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A Regression Modelling Approach for Stem Volume Estimation of Two Exotic Plantations within Dogo-Kétou Forest Reserve, Benin Republic

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Abstract: Stem volume models play an important role in forest management, evaluating the economic value of a forest stand and assisting forest managers and other interested parties in determining the optimal strategies for the utilization and conservation of forest resources. Little attention is given to the use of multivariate regression models for plantation species in the study area. This study involved the development of a multivariate regression equation with continuous and categorical independent variables for simultaneous prediction of merchantable volume for *Gmelina arborea* and *Tectona grandis* in Dogo-Ketou Forest Reserve. Simple random sampling technique was adopted for plot location from the selected two plantations. Thirty-one temporary plots of dimension 25m by 25m were selected for complete enumeration in all the two plantations of the same age. Tree growth variables measured included diameter at breast height (Dbh) and merchantable height. All data obtained were analyzed using descriptive statistics and multivariate regression analysis. The predictors for the equation were Dbh, merchantable height and tree species type. The results of the analysis revealed that *Gmelina arborea* exhibited higher average Dbh and height, wider Dbh and height range, more pronounced positive skewness in Dbh distribution, and more negative skewness in height distribution compared to *Tectona grandis*. Kurtosis values indicated relatively flatter Dbh and height distributions for both species, with *Gmelina arborea* showing a more peaked height distribution. Gmelina arborea also showed higher mean volume than *Tectona grandis*. The multivariate regression model developed is: Volume (m^3) = -0.467 + 0.024*(Height) + 2.683*(Dbh) + 0.016 (Tree species) with R^2 of 91.3%. The diameter at breast height (Dbh), height, and tree species were found to be statistically significant predictors for stem volume estimation. The developed model for both plantation species will provide useful basis for yield prediction in the study area.

Keywords: Exotic Plantations, Volume Estimation Model, Dogo-Kétou Forest Reserve, Benin Republic

1. Introduction

Estimating tree volume continues to be one of the primary objectives for sustainable management of forest resources and a number of statistical models are usually used in forestry to attain this goal. As explained by J. A. Kershaw et al. and H. E. Burkhart et al., models for estimating tree volume are important tools in forest management [1, 2]. Volume models provide a mathematical and statistical approach for estimating the amount of wood in a tree without cutting it down in order to manage wood resources, make economic choices, and encourage sustainable forest management. According to D. U. U. Okali, constant demands for wood and non-timber products for domestic consumption and export are only a few of the causes putting a pressure on West Africa's natural forest ecosystems [3]. The author further pointed out that plantation forests have often been found as a quick fix to the subregion's recurring problem of over-exploitation of natural forest resources. Forest planted with exotic species such as *Tectona grandis* and *Gmelina arborea* were more successful than indigenous species within Wari-Maro Forest Reserve of Benin [4]. Studies on exotic plantation species in West Africa have shown that yield and growth models could be useful for forest managers and owners in taking sound decisions as well as planning for harvesting [5]. In Nigeria, a study revealed that non-linear model for volume is very suitable for yield estimation of *Gmelina arborea* in Oluwa Forest Reserve [6]. In the same vein, results of research work carried out in a Strict Nature Reserve in Nigeria further showed the importance of non-linear equations such as Weibull, Gompertz Relation and Logistic Power models for efficient tree volume In applying models for volume prediction, data obtained previous inventories exercise at one instant in time serve as a reliable information on current and future stem volumes and by using appropriate statistical models [8]. Allometric relationship between tree diameter and total tree height is commonly used to estimate tree volume and thus is a fundamental component of many growths and yield for forest planning [9].

From all the aforementioned studies, their findings have generally shown that the use of tree volume models are very essential tools for sustainable forest resources management. However, reliable statistical models for stem volume prediction have not been developed for exotic plantations of *Tectona grandis* and *Gmelina arbore* in Dogo-Kétou Forest Reserve of Benin Republic. The selection of *Tectona grandis* and *Gmelina arborea* for this research is supported by their particular relevance in wood and pole production, as well as the critical roles they play in forest soil protection and ecosystem services.

In this study therefore, the general objective was to develop a Multivariate Regression Equation for predicting stem volume using Dbh, Height and Species type for *Tectona grandis* and *Gmelina arborea* in the study area to enable forest managers and forest owners make sound decisions and estimate wood yield from their forest estates at a given time.

