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A YIELD SYSTEM FOR THE MANAGEMENT OF TEAK STANDS IN NORTH-CENTRAL NIGERIA

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ABSTRACT

This study developed a yield system for the management of teak stands in North-Central Nigeria. A Stratified random sampling proportional to size was used to demarcate 50 Temporary Sample Plots (TSP) of 25 m × 25 m size in the Tectona grandis L.f. plantation. The number of stems per plot was counted and Total height (TH), diameters at: breast height (DBH), base, middle and top were measured. The Weibull distribution was adopted in characterising the stand distribution using the method of moments. Stand-level models were developed and site index (S) constructed at an index age of 20 years. These models together with the Weibull distribution was used to project yield at 15, 20 and 25 years. The Number of trees/ha, quadratic mean diameter, dominant height and stand basal area ranged from 80 to 880 N/ha, 10.7 to 17.2 cm, 5.8 to 16.6 m and 1.0 to 16.71 m^2/ha, respectively. The Weibull distribution was suitable (p-value > 0.05). The developed stand-level models were $lnH_d = 3.5799 - 12.7757A^{-1}$; $G = -9.18844 + 0.655992H_d + 0.015360N + 12.5265S^{-1}$; $mean\ D = D_q - exp(-3.1136 + 0.14295H_d)$. ***Stands were grouped into five site classes, with site Class I being the most productive and Class IV being the lowest. The result of the stand projection showed that the total volume at 15, 20 and 25 years were 210.383 m^3/ha, 277.441 m^3/ha and 329.083 m^3/ha, respectively. This study provided detailed information on the site classes, current and future yield of the teak plantation. The projected yields were reasonable. This will improve management and silvicultural decisions.***

Keywords: Yield models, Site index, Weibull distribution, Teak stands

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INTRODUCTION

Forests are a complex ecosystem constantly changing, they are important to the sustainability of life on earth (Jenkins and Schapp, 2018). Due to the increase in human population, natural forests have been transformed into urban areas and the total green area on earth has been reduced alongside the increase in the harsh effects of climate change. This has brought about the need to establish artificial forests by planting or seeding, also known as plantations. Although plantations do not replace natural forests, they help to mediate the effects of climate change and reduce deforestation pressures (Ghazoul, 2013). The objective of the plantation determines the management of the landowners. In planning forestry operations, estimates of future wood volume that will accumulate from alternative management practices are essential.

In a bid to estimate or forecast future wood volume, there is also a need to understand the structure of a forest stand because conditions such as anthropogenic factors, climatic conditions, mortality, and competition often give rise to tree stands occupying different diameter classes. As a result of the need to understand and predict the number of trees occupying a diameter class, distribution models have been developed and applied to a lot of forests including plantations. Distribution models such as Weibull, gamma, Johnson SB, and normal distribution have been used and applied to model the structure of forests and plantations. It is however important to note that some literature such as (Garcia, 2001; Cao, 2006; Cao, 2014) argued that detailed information from individual-tree models and size-class models typically results in stand-level outputs that are not as accurate or precise because they suffer from an accumulation of errors while whole-stand models often provide well-behaved outputs at the stand level, but these outputs lack information on stand structures.

In place of the above argument, researchers have developed a way of linking individual tree models with whole stand models. In this method, outputs from the individual-tree model are adjusted such that the resulting stand summary matches prediction from a whole-stand model and this method is termed disaggregation system. This method assumes that outputs from whole-stand models are more reliable than those from individual-tree models (Cao, 2014).

Tectonagrandis L.F. (Teak) is one of the world's premier hardwood timbers, rightly famous for its mellow colour, fine grain, and durability and it constitutes about eight percent of the total plantation area in countries with climates suitable for its growth (Pandey and Brown, 2000). It is one of the most valuable hardwood species in the world. The high demand for teak indicates that the supply from the natural forest cannot meet up with demand; therefore, the focus has been shifted to plantation-grown teak to meet up with the demand for teak. The University of Ilorin embarked on an afforestation program in 2008 with the sole aim of producing poles for the wood-based industry. Since the establishment of the plantation, models providing a system where both whole stand variables and individual tree variables can be accurately estimated are lacking. This will often give rise to an inability to accurately forecast the yield that can be obtained from the plantation. Also, the dearth of information on estimated yield will result in an inability of the forest manager to accurately make informed decisions about the amount of material that is available for harvesting at any particular point in time. Where these problems thrive, management decisions are often ineffective and long-term management plans to ensure the sustainability of the plantation cannot be accurately mapped out. The main objective of this study was to develop a yield system for the management of the teak plantation at the University of Ilorin.

