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Development of Yield Function and Height-Diameter Trees Species in Arboretum, University of Port Harcourt, Nigeria

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Abstract

The aim of the research was to create models for forecasting tree heights and stem volumes of tree species stands in the Arboretum at the University of Port Harcourt, using simple random sampling. All trees were determined for their diameters at breast height (Dbh) and overall height. The data were examined using descriptive and regression methods. Height-diameter and stem volume models were fitted to the dataset using linear, logarithmic, quadratic, and cubic functions. The analyst was tree Dbh (cm). The established models were evaluated using the coefficient of determination (R^2), root mean square error (RMSE), and Akaike's information criterion (AIC). Model justifications were performed using the t-test and mean bias. All the results for the selected models were significant ($P < 0.05$), height-diameter models consistently gave poor outcomes with low R^2 values. The best among the height-diameter models is quadratic function with R^2; RMSE and AIC values of 0.50; 4.03 and 5787. Also, volume models had very high $R^2$with low RMSE and AIC values among which quadratic modelhad the best with highest R^2; RMSE and AIC values of 0.93, 0.44 and 662.1. Model validation in all the height and yield function revealed no significant difference between the observed and the predicted of height and stem ($P>0.05$).The study recommended linear and quadratic models for trees in the plantation, due to their satisfactory of height and yield prediction as well as strong biological interpretability.

Keywords: Yield, Arboretum, height, diameter, trees.

Introduction

Sustainable forest management entails magnitude of information on estimate of growing stocks within the forest. Forest resource is relevant for making decisions when reliable information in different levels regarding the timber harvesting, biomass, species diversity, watershed protection, climate change impact evaluation and socio-economic benefits[1-4]. Taking forest stock mostly comprises the collection of resource information which objectively provide precise assessment of the forest characteristics such as the wood volume, biomass, or species diversity within the region of interest[5]. Specifically, these characteristics are estimated through models constructed using tree species, diameter at breast height (DBH), and tree height[6].

Development of a suitable Height-Diameter model is very important component for estimating yield models in given useful information for effective preparation and controlling of forestry resources. Forest managers and planners rely on effective and accurate models to anticipate forest growth and products, site index, and mortality when making decisions and managing their forests. As a result, advance and yield modeling are extremely valuable tools for the operational and strategic management of forest holdings, whether in a vast forest area or a plantation. Models remain powerful tools for managing any forest stand[7]. Tree height-diameter is one of the most important forest physical variables used in forest measurements and inventories, since it has a considerable impact on estimating forestry volume and aboveground biomass. For timber production, the proper estimate taking for growing stock is often expressed in terms of tree volume, which can be assessed from measurable tree attributes like diameter and height. Diameter at breast height (DBH) may appear measured precisely. However, as a result of visual obstacles, tree height evaluation is less precise, more difficult, and longer consuming, particularly in tall and closed covering stands[8,9]. Using the height-diameter relationship has shown to be a practical way to reduce asset count and interval use.

Furthermore, height-diameter represents an inherent feature of an allometric growth device for the overall state forest structure, forest total resource utilization, biomass productivity, spatial total resource utilization, biomass productivity, spatial distribution, death, rebirth, and so on[10-13]. Alternatively, the height-diameter connect of tree species varies from point to position, even within the same position, and is usually dynamic over time[14].

A better understanding of the relationship between hypsometric equations and forest growth and yield models would benefit forest monitoring, management, and volume estimation[15]. Foresters must understand every aspect of the forest or plantation they manage, including the location, size, quantity, and quality of available resources, as well as how these resources change over time. This information can be gained through appropriate resource modeling. In this investigation, to determine the most suited model(s), tree species height and volume estimations in the position were fitted to height-diameter data. Four statistical criteria were employed to evaluate the model's performance, and 33% of an independent dataset was utilized to validate and compare the models. The aim of this study were to establish the stand-specific height-diameter and trunk volume prediction for the stand.