2. Materials and Methods

2.1. Study Area

The study area, Dogo-Kétou Forest Reserve, is located in Idigny district situated within the commune of Kétou in the south of Bénin Republic (West Africa). The Forest Reserve has an area of 42,850 hectares [10]. It is situated between longitudes 2°34' 26" and 2°42' 35" of east; 7°32' 9" and latitudes 7°41' 23" of north. The climate is tropical with a bimodal rainfall regime of four seasons. The long rainy season extends from March to July; the short dry season is between the beginning and end of August; the short rainy season extends from September to October; the long dry season extends from November to February. The annual average rainfall is about 1,073 mm with an average of 65 rainy days. The rainfall pattern tends to be unimodal. The temperature varies between 25°C and 34.5°C with a relative humidity of the air from 78% to 95% throughout the year. The vegetation formations encountered range from gallery forests to wooded and shrubby savannahs. The prevailing winds are generally from the southwest; the harmattan prevails between December and January and extends into February. The following tree species are generally found in this area: *Cynometra megalophylla*, *Diospyros mespiliformis*; *Berlinia grandiflora; Cynometra megalophylla, Anogeissus leiocarpa*; *Combretum collinum, Isoberlinia doka, Pterocarpus erinaceus, Vitellaria paradoxa, Lophira lanceolata, Brachiaria deflexa*, *Securinega virosa* and Brachiaria deflexa. Animal species exist in the plantations and especially along the ravines. Among the most frequent are *Zerus erythrocebus*, *Cricetomys gambiaus* and *Tryonomys swinderianus*.

The tree, *Gmelina arborea*, often known as the Gmelina tree, is a medium to large-sized deciduous tree in the Verbenaceae family. It is native to Southeast Asia and is found in tropical climates all around the globe. [11]. The tree may reach a height of 20-30 meters and has a straight, cylindrical trunk with a diameter of around 60 centimeters. *Gmelina arborea* is recognized for its robust and versatile wood, which is used in the manufacture of furniture, building, and plywood. It is also well-known for its medicinal capabilities, with different portions of the tree utilized in traditional medicine to treat conditions such as fever, inflammation, and respiratory diseases. *Gmelina arborea* is also recognized to give significant ecological advantages such as soil improvement, erosion control, and as a source of nectar for bees. [11]. *Tectona grandis* is a subtropical deciduous tree of the Verbenaceae family. This species thrives well in areas with rainfall and temperatures ranging from 900-2500mm and 17-430 C, respectively [12]. *Tectona grandis* is an important and useful multifunctional tropical hardwood tree species. It is a fast-growing tree species with the potential to regenerate and may be utilized for a number of purposes.

2.2. Data Collection Procedure

For the purpose of this study, two distinct exotic plantations consisting of *Gmelina arborea* which covers an area of 16.92 hectares and *Tectona grandis* with 23.5 hectares, were identified. These plantations, which are adjacent to each other, have been established for a period of ten years. Each plantation was demarcated into temporary plot size of 25m by 25m. Simple Random Sampling (SRS) technique was adopted in the selection of sixteen plots from Teak plantation and fifteen plots from Gmelina plantation for complete tree enumeration. Tree growth variables, including merchantable height and diameter at breast height (Dbh), were measured on all living trees in each selected plot. The Dbh was determined using diameter tape while merchantable height was measured by using Spiegel Relaskop.

2.3. Data Analysis

Merchantable volume over bark for all trees within each selected plot was estimated using the formula as described by

J. K. Vanclay [13]:

$$Vol = (\pi d^2 /4)*H \quad (1)$$

Where Vol is merchantable volume in cubic meter, π is 3.142, Dbh is the diameter at breast height in cm and H is Tree merchantable height in meter. The statistical methodology adopted for the study is multiple regression with categorical variable. Multiple regression analysis is a statistical method for predicting the value of a dependent (target) variable based on the values of several independent (predictor) variables. It fundamentally extends simple linear regression (which only considers one independent variable) to include multiple predictors when categorical variables are included in a model, they are typically converted into a set of 'dummy' variables, each representing one level of the categorical variable [14]. The general equation for a multiple regression model with a categorical variable can be represented as

$$Y= \beta_0 += \beta_1 x_1 += \beta_2 x_2 + \ldots = \beta i*Di+ \varepsilon \quad (2)$$

Where Y is the dependent variable, x_1, x_2,... are the continuous independent variables, Di represents the dummy variable, β_0, β_1, β_2,... βi are the parameters to be estimated and ε is the error term.