MATERIALS AND METHODS

The study was carried out in the Teak plantation of the University of Ilorin, Ilorin-South, Kwara state. The teak plantation is geographically located on latitude 8° 29' 30" and 8° 29' 0" N and longitude 04° 38' 30" and 04° 39' 0" E (Figure 1). The plantation covers a total land area of 616ha and is comprised of five different age series.Kwara State lies within a region described as a tropical climate and experiences a double-maxima of rainfall, with an annual mean ranging from 1000 to 1500mm, and is a tropical wet and dry climate (Olanrewaju, 2009). Temperature is relatively high and ranges from 25°C to 30°C in the wet season and the dry season a temperature range of 33°C to 34°C. Relative humidity at Ilorin in the wet season is between 75 to 80% while in the dry season it is about 65%. (Akpenpuun and Rasheed, 2013).

Experimental design

Stratified random sampling was used in laying out temporary sample plots across the five-age series (13, 12, 11, 10, and 9). The plantation was stratified based on their age series and each stratum was divided into sample plots. Sample plots of 25 m by 25 m ($625\ m^2$) were then randomly selected from each one. A total of 30 plots were established on the plantation. Tree variables such as total height was measured with the aid of a Spiegel Relaskop, diameter at breast height (DBH) was measured with a girth tape.

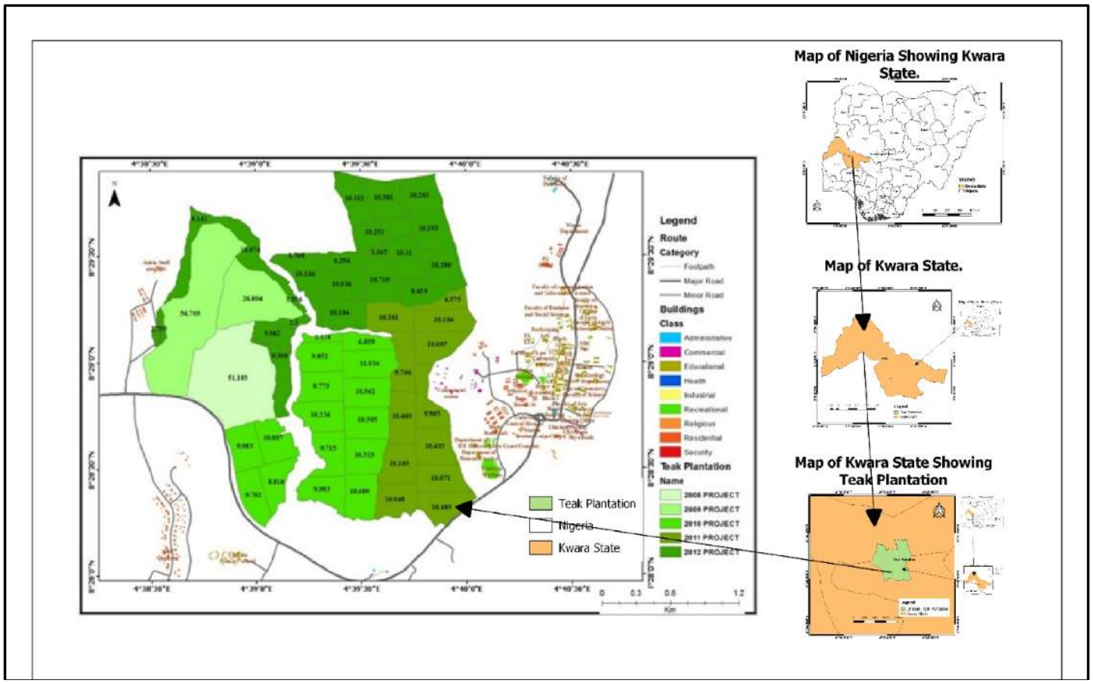

Figure 1: Georeferenced Map of the study area

Table 1:Distribution of Sample Plots across Age Series

Age Series (years)	Area of Age Series (ha)	Number of Sample Plots
3	57	3
12	130	6
11	150	7
10	157	8
9	122	6
Total	**616**	**30**

Diameter Distribution Model

A three-parameter Weibull function (Weibull, 1951) was used to fit the diameter distribution of the teak stand. This function is one of the most frequently used distributions in forestry because of its flexibility, simplicity in expression, and ease of computing the proportion of trees in various diameter classes. The probability density function (PDF) and cumulative distribution function (CDF) are expressed as:The PDF:

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

The CDF:

$$F(x) = 1 - exp\left(\left(\frac{x-a}{b}\right)^{c}\right) \ldots\ldots\ldots [2]$$

Where: f(x) = PDF; F(x) = CDF; c is shape parameter (c > 0); b is scale parameter (b > 0); a is the location parameter taken as the minimum observe diameter; x is tree diameter.