Methodology

This study was conducted at the University of Port Harcourt's Department of Forestry and Wildlife Management Arboretum. Located in latitudes 4.90794E and 4.90809 N and longitudes 6.92413 and 6.92432 E, Ikwerre and Obio/Akpor Local Government Areas in Rivers State[16] cover an area of approximately 400 hectares (4226.25815m^2). The site distinguishes between dry and wet seasons[17]. The site is home to a variety of exotic and indigenous trees, including *Gmelina arborea, Tectona grandis, Khaya grandifoliola, Nuclea diderrichii, Irvingia gabonensis, Entandrophragma cylindricum, Terminalia ivorensis, Ricinodendron heudelotti, Treculia africana, Garcinia kola, Persea americana, and Anona muricata.* In addition, the arboretum features a variety of shrubs, herbs, and climbers.

Data Collection: Total enumeration sampling was utilized. A temporary sample plot of 25m x 25m in size was randomly picked, resulting in 10 plots per hectare being laid. All trees in the sampled plots were measured using a contemporary inventory clinometer for height (h) and a diameter tape for diameter at breast height. All gathered measures were used to calculate stem volume, basal area, number of stems per plot, and diameter dispersion. Table-1 displays descriptive statistics for the measured tree parameters.

Data analysis: To estimate the basal area of each tree in a sample plot, use the formula:

$$BA = \frac{\pi D^2}{4} \quad (1)$$

BA= Basal Area (m), D= Diameter (cm), π =3.142.

Each plot's total BA was calculated by adding the BA of each tree in the plot (BAp = Σ BAtree). The mean BA for the plot was calculated with the formula

$$mBA = \Sigma \frac{BA}{n} \quad (2)$$

was used to determine the plot's mean BA where n is the number of plots or sampling units and mBA is the mean basal area per plot. The mean basal area per plot was multiplied by the number of plots in a hectare (10 plots) to determine the basal area per hectare.

$$BA\ ha = mBA \times 10 \quad (3)$$

Volume Estimation:

$V=DBH^2 \times H$ (Newton's formula of [17]) (4)

was used to estimate the volume of each tree in each sampleplot.

where V stands for volume, DBH for breast height, and H for overall height. Each plot's individual tree volumes were added to determine the plot volume. Volume/hectares were then obtained by multiplying plot volumes by 10.

Models Adopted: A series of regression equations height-diameter and stem volume (yield). Models were fitted to the data of the developed regression equations at individual tree level. The following height-diameter models were obtained namely:

Linear Models: $H = \beta_0 + \beta_1 Dbh$ (5)
Logarithmic Models: $H = \beta_{0+} \beta_1 In\ Dbh$ (6)
Quadratic Model: $H = \beta_{0+} \beta_1 Dbh_{\ +} \beta_2 Dbh^2$ (7)
Cubic Model: $H = \beta_{0+} \beta_1 Dbh_{\ +} \beta_2 Dbh^2{}_{+} \beta_3 Dbh^3$ (8)

The following stem volume (yield) functions were adopted, viz:
Linear Models: $V = \beta_0 + \beta_1 Dbh$ (9)
Logarithmic Models: $V = \beta_{0+} \beta_1 In\ Dbh$ (10)
Quadratic Model: $V = \beta_{0+} \beta_1 Dbh_{\ +} \beta_2 Dbh^2$ (11)
Cubic Model: $V = \beta_{0+} \beta_1 Dbh_{\ +} \beta_2 Dbh^2{}_{+} \beta_3 Dbh^3$ (12)

where: H = tree total height (m); Dbh = diameter at breast height (cm); V = stem volume (m^3); ln = natural logarithm (log); b_0, b_1, b_2, and b_3 = are regression constants estimated.

Assessment of the Models: Model evaluation tends to form an integral part of the model development process which assist in recommending those with good fit for further uses. The following statistical criteria were used:

Coefficient of Determination (R^2): This is the measure of the proportion of variation in the dependent variable that is explained by the behavior of the independent variable. It was computed as:

$$R^2 = \left(1 - \frac{RSS}{TSS}\right) \quad (13)$$

The R^2 values range between 0 and 1, and can be expressed in percentage by multiplying the value by 100. The R^2 score needs to be high (>50%) for the model to be approved.

