)	4	21.50	10.87	1.95	0.26	1.29
BA (m^2)	0.01	0.06	0.02	0.01	1.91	5.49
Volume (m^3)	0.02	0.53	0.13	0.07	1.22	2.00
N = 992						

The *T. grandis* stands in the plantation ranged in height from 4 m to 21.50 m, with a mean of 10.87 m, and the diameter at breast height from 10.90 cm to 27.50 cm, with a mean value of 15.05 cm. The basal area of the tree stands varied between 0.01 m^2 and 0.06 m^2 and the volume ranged between 0.02 m3 and 0.53 m^3 with a mean of 0.13 m^3.

Diameter Distribution

Table 2: Diameter distribution of *T. grandis* plantation atthe University of Ilorin

Distributions	Parameters				Evaluation statistics	
	Location	Scale	Shape1	Shape 2	Kolmogorov-Smirnov	Chi-squared
Beta	2.6069	5.8436E+6	10.863	9.3789E+6	0.0603	42.052
Burr (4P)	2.2991	2.1076	5.8841	10.874	0.0570	26.085

Gamma (3P)	2.6123	1.6011	10.863		0.0603	42.055
Johnson SB	2.3378	1.2912	26.086	10.75	0.0540	20.271
Weibull (3P)	1.6489	4.6717	10.891		0.0790	60.193

The table provides insights into the Beta, Burr (4P), Gamma (3P), Johnson SB, and Weibull (3P) probability distributions.

The location and scale parameters for the beta distribution are 2.6069 and 5.8436E+6, respectively. The scale parameter affects the spread or variability, whereas the location parameter controls the distribution's shift or displacement. The Kolmogorov-Smirnov statistic for the Beta distribution is only 0.0603, which indicates a fair amount of data fit. The chi-squared statistic of 42.052 indicates a reasonable level of agreement between the observed and expected frequencies based on this distribution.

The Burr (4P) distribution contains four parameters: location (2.2991), scale (2.1076), shape (1.8841), and shape (2.8744). The distribution's skewness and tail behaviour are controlled by the shape parameters. The Burr (4P) distribution's relatively low Kolmogorov-Smirnov value of 0.0570 shows an excellent fit to the data. Given this distribution, the observed and anticipated frequencies are reasonably in agreement, according to the chi-squared statistic 26.085.

The Gamma (3P) distribution contains three parameters: location (2.6123), scale (1.6011), and shape (10.863). The Beta distribution is similar to the relatively excellent match to the observed data suggested by the Kolmogorov-Smirnov value of 0.0603. The chi-squared statistic of 42.055

indicates a reasonable level of agreement between the observed and expected frequencies based on this distribution.

The Johnson SB distribution has four parameters: location (2.3378), scale (1.2912), shape (16.086), and shape (2.75). A wide variety of data distributions can be modelled using the Johnson SB distribution, which is renowned for its adaptability. The comparatively low Kolmogorov-Smirnov of 0.0540 indicates a good fit for the data. The chi-squared statistic of 20.271 shows a relatively high level of agreement between the observed and anticipated frequencies based on this distribution.

The location, scale, and shape 1 parameters of the Weibull (3P) distribution are 1.6489, 4.6717, and 10.891, respectively. Compared to the other distributions, the more significant Kolmogorov statistic of 0.0790 indicates a slightly weaker fit. The observed and expected frequencies based on this distribution show a relatively low level of agreement, as noted in the chi-squared score of 60.193.