Method of Moment

This is a derivative method where the parameters of the Weibull distribution are derived from the first (arithmetic mean diameter) and second moment (i.e., variance) of the diameter distribution. This method was recently used by Ogana *et al.* (2015); Gorgoso-Varela *et al*. (2020). It is given by:

$$\infty\sigma^2 = \frac{(\bar{d}-a)^2}{\Gamma^2\left(1+\frac{1}{c}\right)}\left[\Gamma\left(1+\frac{2}{c}\right) - \Gamma^2\left(1+\frac{1}{c}\right)\right] \ldots.. [4]$$

Where: $\bar{d}$ is the arithmetic mean diameter of the distribution, σ^2 is the variance and Γ(i) is the Gamma function; *a*, *b* and *c* are the same as in equation (2). Equations (3) and (4) were solved iteratively to get the estimates. The variance was estimated as the difference between the quadratic mean (*Dq*) and arithmetic mean ($\bar{d}$) diameters, expressed as:

$$var(\sigma^2) = D_q^2 - \bar{d}^2 \ldots\ldots [5]$$

The 3-parameter Weibull distribution was fitted to the plot data and the quality of fits produce was evaluated based on Kolmogorov-Smirnov (D_n) and Cramer-von Mises statistics

(ω^2). The smaller the indices are, the better. A 5% significance was used for the test. The null hypothesis (H_0) is that the observed and fitted distributions are not significant. Thus, H_0 is rejected at α< 0.05.

$$D_n = Supx|F(x_i) - F_0(x_i)| \ldots\ldots [6]$$

$$\omega^2 = \sum_{i=1}^{n}\left\{\hat{F}(x_i) - \frac{(i-0.5)}{n}\right\}^2 + \frac{1}{12n} \ldots. [7]$$

Where sup$x$ is the supremum value for x; $F(x_i)$ represents the observed cumulative frequency distribution for the sample x_i (i = 1, 2, …, n); $F_0(x_i)$ the probability of the theoretical cumulative frequency distribution.

Stand level models

Models for predicting site index, density, basal area, quadratic mean diameter, arithmetic mean diameter, and volume was developed in this study. The models were used to recover the parameters of the Weibull distribution for the future stand.

Table 2: Stand Level Models

Model Name	Equation	Equation.
Site Index	$S = H_d exp\left[b_1\left(\frac{1}{A} - \frac{1}{A_i}\right)\right]$	8
Basal Area *(G, m2/ha)*	$G = b_0 + b_1 H_d + b_2 N + b_2 S^{-1}$	9
Quadratic Mean Diameter	$D_q = b_0 + b_1 S + b_2 A$	10
Arithmetic Mean Diameter	$\bar{d} = D_q - exp(b_0 + b_1 H_d)$	11
Schroder and Alvarez	$H = 1.3 + (a + bHd - cdg + dG)exp^{-e}/\sqrt{D}$	12

Where A represents stand age; Ai is the indexed age (20 years); Hd is the dominant height (in m); b0, b1, b2 are the model parameters to be estimated. Other variables are previously defined.

Assessment of the Model

The quality of fit of the models was assessed based on both numerical and graphical plots of residuals. The goodness of fit indices such as root mean square error (RMSE), Akaike information criterion (AIC), Bayesian information criterion (BIC), and adjusted coefficient of determination ($\bar{R}^2$). The smaller the RMSE, AIC, BIC, and high $\bar{R}^2$, the better.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-p}} \ldots\ldots\ldots [12]$$

$$AIC = n\ln\left(\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}\right) + 2p \ldots\ldots\ldots [13]$$

$$BIC = n\ln\left(\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}\right) + p\ln n \ldots\ldots\ldots [14]$$

$$\bar{R}^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_{i_i})^2}\left(\frac{n-1}{n-p}\right) \ldots\ldots\ldots [15]$$

Where n is the number of observations; p is the number of parameters; y_i, $\hat{y}_i$ and $\bar{y}_i$ represent observed, predicted, and the average of the response variable, respectively.