The estimated coefficients (β1, β2,... βi) from the regression analysis quantify the intensity and direction of the association between the dependent variable and each predictor [14-16]. In this study, four major variables were considered; Stem Volume as dependent variable, Dbh and Height as continuous variables while Tree Species represent the independent categorical variable with two levels where *Gmelina arborea* and *Tectona grandis* were transformed into two dummy variables (*Gmelina arborea*=0, *Tectona grandis*=1).

2.4. Statistical Analysis

Before delving into exploration, the data were cleaned and missing values removed to avoid of values. Data summarization was thereafter carried out to obtain basic descriptive statistics and summaries of the dataset, which included measures of central tendency (mean, median) and dispersion (standard deviation, interquartile range) to have an initial overview of the data's distribution and variability. The Kolmogorov-Smirnova test was also used to confirm the non-normality of the data while bivariate analysis, using the Mann-Whitney U test, was explored to investigate if there is a significant difference in the average volume of the two species of tree (*Gmelina arborea and Tectona grandis*), while a multivariate regression analysis was used to determine the predictors of the stem volume of the two exotic species. The regression model was defined in the equation below;

$$\text{Volume (m}^3) = ß_0 + ß_1(Dbh) + ß_2(\text{Height}) + ß_3(\text{Tree species}). \quad (3)$$

Where the regression Coefficients (β_i) represent the estimated change in the volume (m^3) of the tree for a one-unit change in the corresponding independent variable, Dbh and height, while holding all other variables constant. Also, it is expected that the volume from plantations of *Gmelina arborea* and *Tectona grandis* will be predicted when either of the two species is inserted into the equation. A positive coefficient indicates a positive relationship ($\beta_i > 0$), indicating that an increase in the independent variable is associated with an increase in the volume (m^3). Conversely, a negative coefficient ($\beta_i < 0$) indicates a negative relationship, where an increase in the independent variable is associated with a decrease in the volume (m^3). The β_0 (Intercept term) represents the expected value of the volume (m^3) of the tree when all independent variables are zero. The adjusted R-squared measures the proportion of the variation in the volume of the tree that can be explained by the independent variables in the regression model above. All statistical analysis was carried out at a 5% level of significance. IBM SPSS Statistics (version 25.0) was used for data analysis.

3. Results

A total of 708 trees were observed and analyzed in this study, 57.2% (n = 405) being the Gmelina tree and 42.8% (n = 303) the Teak tree, as shown in Figure 1.

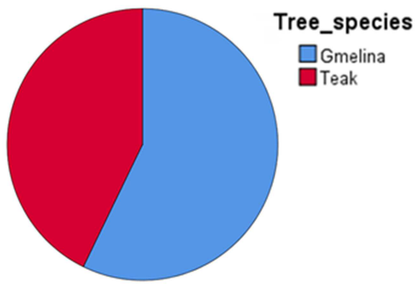

Figure 1. *Distribution of all the enumerated trees by species type.*

Table 1. *Descriptive statistics for Dbh of Tectona grandis and Gmelina arborea Plantations.*

	Tectona grandis	Gmelina arborea
Average Dbh (m)	0.14	0.18
Minimum	0.13	0.15
Maximum	0.16	0.22
Skewness	0.24	0.53
Kurtosis	-0.55	-0.49

Table 1 presents descriptive statistics for the diameter at breast height (Dbh) of *Tectona grandis* and *Gmelina arborea* plantations. The average Dbh for *Tectona grandis* is 0.14 meters, while for *Gmelina arborea*, it is slightly higher at 0.18 meters. The minimum Dbh recorded for *Tectona grandis* is 0.13 meters, whereas for *Gmelina arborea*, it is 0.15 meters.

The maximum Dbh observed for Tectona grandis is 0.16 meters, while for *Gmelina arborea*, it is slightly larger at 0.22 meters. The skewness values indicate the degree of asymmetry in the distributions, with *Tectona grandis* having a skewness of 0.24 (possibly indicating a slight positive skew) and *Gmelina arborea* having a higher skewness of 0.53 (possibly indicating a more pronounced positive skew). The kurtosis values measure the peakedness of the distributions, with both species showing negative kurtosis values (-0.55 for *Tectona grandis* and -0.49 for *Gmelina arborea*), suggesting relatively flatter distributions compared to a normal distribution.