RMSE or Root Mean Square Error was used to calculate this;

$$RMSE = \sqrt{\frac{RSS}{n-p}} \quad (14)$$

where n is the total number of observations, RSS is the regression sum of squares, TSS is the total sum of squares, and p is the number of parameters in the model, or the total number of variables taken into consideration. The residuals were used to calculate the root mean square error (RMSE) and Akaike's information criterion (AIC). They were employed to evaluate the models' performance and choose the model that best captured the link between height and diameter as well as between height and diameter for individual trees. RMSE indicate the accuracy of the estimates; and the AIC is an index used to select the best model from a group of candidate models[18]. In general, the most suitable models are those with the lowest RMSE, and AIC, and with the highest value R^2 are known to perform best[19].

Significance of Regression (F-ratio): This was used to test the overall significance of the regression equations (models). The critical value of F (F-tabulated) at α equals 0.05 was compared with the variance ratio (F-calculated). Where the F-calculated is greater than the critical values (F-tabulated), such equation (model) is therefore significant, and was accepted for prediction.

Models Validation: In this study, model validation was done by dividing the data into two sets. A third set was utilized to validate the model, while the remaining set was used to construct models. Models were built using the calibrating set, while models Adesoye, P.O.[20], Akindele, S.O.[21] and Adeyemi, A.A.[22] were tested using the validating set. If there is a significant difference between the mean predicted and observed values of the dependent variables in each setup, the model's output will be compared with field-based observed values using the Student t-test and simple linear regression. The student t-test was used to determine whether there was a significant difference between the predicted values (model output) of the several models that were developed and the actual values or field value.

Bias in Percentage Calculation: The difference between volumes derived using Newton's formula (observed volume) and model output will be divided by the same observed volume and multiplied by 100 to get the absolute percentage difference (% bias).

$$\text{Bias is equal } \frac{Y-\acute{Y}}{Y} \times 100 \qquad (15)$$

Y is the observed value, and Ý is the anticipated value (the model's output). For the model to be appropriate for management purposes, the value needs to be comparatively little.

Results and Discussion

An overview of the descriptive: The summary descriptive statistics for each tree growth characteristic for the pooled data are first shown in Table-1 and 2. The mean value of 5.70± 2.86 is displayed in the summary statistics for tree growth variables on plot and stand bases. Numerous tree species were represented in the dataset (484), Table-2 shows tree heights ranging from 9.13 to 19.88m and DBHs between 0.16 and 0.33 cm. In order to forecast the height of trees, the study tested and assessed a few chosen height-diameter and volume models. The findings showed that the stand's mean basal value was less than the 48 cm recommended by Nigeria's wood production policy. Additionally, the results showed that the area had a poorly stocked planted stand[7,23]. With diameters ranging from 0.07 to 0.77 cm and heights ranging from 4.07 to 30.60m, the calibration data, which came from 323 unique trees, covered a broad range of tree sizes. 161 distinct trees with diameters ranging from 0.06 to 0.63cm and tree heights provided the validation data from 6.90 to 28.60 meters respectively in Table-2.

Table-1: Individual tree growth variable descriptive statistics for combined data.

Variables	Minimum	Maximum	Mean ± SD	S. E
DBH	0.06	0.77	0.26±0.13	0.006
TH	4.70	30.60	14.69±5.95	0.270
Vol	3.53	5.97	5.70±1.59	0.072
BA	0.00	0.77	0.07±0.00	0.002
Plots	1.00	10.00	5.70±2.86	

N.B.: Dbh = Tree diameter at breast height; TH =Tree total height; Vol = Stem volume; BA = Basal area.

Features of regression models: The link between height and diameter is crucial for determining forest stock growth and yield models. In order to forecast the height of trees, the study tested and assessed a few chosen height-diameter and volume models. Based on a review of the multi-model performance criteria, the majority of the candidate models created in the table performed rather well in fitting the height-diameter relationship for the tree species in the plantation. All models' fitting outcomes were analysed and assessed using multiple-model performance criteria. Each model described over half of the observed data and fit the dataset well variance (R^2), with the exception of logarithmic at 35%. With the exception of the logarithms function, the high R^2, low RMSE, and significance of regression achieved for the volume, height-diameter models in this study indicate good fits. With a very low R^2 and better model validation results, the logarithm function was subpar. The quadratic function was the most effective height and diameter model overall, while any function may be deemed better or worse depending on the circumstances. Across all four functions, the model typically creates intercepts (bo) that are near to one, and under the models for height and diameter, the slope (b_1) was also above zero.