RESULTS

The summary data obtained from the 5-age series is presented in Table 4. A total of 1,336 trees were measured from all the age series. The mean DBH values range between 11.89±0.16cm and 14.55±0.13cm. The mean heights for years 2012, 2011, 2010, 2009 and 2008 were 7.07m±0.26, 11.39m±0.12, 9.62m±0.09, 10.85m ±0.08 and 9.72m±0.1, respectively. It can also be observed that the number of trees per ha (N) ranged between 80 and 880 across all age series. The stand basal area also ranged from 1.40 to 11.56 m^2/ha while the quadratic mean diameters were between 11.94 and 14.79cm.The mean dominant height recorded across the age series ranged from 7.51m to 13.42m (Table 3).

Table 3: Summary statistics of tree and stand variables by age series

Age	Statistics	Variables					
		Dbh (m)	Tht (m)	G (m^2/ha)	N (trees/ha)	Dq (cm)	H_d (m)
9	Mean	11.89	7.07	1.4	129	11.94	7.51
	Stan. Error	0.16	0.26	0.05	5.58	0.1	0.18
	Minimum	10	3.4	1	80	10.7	5.8
	Maximum	15	13	2.14	208	13.7	9.6
10	Mean	14.29	11.39	8.93	512	14.61	13.42
	Stan. Error	0.18	0.12	0.21	7.81	0.08	0.12
	Minimum	10	5.4	1.12	80	12.7	7.7
	Maximum	27.5	18.2	16.71	720	17.2	16.6
11	Mean	13.23	9.62	6.87	465	13.5	11.4
	Standard Error	0.16	0.09	0.16	8.65	0.05	0.06
	Minimum	10	3.6	1.76	160	11.7	9.4
	Maximum	26.5	15.3	11.29	688	14.9	13.4
12	Mean	14.55	10.85	11.56	673	14.79	12.88
	Standard Error	0.13	0.08	0.11	5.72	0.04	0.05
	Minimum	10	6.3	5.99	304	13.5	11.6
	Maximum	22.8	21.5	14.42	800	16.7	14.6
13	Mean	13.94	9.72	9.7	616	14	11.53
	Standard Error	0.2	0.1	0.22	14.28	0.05	0.06
	Minimum	10	6.7	6.09	400	13.5	10.3
	Maximum	22	13.1	13.75	880	15.4	12.6

Fitting the diameter distribution with 3P Weibull function

The Weibull distribution was adopted in fitting the diameter distribution because of its simplicity. The shape, scale and location parameters were estimated using the method of moments for each age series. The estimated parameters of the Weibull distribution are presented in Table 4. The shape and scale parameters of the distribution range from 1.133 – 1.981 and 2.034 – 5.189, respectively while the location parameter was 10 (the minimum diameter inventoried). The Kolmogorov-Smirnov and Cramer-von Mises fit indices were used in assessing the goodness of fit of the Weibull distribution. The Weibull distribution was fitted according to the age series. The result of the study shows that the p-value of the K-S recorded non-significant values for years 9, 10, and 13 (0.434, 0.5293 and 0.2957 respectively) while significant values were recorded for years 11 and 12 (0.00166 and 0.0427 respectively). However, with the Cramer von Mises statistic, the fits of the Weibull distribution were not significantly different from the observed distribution across the age series. This showed that the Weibull distribution described the structure of the stand relatively well.

Table 4: Weibull parameter estimates and the goodness of fit tests

Age	c	b	a	Kolmogorov-Smirnov(KS)		Cramer-von Mises (ω^2)	
				Statistic	p-value	Statistic	p-value
9	1.2360	2.0346	10	0.1080	0.4340	0.1229	0.4848
10	1.2716	4.6344	10	0.0433	0.5293	0.0886	0.6442
11	1.1330	3.3476	10	0.0888	0.0166	0.2058	0.2565
12	1.9814	5.1896	10	0.0660	0.0427	0.4525	0.0526
13	1.3583	4.2576	10	0.0736	0.2957	0.0968	0.6012

c: shape parameter; b: scale parameter; a: location parameter

Modelling stand variables

Site index

The fitted Schumacher model (equation [8]) had RMSE,$\bar{R}^2$, AIC and BIC of 0.212, 0.296, -9.461 and -3.725, respectively. This model was used to derive the anamorphic site index curve for the teak plantation. The index age was set at 20 years and the stands were grouped into site classes, with site Class I being the most productive and Class IV being the lowest (Figure 2). Trees growing in class I are expected to attain a dominant height of 24m at age 20, trees in class II will attain a dominant height of 20m.Tree growing in site class III will have an estimated dominant height of 16m at the same reference age. Whilst trees growing in site class IV will have a dominant height of 12m as the trees increase in age, there is also a simultaneous increase in their dominant height.