Table 2. *Descriptive statistics for height of Tectona grandis and Gmelina arborea Plantations.*

	Tectona grandis	Gmelina arborea
Average Dbh (m)	5.86	9.10
Minimum	3.79	6.88
Maximum	7.52	10.88
Skewness	-0.37	-0.66
Kurtosis	-0.77	0.95

From Table 2, the average height for Tectona grandis is 5.86 meters, whereas *Gmelina arborea* has a higher average height of 9.10 meters. The minimum height observed for *Tectona grandis* is 3.79 meters, while for Gmelina arborea, it is 6.88 meters. The maximum height recorded for Tectona grandis is 7.52 meters, whereas *Gmelina arborea* has a maximum height of 10.88 meters. The skewness values indicate the symmetry of the distributions, with *Tectona grandis* having a negative skewness of -0.37 (possibly indicating a slight left skew) and Gmelina arborea showing a more pronounced negative skewness of -0.66 (possibly indicating a more significant left skew). The kurtosis values measure the peakedness of the distributions, with *Tectona grandis* having a negative kurtosis value of -0.77 (indicating a relatively flatter distribution), while *Gmelina arborea* exhibits a positive kurtosis value of 0.95 (indicating a more peaked distribution).

The descriptive statistics is presented for various parameters related to tree measurements, specifically focusing on volume (m^3), diameter at breast height (Dbh), and height. The statistics provided include the mean, standard deviation, median, interquartile range (IQR), and range. The mean values indicate the average measurement for each parameter, such as a mean volume of 0.1942 m^3, mean Dbh of 0.1666, and mean height of 8.0853. The standard deviation measures the variability around the mean, with smaller values indicating less dispersion, the standard deviation for volume is 0.1420, for Dbh it is 0.0405, and for height it is 2.7924. The median values represent the middle value in the dataset and are less influenced by outliers. The IQR provides a measure of dispersion for the middle 50% of the data, and the range represents the span between the minimum and maximum values. Furthermore, the table includes specific statistics for two tree types, *Gmelina arborea* and *Tectona grandis*. For Gmelina trees, the mean volume is 0.2499 m^3, with a standard deviation of 0.1603, a median of 0.2080, an IQR of 0.17, and a range of 0.04-1.09 m^3. Teak trees, on the other hand, exhibit a lower mean volume of 0.1198 m^3, a standard deviation of 0.0561, a median of 0.1090, an IQR of 0.07, and a range of 0.00-0.34 m^3. The result of Kolmogorov-Smirnov (KS) test analysis showed that there is a significant difference between the average volume (m^3) of *Gmelina arborea* and *Tectona grandis* ($p<0.05$).

Table 3. *Descriptive Analysis of all the tree growth variables.*

Parameters	Mean	Std. Deviation	Median	IQR	Range
Volume (m^3)	0.1942	0.1420	0.1530	0.1400	0.0-1.09
Dbh (m)	0.1666	0.0405	0.1560	0.05	0.02-0.36
Height (m)	8.0853	2.7924	7.8400	3.8000	1.80-17.28
Gmelina tree (m^3)	0.2499	0.1603	0.2080	0.17	0.04-1.09
Teak Tree (m^3)	0.1198	0.0561	0.1090	0.07	0.00-0.34

The Spearman's correlation coefficient indicates that there is a significant strong positive relationship between the volume (m^3) and diameter ($r = 0.81$, $p<0.0001$) as well as the volume of the and height of the trees ($r = 0.74$, $p<0.0001$), (Table 4, Figures 2 & 3).