The results of Adekunle V.A.J.[7], which showed that a model with a good fit is indicated by an intercept (b_o) around zero and a slope (b_1) near one, were at odds with this conclusion. The observed development, however, might have been caused by the generally poor height-to-diameter connection. Both the quadratic and cubic functions fared rather well according to the aforementioned criteria, with the quadratic functions offering the most accurate height forecast. Good fits are strongly indicated by the yield (volume) model valuation's high R^2 and low RMSE.

The models with good fits that were shown were comparable to those that were found by Adekunle V.A.J.[7], who identified high indexes of fit, including the R^2 indicator, as indicative of a strong fit model that is appropriate for use with the data at hand.

The cubic and quadratic functions did fairly well. However, the quadratic function was the overall best volume model. The volume (yield) prediction typically yields a negative intercept based on observation Avery, T.E. & Burkhart, H.E.[24]. Conversely, the logarithmic function almost always displayed positive intercepts. The low model fitting performance and efficiency could possibly be explained by this.

Table-2: Summary statistics for all plots sampled trees and trees used for model calibration and validation.

S/N	No of Plots	No of Trees	Dbh (cm)	TH (m)	Vol(m^3)	B A (m^2)
			Mean	Mean	Mean	Mean
1	1	50	0.21	12.47	0.60	0.04
2	2	36	0.16	9.13	0.21	0.02
3	3	45	0.22	12.23	0.52	0.04
4	4	36	0.21	13.54	0.49	0.04
5	5	57	0.23	11.33	0.68	0.06
6	6	53	0.33	12.11	1.60	0.11
7	7	58	0.33	18.84	1.86	0.10
8	8	51	0.27	19.57	1.23	0.06
9	9	38	0.21	19.88	2.13	0.09
10	10	60	0.29	16.47	2.13	0.10
Total	10	484	2.45	145.57	11.43	0.65
Grand mean	-	-	0.25	14.56	1.14	0.07
Calibration	-	323	0.25	12.89	-	0.96
Validation	-	161	0.28	18.35	-	1.76

Note: DBH: Diameter at breast height; Vol ;Volume; TH; Tree Height; BA; Basal Area.

Table-3: Models of height and diameter used for the study area's tree species.

Function	Model Forms	R^2	RMSE	AIC	P-value
Linear	$H = 6.375 + 29.743\ Dbh$	0.50	4.05	5859	0.000
Logarithmic	$H = 21.190 + 4.805\ In\ Dbh$	0.35	4.43	6561	0.000
Quadratic	$H = 7.157 + 19.983\ Dbh + 20.544\ Dbh^2$	0.50	4.03	5787	0.000
Cubic	$H=7.150+21.051Dbh+13.521Dbh^2+10.433Dbh^3$	0.50	4.03	5788	0.000

N.B.: α = 0.05; ln = natural logarithm; R^2= co-efficient of determination; RMSE = root mean square error; AIC= Akaike's information criterion.

Validation of the Models: Since there was no discernible difference between the observed and predicted mean volume values, the validation of the volume models showed that the models could predict trees for separate plots. This is consistent with[25] reports that demonstrate positive outcomes when choosing trees from various size ranges. These are additional signs that the linear, logarithmic, quadratic, and cubic function models match the field data well and can therefore be used. The results are consistent with Adekunle V.A.J.[7] and Akindele, S., & LeMay, V.[23], which show that models with a strong fit are indicated by closer observed and predicted values.

Model Fitting: Table-8 displays evaluations for the height-diameter model consistencies. The cubic, logarithmic, and quadratic functions had lower mean bias values. The linear model's high result, however, suggested that the area's tree heights were overestimated. With regard to the yield models, every model in the table produced mean bias values that were quite modest, with the Exception of the logarithm, which had a greater value.