Figure 2: Site index for *Tectona grandis* with index age of 20 years

Basal area per ha

The basal area per hectare was fitted using a linear regression model with dominant height, numbers of trees and site index as predictor variables (equation [9]). The RMSE, $\bar{R}^2$, AIC and BIC of the fitted model were 1.026, 0.945, 150.257, 159.817, respectively. The diagnostic plot showed that the points are randomly distributed and do not seem to follow a pattern; the points were within the range of 4 to -4 indicating homoscedasticity (Figure 3).

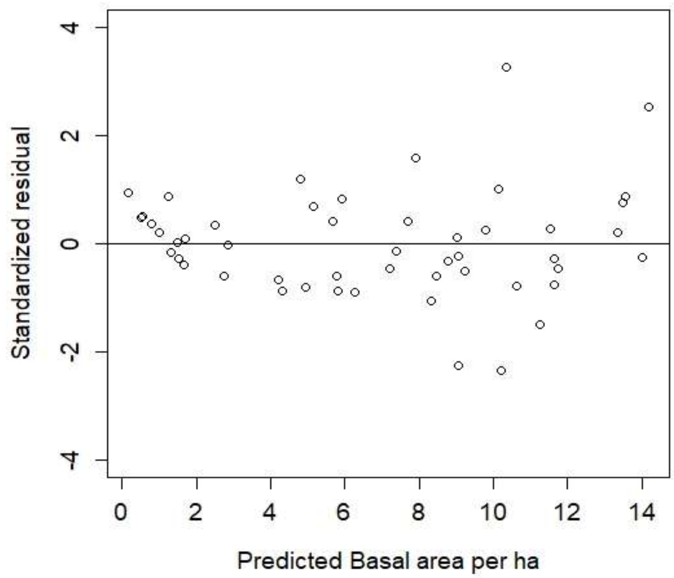

Figure 3: Scatter plot of residuals against fitted basal area per ha

Quadratic mean diameter

The quadratic mean diameter was fitted as a linear regression model with site index and age as predictor variables (equation [10]). The RMSE,$\bar{R}^2$, AIC and BIC were 0.903, 0.583, 136.637 and 144.285, respectively. The residual plot shows a homoscedastic trend of +2 to -2. The assumption of independence was also satisfied as residual points do not appear to follow a pattern (Figure 4).

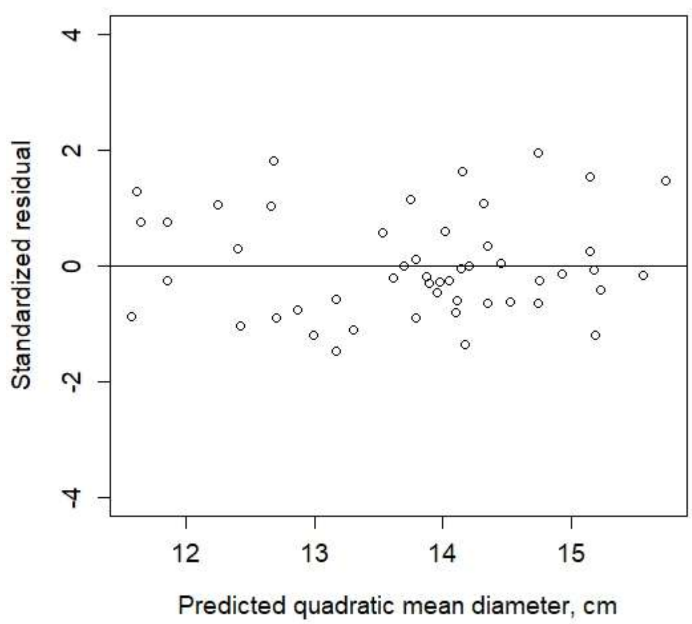

Figure 4:**Scatterplot of residuals against predicted quadratic mean diameter**

Mean Diameter

The mean diameter was fitted as an exponential model with quadratic mean and dominant height as the predictor variables (equation [11]). The RMSE, $\bar{R}^2$, AIC and BIC for the model were 0.125, 0.991, -61.891 and -56.155, respectively. The residual plot also showed that the assumptions of homoscedasticity and independence of residuals were satisfied (Figure 5).