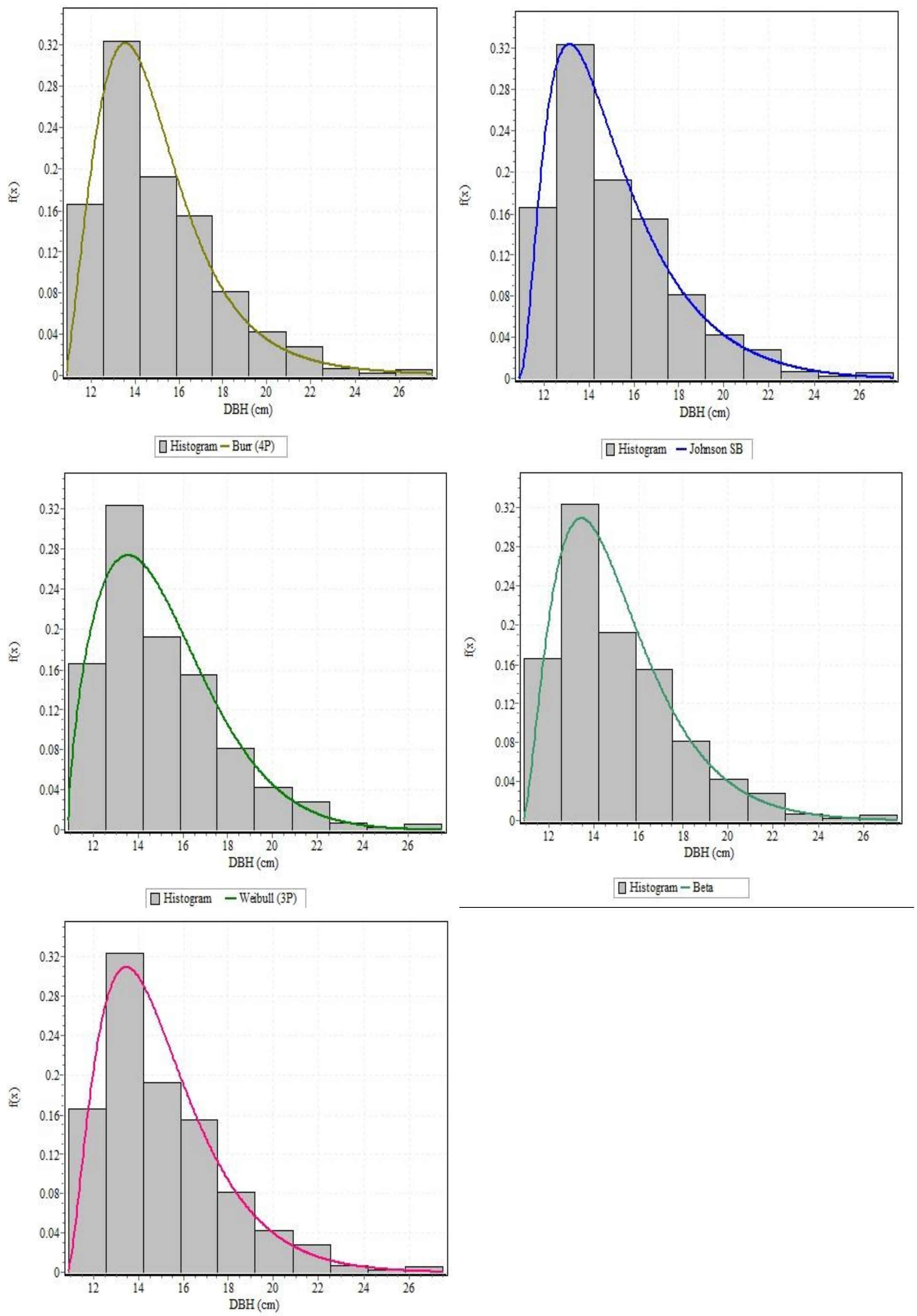

Figure 1: Diameter distribution models of *T. grandis*

Discussion

The diameter at breast height (DBH) is one of forestry's most critical growth variables. DBH affects tree volume, value, conversion costs, and product specs. Therefore, diameter distributions may also describe most stand characteristics (Bailey and Dell, 1973; Alo*et al*., 2017). Forest management and planning include modelling the diameter distribution of a forest stand (Nord-Larsen and Cao 2006; Egonmwan and Ogana 2020).

The skewness and kurtosis statistics indicated more trees in the lower-diameter class than in the upper-diameter class (Adekunle*et al*., 2002). This demonstrates the comparatively young age of the trees and the plantation's capacity for regeneration. According to Nurudeen (2011), high skewness and kurtosis indicate a right-tailed distribution and a sustainable supply of tree stands.

The Johnson SB distribution yielded the lowest value among the five distributions examined regarding their fit to the data using the Kolmogorov-Smirnov and chi-squared tests, with values of 0.0540 and 20.271, respectively. Since the calculated D-value was less than or equal to the tabulated D-value (0.05), the Kolmogorov-Smirnov test indicates that only the Johnson SB distribution adequately fits the diameter data among the five distributions. This suggests that while the null hypotheses for the other distributions were rejected, they were accepted for the Johnson SB distribution. Consequently, the data for Johnson SB follows the specified distribution, unlike the other distributions. This finding aligns with Solomon's (2016) research on the diameter distribution of the *T. grandis* plantation in the Oyinmo Forest Reserve.

Moreover, Egonmwan and Ogana (2020) found that the Johnson SB model provided a good fit for the diameter distribution in the study of the *T. grandis* plantation in the Oluwa Forest Reserve, as indicated by the D-value being lower than the tabulated D-value (0.05). Although several authors have widely used the Weibull probability distribution function to forecast diameter in even-aged stands (Akindele, 2002; Sun *et al*., 2019; Egonmwan and Ogana, 2020), it was the least utilised function in this study. In Aigbe and Omokhua's (2014) study in the Oban Forest Reserve, the Weibull model was the most flexible, followed by the Burr (4P) model based on the Kolmogorov-Smirnov test. However, the Johnson SB model performed the best when considering the chi-squared analysis.

Contribution to Knowledge

The findings of the study will help to provide empirical information on the crown width, slenderness coefficient, diameter distribution and volume models for teak stands atthe University of Ilorin which will help the decision-makers and relevant stakeholders in the management of the forest stands.

The various models to be generated in the study can be used to estimate the growth characteristics of the plantation in the future.

Further analysis of the diameter distribution using different probability distributions can help identify the most suitable distribution for modelling purposes, which can have implications for growth and yield estimation.

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