Table-4: Model of Volume used for the study area's tree species.

Function	Model Forms	R^2	RMSE	AIC	P-value
Linear	$V = -1.898 + 118.77\ Dbh$	0.93	4.05	663.14	0.000
Logarithmic	$V = 2.889 + 2.204\ In\ Dbh$	0.52	0.77	774.66	0.000
Quadratic	$V = -1.739 + 9.897\ Dbh + 4.168\ Dbh^2$	0.93	0.44	662.09	0.000
Cubic	$V = -1.752 + 11.657Dbh - 7.406Dbh^2 + 17.196Dbh^3$	0.93	0.44	662.71	0.000

N.B.: α = 0.05; ln = natural logarithm; R^2= co-efficient of determination; RMSE = root mean square error; AIC= Akaike's information criterion.

Table-5: Model validation results for the height-diameter models of tree species.

Function	Model Forms	Mean Obs.	Mean Pred.	t_{cal}	P-value
Linear	$H = 6.375 + 29.743\ Dbh$	*12.10±0.39*	16.12±0.29	8.72	*0.771*
Logarithms	$H = 21.190 + 4.805\ In\ Dbh$	*12.10±0.39*	15.48±1.16	-8.15	*0.794*
Quadratic	$H = 7.157 + 19.983\ Dbh + 20.544\ Dbh^2$	*12.10±0.39*	16.16±3.77	8.41	*0.786*
Cubic	$H = 7.150 + 21.051Dbh + 13.521Dbh^2 + 10.433Dbh^3$	*12.10±0.39*	16.16±2.82	*8.36*	*0.789*

N.B.: α = 0.05; mean obs. = mean observed value; mean pred. = mean predicted value.

Table-6: Results of model validations for the *Tree species* Volume models.

Function	Model Forms	Mean Obs.	Mean Pred.	t_{cal}	P-value
Linear	$V = -1.898 + 118.77\ Dbh$	*0.46±0.09*	37.01±1.04	-35.08	*0.849*
Logarithm	$V = 2.889 + 2.204\ In\ Dbh$	*0.46±0.09*	0.27±*0.07*	1.55	*0.881*
Quadratic	$V = -1.739 + 9.897\ Dbh + 4.168\ Dbh^2$	*0.46±0.09*	2.00±*0.11*	10.43	*0.835*
Cubic	$V = -1.752 + 11.657Dbh - 7.406Dbh^2 + 17.196\ Dbh^3$	*0.46±0.09*	1.20±0.12	*-10.07*	*0.826*

N.B.: α = 0.05; mean obs. = mean observed value; mean pred. = mean predicted value

Table-7: Consistencies in model fitting for the height-diameter models of tree species.

Function	Model Forms	Mean Obs.	Mean Pred.	Mean Bias
Linear	$H = 6.375 + 29.743\ Dbh$	*12.10±0.39*	16.12±0.29	0.019
Logarithms	$H = 21.190 + 4.805\ In\ Dbh$	*12.10±0.39*	15.48±1.16	0.011
Quadratic	$H = 7.157 + 19.983\ Dbh + 20.544\ Dbh^2$	*12.10±0.39*	16.16±3.77	0.011
Cubic	$H = 7.150 + 21.051Dbh + 13.521Dbh^2 + 10.433Dbh^3$	*12.10±0.39*	16.16±2.82	0.011

N.B.: Mean obs. = mean observed value; mean pred. = mean predicted value.

Growth Variables Correlation: The matrix demonstrated a statistically significant positive association between the growth variables volume, diameter at breast height, and tree height. The majority of the parameters show strong and positive associations, which is consistent with the findings of Eguakun, F.S. et al[14]. The development of height and volume-diameter connections for all functions revealed a nearly uniform distribution of values to the left and right of the mean in all cases. Random derivations were used for the plotted graphs. These results indicate that the distribution's normality assumption was not broken. Similar conclusions from these developments were reported by Akindele, S., & LeMay, V.[23] and Paula, Soares., & Margarida, Tome[26,] who found that an even dispersion of residuals above and below the zero line indicated a good model that supported the assumption of normality. However, there appeared to be no relationship between model performance and the trends seen in the plots of stem height, diameter, and volume in this study Akindele, S., & LeMay, V.[23]. The inconsistency of the anticipated tree model could be due to Dbh, height, or shape. This study may be attributable to the fact that stem height was predicted solely using Dbh, which may not have sufficiently approximated or described stem height.