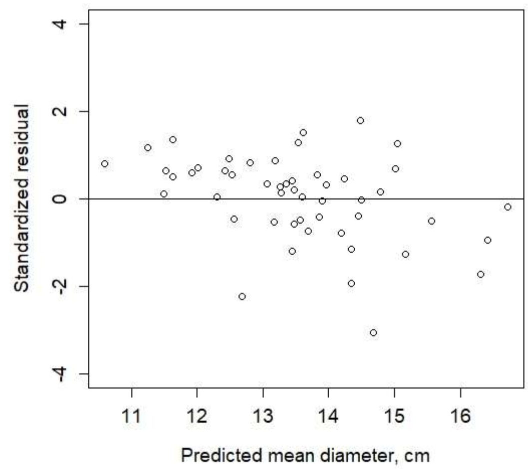

Figure 5:**Scatterplot of predicted mean diameter and residual error**

Simulation of the stand development at 15, 20 and 25 years

Tree height

The projected yield in terms of volume at 15, 20 and 25 years is presented in Table 5 below. A 2 cm diameter class was used to show the yield for each class, the number of trees per ha and predicted volume. Yield simulations were carried by relating the parameters of the Weibull distribution with the projected stand variables derived from equations 8to 12. To get the mean height of each class, the Schroder and Alvarez (II) model was used (equation [12]. Analysis of the residual shows that the residuals satisfied the assumption of homoscedasticity that is constant variance. From the projected stand (Table 5), it was observed that at 15 years, the stand will record a maximum volume44.895 m^3/ha in a diameter class of 14 – 16 cm. At ages 20 and 25, the stand will record a maximum volume of 43.365 m^3/ha and 40.934 m^3/ha, respectively in diameter class 20 – 22 cm. The total volume at 15, 20 and 25 years were 210.383 m^3/ha, 277.441 m^3/ha and 329.083 m^3/ha, respectively.

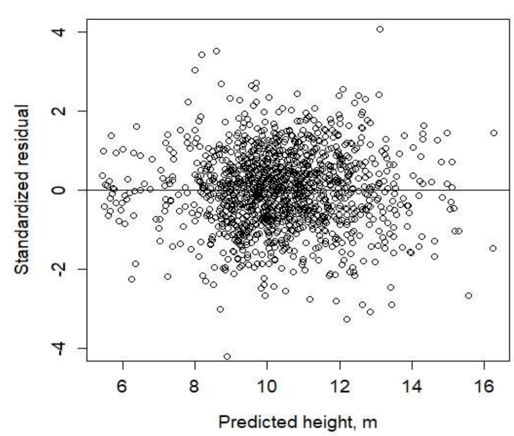

Figure *6*: **Scatter plot of predicted height and standardized residual error**

Table 5: Projected yield at 15, 20 and 25 years based on the maximum observed density (880 trees per ha)

L	U	CM	15 years		20 years		25 years	
cm	cm	cm	N (trees/ha)	V (m^3/ha)	N (trees/ha)	V (m^3/ha)	N (trees/ha)	V (m^3/ha)
10	12	11	79	6.945	43	3.780	33	2.901
12	14	13	173	26.839	99	15.359	75	11.636
14	16	15	196	44.895	130	29.777	99	22.676
16	18	17	169	36.018	137	29.198	110	23.444
18	20	19	120	37.094	127	39.258	110	34.003
20	22	21	73	29.586	107	43.365	101	40.934
22	24	23	39	13.907	82	29.241	88	31.381
24	26	25	18	8.674	59	28.433	72	34.698
26	28	27	7	4.205	40	24.026	57	34.238
28	30	29	3	1.548	25	12.900	43	22.188
30	32	31	1	0.672	15	10.079	31	20.829
32	34	33	0	0	8	6.504	22	17.885
34	36	35	0	0	4	2.740	15	10.274
36	38	37	0	0	2	1.745	9	7.855
38	40	39	0	0	1	1.036	6	6.215
40	42	41	0	0	0	0	4	3.444
42	44	43	0	0	0	0	2	2.165
44	46	45	0	0	0	0	1	1.272
46	48	47	0	0	0	0	1	1.045
48	50	49	0	0	0	0	0	0
Total				**210.383**		**277.441**		**329.083**