Table 4. *Relationship between Volume, diameter and height.*

		Height	Diameter	Volume
	Correlation Coefficient	1.000	.267**	0.741**
Height	Sig. (2-tailed)	-	0.000	0.000
	n	708	708	708
	Correlation Coefficient	0.267**	1.000	0.810**
Diameter	Sig. (2-tailed)	0.000	-	0.000
	n	708	708	708
	Correlation Coefficient	0.741**	0.810**	1.000
Volume	Sig. (2-tailed)	0.000	0.000	-
	n	708	708	708

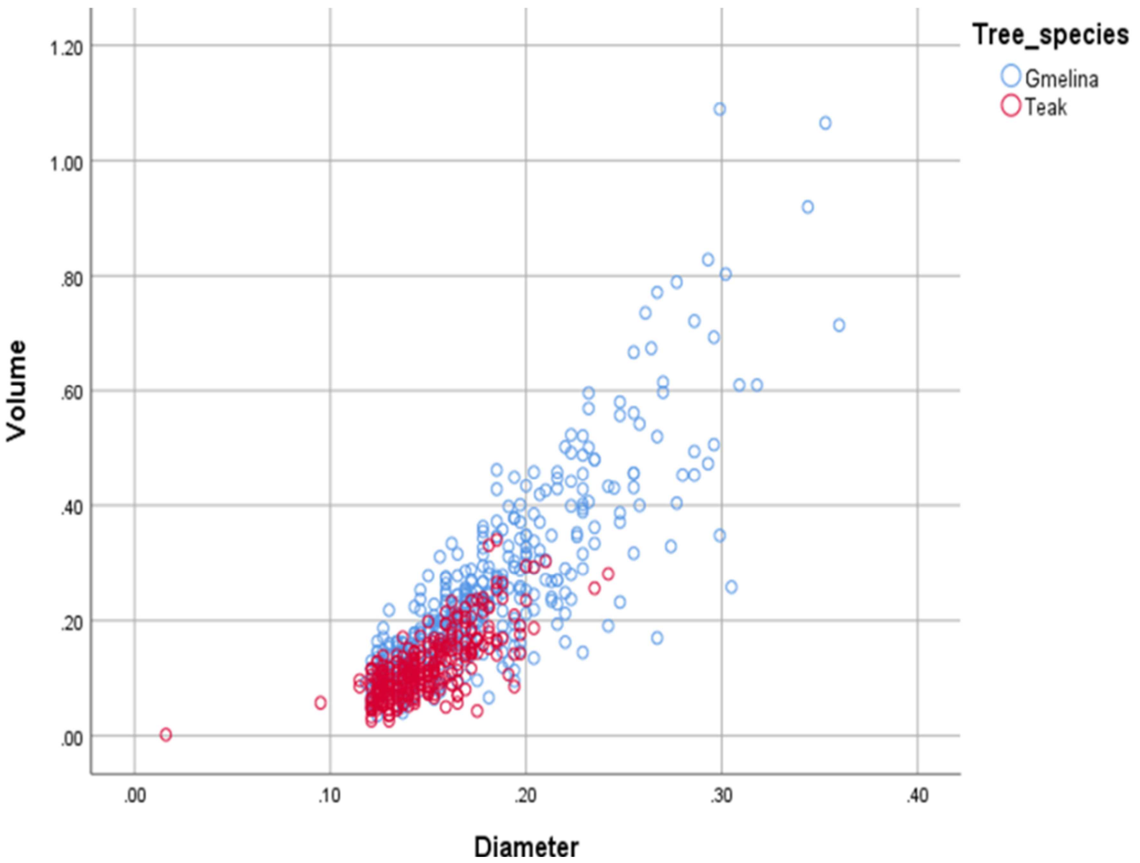

Figure 2. *Scattered plot for the relationship between volume and diameter.*

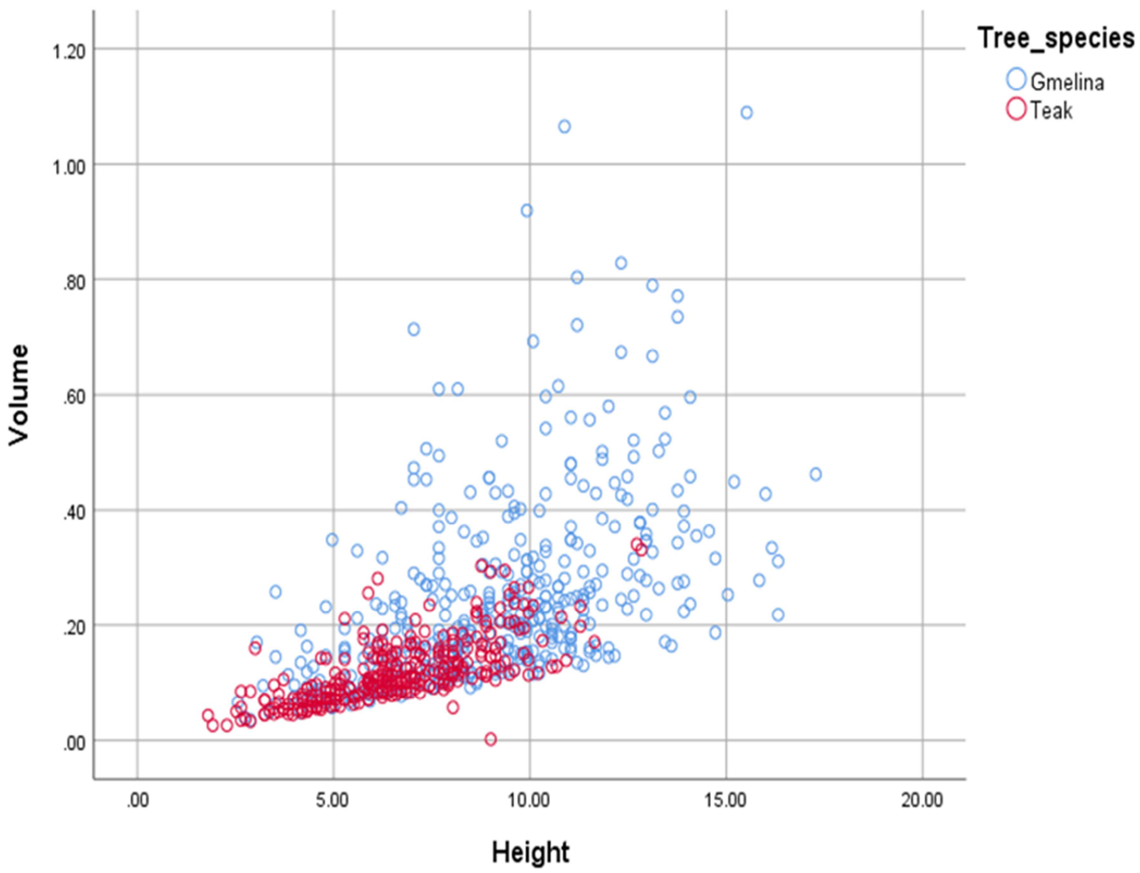

Figure 3. *Scattered plot for the relationship between volume and height.*

Table 5 shows the multivariate regression model developed as: Volume (m^3) = -0.467 + 0.024*(Height) + 2.683*(Dbh) + 0.016 (tree species) with adjusted R-squared of 91.3%.

The adjusted R-squared indicates that 91.3% of the variable in the volume of the tree can be explained by the variation in the height, diameter and tree species.

Table 5. *Multivariate regression analysis of the data.*

Parameters	Coefficients (β_i)	Std. Error	Statistic (t)	Sig.	95% Confidence Interval for β_i
(Constant)	-0.467	.012	-37.923	<0.0001	(-0.491, 0.443)
Height	0.024	.001	37.199	<0.0001	(0.022, 0.025)
Diameter	2.683	.042	63.298	<0.0001	(2.600, 2.766)
Tree_ species	0.016	.004	4.149	<0.0001	(0.008, 0.023)