Table-8: Consistency of model fitting for the Tree species Volume models.

Function	Model Forms	Mean Obs.	Mean Pred.	Mean Bias
Linear	$V= -1.898+ 118.77\ Dbh$	*0.46±0.09*	37.01±1.04	0.0402
Logarithm	$V = 2.889+2.204\ In\ Dbh$	*0.46±0.09*	0.27±*0.07*	4.4085
Quadratic	$V= -1.739+ 9.897\ Dbh+4.168\ Dbh^2$	*0.46±0.09*	2.00±*0.11*	0.2410
Cubic	$V=-1.752+11.657Dbh-7.406Dbh^2+17.196Dbh^3$	*0.46±0.09*	1.20±0.12	0.2360

N.B.: Mean obs. = mean observed value; mean pred. = mean predicted value.

Table-9: Correlation matrix for tree growth characteristics of Tree Speciesat the study area.

	DBH	TTH	Vol	DBH^2	Ln DBH	Ln TH	Ln Vol
DBH	1.000		.			.	
TTH	0.705**	1.000	.				
Vol	0.963**	0.841**	1.000				
DBH^2	0.940**	0.691**	0.925**	1.000			
Ln DBH	0.908**	0.595**	0.849**	0.784**	1.000		
Ln TH	0.627**	0.911**	0.748**	0.568**	0.577**	1.000	
Ln Vol	0.766**	0.695**	0.830**	0.737**	0.723**	0.711**	1.000

V = Volume (m^3), Dbh = Diameter at breast height (cm), Dbh^2 = Square Diameter at breast height (cm), Ln Tree height = Natural logarithm of total height (m), Ln Dbh = Natural logarithm of diameter at breast height (m), Ln vol = Natural logarithm of volume (m^3).

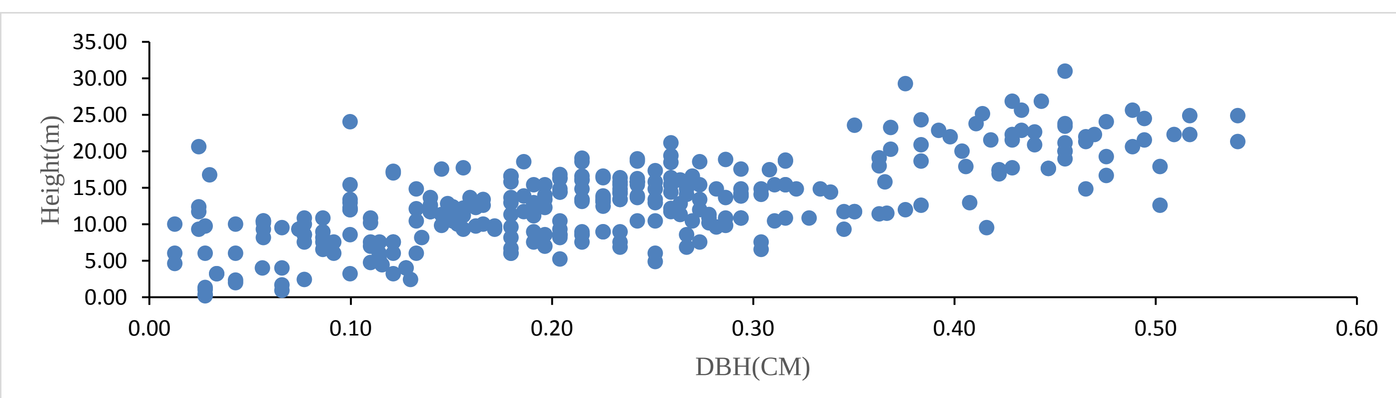

Figure-1: Scattered diagram the relationship between Height and Diameter at breast height.