DISCUSSION

The Weibull distribution used to fit the diameter distribution for the stand showed that the location, scale and shape parameters were positive. This is in agreement with the results of Saka (2021) which states that the shape and scale parameters should always be positive, and the location parameter can either be positive or zero, but never negative for the diameter distribution. The Weibull distribution's ability to predict diameter distribution in both even-aged and uneven-aged stands is well established in forestry literature. Ige and Adedapo, (2021) opined that the Weibull distribution gives a better fit in modelling diameter distributions for *Nauclea diderrichii* stands in Southwest Nigeria. Ogana et al. (2015) observed that the 3-parameter Weibull distribution gave the best fit in characterising tree diameter distributions in Oluwa Forest in comparison to gamma and beta distributions. However, Mayrinck et al. (2018) in their study to evaluate the horizontal structure of *Khaya ivorensis* plantations in Brazil using beta, gamma, Johnson's SB, and Weibull functions fitted by different methods noted that Johnson's SB outperformed the other functions. To put it succinctly, the ease of fit and high coefficient of determination values of the models in various studies have favoured the use of the Weibull parameter in predicting stand development. Ogana et al. (2015) adopted the method of moment to estimate the parameters of the Weibull distribution as the computation is straightforward and reliable. Ogana et al. (2017) reported that the method of moment, Conditional Maximum Likelihood and Knoebel and Burkhart are appropriate for modelling the distribution of Gmelina using the Johnson SB distribution. It was, however, stated that the superiority of MOM over CML and KB was obvious in most of the plots. Based on recommendations of literature the method of moment was adopted in modelling the distribution of teak in the study area using the Weibull distribution.

Minoche et al. (2017) stated that one of the most important factors which affect tree growth is site quality. The relationship between the dominant height and age is considered by researchers to be the most consistent way of developing site index curves which serves as an indicator for site quality. The anamorphic site index curve constructed in this study showed the expected height development in the teak plantation at a base age of 20 years. The curves are biologically realistic and provide information on the site quality of the plantation. A similar reference age was used by Akindele (1991) to determine the site index for South-western Nigeria where he surmised that teak grows notably well in the dry high forest region of South-western Nigeria. According to Torres et al. (2012) models developed for estimating site index does not only guarantee accurate measurement of site quality but it is also useful in improving teak plantation planning and management. Several site indexes curves have been developed for teak plantation across different locations. Seppänen, and Mäkinen(2020) developed a comprehensive yield model for teak in Panama and stated that the height growth of teak during the first half of its rotation period is rapid. It was also reported that about 80% of height growth of teak is already achieved by mid rotation.

The yield table gives volume estimates and the number of trees per ha for the corresponding diameter classes projected at a maximum density of 880 trees per ha. The yield can be estimated by multiplying the mean class volume by the number of trees per ha to give the total volume for 10 each diameter class; and for each projection period, the sum of the disaggregated yield in terms of volume can be gotten. At 15 years, the maximum volume is projected to be 44.895 m3 /ha and is within the 15 cm average diameter class. Whereas the 20- and 25-year volume estimations give 43.365 m3 /ha and 40.934 m3 /ha, respectively at the same average diameter class 21. This can be used in the effective management of the plantation and the managers can have valid estimations of what to expect from the plantation over the years and make the best decisions for the plantation's growth. Different product specifications could be determined from the yield table. For example, if a diameter class of $\geq$ 30 cm is specified for timber

(Egonmwan and Ogana, 2020), a significant amount of volume will be available at 20 years and above only. At 20 and 25 years, the timber volume would be 22.104 m3 /ha and 70.984 m3 /ha, respectively. Besides timber, other products such as pole, rafter and fuelwood can be realised from the stand. Furthermore, Egonmwan and Ogana, (2020) developed a yield system for the management of teak in Oluwa forest reserve however; age was a limitation to the study. It is however important to note that effective diameter distribution yield system requires plot data containing age, site index (or average dominant height), density, height, and diameter for specific sample trees for effective creation of a diameter distribution yield system (Burkhart and Tomé 2012).

CONCLUSION

This study has modelled the growth and yield of plantation grown teak at the University of Ilorin. A three-parameter Weibull function was used to fit the diameter distribution of the teak stand using the method of moments to derive the parameters.The study's results indicate models that can be used to predict current and prospective values for each stand variable in the plantation. These models were utilised in yield estimation. A yield table containing information on the diameter classes, number of trees per ha and the estimated volume at ages 15, 20 and 25 were constructed. This will aid in defining the stand structure, product specification and effective management of the plantation.

RECOMMENDATION

The following recommendations are made from the results of this research;

1. As the yield table gives the maximum volumes and diameter classes in which they exist, adequate planning should be done to monitor effectively the stand structure and harvest based on specification e.g., for poles, or timber at different ages.
2. A wholesome database of the plantation should be created for future references
3. Beating up should be supervised and done regularly to ensure straight boles and to cover up under stocked areas

REFERENCES

Akindele, S. O. (1991). Development of a site index equation for Teak plantations in South western Nigeria. *Journal of Tropical Forest Science*, 162-169.