4. Discussion

The study examined a total of 708 trees, with 57.2% being Gmelina trees and 42.8% Teak trees. The average Dbh for *Tectona grandis* was 0.14 meters, while for *Gmelina arborea*, it was slightly higher at 0.18 meters. Notably, the minimum Dbh recorded for *Tectona grandis* was 0.13 meters, whereas for *Gmelina arborea*, it was 0.15 meters. On the other hand, the maximum Dbh observed for *Tectona grandis* was 0.16 meters, whereas for *Gmelina arborea*, it was slightly larger at 0.22 meters. The skewness values indicated the degree of asymmetry in the distributions, with *Tectona grandis* having a skewness of 0.24, possibly indicating a slight positive skew, while *Gmelina arborea* exhibited a higher skewness of 0.53, suggesting a more pronounced positive skew. Additionally, both species displayed negative kurtosis values (-0.55 for *Tectona grandis* and -0.49 for *Gmelina arborea*), indicating relatively flatter distributions compared to a normal distribution. These findings shed light on the variability in tree diameter between *Tectona grandis* and *Gmelina arborea* plantations, highlighting the differences in average Dbh, range, skewness, and kurtosis. These observations are similar to the findings [17]. Such insights are crucial for understanding the growth patterns and structural characteristics of these tree species, which can aid in forest management and decision-making processes. Furthermore, the results from Table 2 reveal that *Gmelina arborea* exhibited a higher average height (9.10 meters) compared to *Tectona grandis* (5.86 meters). The minimum and maximum heights recorded also showed that *Gmelina arborea* had a wider height range (6.88 to 10.88 meters) compared to *Tectona grandis* (3.79 to 7.52 meters). Skewness values indicated the symmetry of the distributions, with both species displaying negative skewness. However, Gmelina arborea had a more pronounced negative skewness (-0.66), suggesting a stronger left skew compared to *Tectona grandis* (-0.37). The kurtosis values reflected the peakedness of the distributions, with *Tectona grandis* exhibiting a negative kurtosis (-0.77), indicating a relatively flatter distribution. In contrast, *Gmelina arborea* showed positive kurtosis (0.95), suggesting a more peaked distribution. In addition, information on the descriptive statistics for volume which indicated the average measurements for each parameter, with *Gmelina arborea* displaying a higher mean volume (0.2499 m^3) compared to *Tectona grandis* (0.1198 m^3). The standard deviations for all parameters showed the variability around the means, with smaller values indicating less dispersion. The Spearman's correlation coefficient analysis, as shown in Table 4 and Figures 2 and 3, revealed significant strong positive relationships between volume and both diameter (r = 0.81, p<0.0001) and height (r = 0.74, p<0.0001) of the trees. The multivariate regression model developed is given as:

Volume (m^3) = -0.467 + 0.024*(Height) + 2.683*(Dbh) + 0.016 (tree species) for merchantable volume prediction for the two exotic plantations. The adjusted R-squared indicates that 91.3% of the variable in the volume of the tree can be explained by the variation in the height, diameter and tree species [16]. The analysis reviewed that diameter, height and tree species were all significant predictors of the volume of the tree (p<0.0001). The coefficients represent the estimated change in the volume of the tree associated with a one-unit change in each independent variable while holding other variables constant. For example, a coefficient of 0.024 for height means that, on average, a one-unit increase in height is associated with a 0.024 increase in the volume of the tree, assuming the diameter and tree species remain constant. Similarly, the diameter of the tree has a positive impact on the volume of the tree, suggesting that more height values were associated with higher volume (m^3) of the tree while controlling for other factors, as shown in the model. The coefficient associated with the tree species indicates the average change in the volume of the tree when the binary dummy variable (0/1) changes from either of the tree species (Gmelina/Teak). Since the coefficient is positive ($ß_3$, = 0.016, p<0.0001), this suggests that the presence of the tree species is associated with a higher average value of the tree volume.

Overall, these findings provide valuable insights into the growth patterns and structural characteristics of *Gmelina arborea* and *Tectona grandis* trees. The results highlight differences in average height, range, skewness, and kurtosis between the two species, indicating distinct growth and distribution patterns and agreed to the results obtained by I. Y. Egonmwan and F. N. Ogana [17]. Additionally, the significant correlation between volume and both diameter and height underscore the interdependence of these tree measurements, which can be essential for forest management practices and decision-making processes.

5. Conclusion

This research work brings to light significant disparities in the growth trends and structural traits of *Gmelina arborea* and *Tectona grandis*. It was observed that *Gmelina arborea* displayed greater average values in diameter at breast height (Dbh), height, and volume compared to *Tectona grandis*, and both species exhibited unique distribution patterns as indicated by their respective skewness and kurtosis figures. Further, the study unveiled a potent connection between a tree's volume and its height and diameter. A multivariate regression model was able to explain 91.3% of the variation in volume through these factors and tree species. The model revealed that enhancements in diameter, height, and the presence of a particular species (*Gmelina arborea*) correspond to an increase in tree volume. These discoveries contribute significantly to our understanding of the structural attributes and growth dynamics of these species and further show that the Dbh, height and tree species are good predictors for volume estimation, forming a crucial basis for effective forest management and decision-making strategies. Moreso, this study was a preliminary one, further investigations are needed to validate the model for future application on these plantations.

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