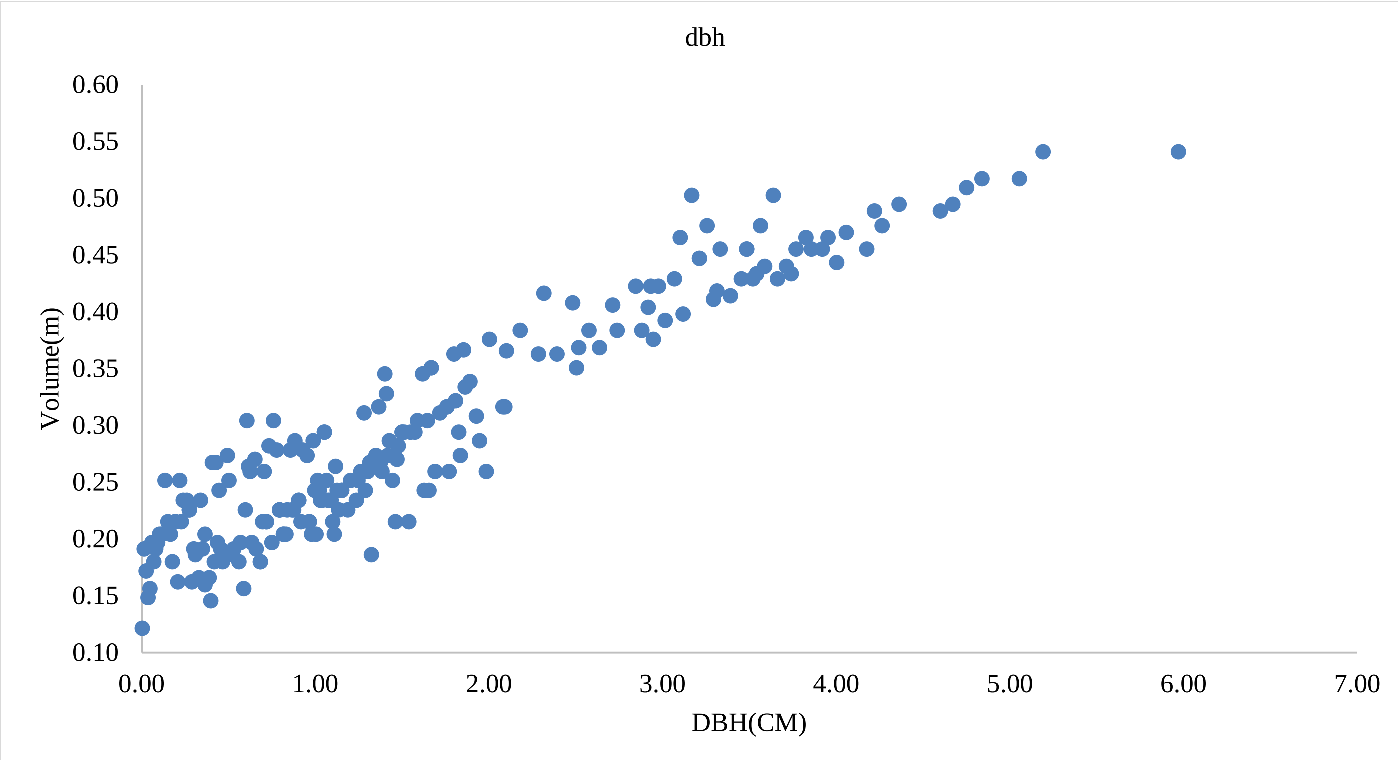

Figure-2: Scattered diagram the relationship between Volume and Diameter at breast high.

Conclusion

Study revealed the maximum satisfactory models for height–diameter and volume connection going by the modeling efficiencies, the quadratic and linear function among all other tested functions were very small mean bias values. This study developed models serves as an efficient instrument for height and volume valuation in the course of ground records representing an significant step for growth and yield assessment in the Arboretum, University of Port Harcourt. They are site detailed, hence their use is limited to forecast heights and volume in the study area.

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