Akpenpuun, Timothy & Busari, Rasheed. (2013). Impact of Climate on Tuber Crops Yield in Kwara State, Nigeria.*American International Journal of Contemporary Research* 3(10),6

Burkhart H. E. and Tomé Margarida. (2012). *Modelling forest trees and stands (Textbook). Springer Science & Business Media*

Cao Q.V. (2006) Predictions of individual-tree and whole-stand attributes for loblolly pine plantations. *Forest Ecology and Management*, e 236:342–347

Cao, Q. V. (2014). Linking individual-tree and whole-stand models for forest growth and yield prediction. *Forest Ecosystems*, *1*(1), 1-8.

Egonmwan, Y., and Ogana, F.N. (2020). Application of diameter distribution model for volume estimation in Tectona grandis L.f. Stands in the Oluwa forest reserve, Nigeria. *Tropical Plant Research*, *7*, 573–580. https://doi.org/10.22271/tpr.2020.v7.i3.070

Garcia O (2001). On bridging the gap between tree-level and stand-level models. In: Rennolls K (ed) Proceedings of IUFRO 4.11 Conference "Forest Biometry, Modelling and Information Science". The University of Greenwich. 25–29 June

Ghazoul, J., (2013). Deforestation and Land Clearing, in Levin, S.A. (Ed.), Encyclopaedia of Biodiversity (Second Edition). Academic Press, Waltham, pp. 447–456.

Gorgoso-Varela J.J., Ogana, F.N.and Ige, P.O. (2020). A comparison between derivative and numerical optimization methods used for diameter distribution estimation. *Scandinavian Journal of Forest Research* 35 (3-4): 156-164.

Ige, P. O., and Adedapo, S. M. (2021). Modelling diameter distributions of Nauclea diderrichii (De Wild.) Merr. stands with Gamma and Weibull functions in Southwest Nigeria. *World Scientific News*, 160, 247-262.

Jenkins, M., and Schaap, B. (2018). Background analytical study—forest ecosystem services. In *Background study prepared for the thirteenth session of the United Nations Forum on Forests* (Vol. 5).

Mayrinck, R. C., Filho, A. C. F., Ribeiro, A., Oliveira, X. M. D., and Lima, R. R. D. (2018). A comparison of diameter distribution models for Khaya ivorensis A. Chev. plantations in Brazil. Southern Forests: *A Journal of Forest Science*, 80(4), 373- 380.

Minoche, D., Herrero, C., Domínguez, M. D., and Martínez-Zurimendi, P. (2017). Determining the site index of Teak (Tectona grandis L.) plantations in Tabasco, Mexico. Ciencia e investigación agraria: revista latinoamericana de ciencias de la agricultura, 44(2), 154-167

Ogana, F.N., Osho, J. S. A., and Gorgoso-Varela, J. (2015). Comparison of Beta, Gamma and Weibull distributions for characterizing tree diameter in Oluwa Forest Reserve, Ondo State, Nigeria. *Journal of Natural Sciences Research*, 5(4): 28-36.

Ogana, F.N., Itam, E.S. and Osho, J.S.A. (2017). Modelling diameter distributions of *Gmelina arborea* plantation in Omo Forest Reserve, Nigeria with Johnson's S_B. *Journal of Sustainable Forestry*, 36(2): 123-133.

Olanrewaju, R. M. (2009). The Climate Effect of Urbanization in A City of Developing Country: The Case Study of Ilorin, Kwara State, Nigeria. *Ethiopian Journal of environmental Studies and management*, *2*(2) DOI: 10.4314/ejesm. v2i2.45921.

Pandey, D., and Brown, C. (2000). Teak: A global overview. *UNASYLVA-FAO-*, *51*, 3–13.

Saka, M. (2021). Characterization of Diameter Distribution and Prediction of Weibull Parameters Equation for Plantation-grown Eucalyptus Species. *Asian Journal of Research in Agriculture and Forestry*. 7. 1-13. 10.9734/AJRAF/2021/v7i330128.

Seppänen, Petteri and Mäkinen, Antti. (2020). Comprehensive yield model for plantation teak in Panama. Silva Fennica. 54. 10.14214/sf.10309.

Torres, D. A., del Valle, J. I., and Restrepo, G. (2012). Site index for teak in Colombia. *Journal of Forestry Research*, 23(3), 405-411.

Weibull, W. (1951) A Statistical Distribution Function of Wide Applicability. *Journal of Applied Mechanics*, 18, 293-297.