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# RELATIONSHIP BETWEEN HEIGHT AND STUMP DIAMETER FOR *Terminalia ivorensis* (A.CHEV) IN SOKPONBA FOREST RESERVE, EDO STATE, NIGERIA

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## ABSTRACT
*Height (H) and Diameter (D) data from Terminalia ivorensis stand were assessed to establish a relationship between height and stump diameter. Two hundred and sixteen (216) individual trees from eighteen randomly selected Temporary sample plots (TSPs) within a forty-year old plantation were used in study. The data collected were fitted to seven different regression models; of which the logarithmic model was adjudged the best, based on regression statistics diagnostic criteria. The equation is LogH = 1.2493 + 0.005LogD with the adjusted coefficient of determination (adj. $R^2$) and overall standard error of 0.9907 and 0.028 respectively and thus found being the best goodness of fit model. Residual analysis showed conformity with the assumption of independence errors in regression analysis. The equations were validated using another set of trees that were not part of those used for estimating the model parameters. No significant difference ($p > 0.05$) was obtained when the predicted and the observed values were compared using ANOVA and Duncan Multiple Range Test.*

**Key words:** Tree height, stump diameter, height - diameter equation, *Terminalia ivorensis,* modelling

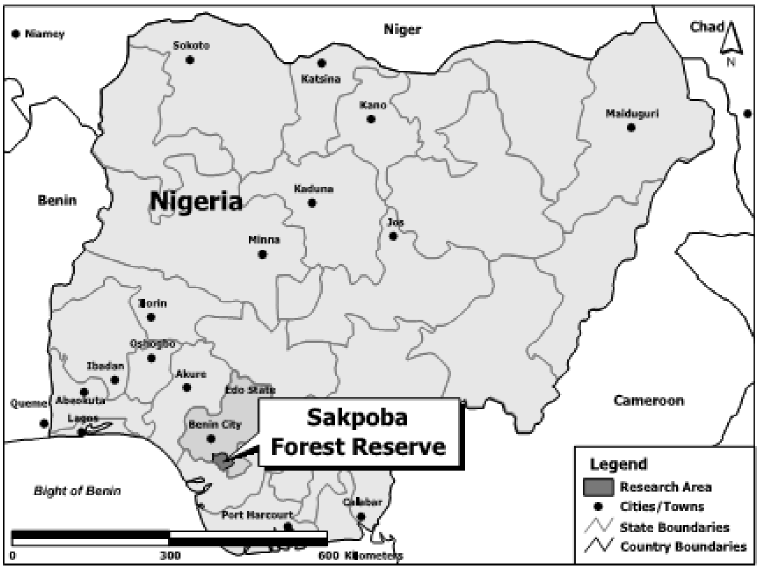
## INTRODUCTION
The tropical forest zone of Nigeria is the main source of supply of timber. *Terminalia ivorensis* (Combretuceace) is a tree species that is found in lowland rainforest zone of Nigeria. There is a large number of *Terminalia spp.,* all of which are widely distributed in the tropics. *Terminalia spp.* is economically very important. The wood is yellow and known as "brimstone wood". It is much used for shingles and may be suitable for palings. Other native uses are for house building such as beams or merely as the framework of mud houses. The logs are also used for canoes building because its timber floats on water. Locally, it is sawn for planks and might be useful for cabinetwork, ceilings flooring and interior work (Danziel *et al,* 2000).

Tree height and diameter at breast height (dbh) are important tree characteristics used in many growth and yield models (Soares and Tome, 2001). Height-diameter curves for tree species have been long used in forest inventories and growth models for predicting missing total height measurements (Curtis, 1967; Wykoff *et. al*., 1982; Huang *et. al*., 1992). Height-diameter equations can either be used for local application or they can have a more generalised use (Krumland and Wensel,) 1988; Tome, 1989; Soares and Tome, 2002). Height–diameter models are then used to estimate the heights of trees measured only for diameter. The development of simple and accurate height–diameter models, based on easily obtainable tree and stand characteristics, is a common precursor to using inventory and sample plot data to calculate volume and other stand attributes. A number of height–diameter equations have been developed using only dbh as the predictor variable for estimating total height (e.g., Curtis, 1967; Wykoff *et al*., 1982; Larsen and Hann, 1987; Wang and Hann, 1988; Huang *et. al*., 1992; Moore *et. al*., 1996; Zhang, 1997; Peng, 1999; Fang and Bailey, 1998; Fekedulengn *et al*., 1999; Jayaraman and Zakrzewski, 2001; Robinson and Wykoff,

2004). However, the relationships between the diameter of a tree and its height varies among stands (Calama and Montero, 2004) and depends on the growing environment and stand conditions (Sharma and Zhang, 2004). Height-diameter models are principally applied in height estimations in forest inventories and as one of the main modules in management-oriented growth models. In forest inventories, height is usually measured only for a subsample of trees, while diameter is measured for all the sampled trees. The major reasons for measuring only a few trees for height being that it requires a major effort, especially for dense stands and trees that is irregular in shape. The usual solution to these problems is to describe tree height (H) as a function of diameter (D). The resulting equation may then be used to derive heights for trees for which diameter but not height measurements were taken.
The main objective of this study is to develop a height–diameter prediction model using stump diameter for *Terminalia ivorensis* grown in Sokponba Forest Reserve in Nigeria. . The best model to be developed will be useful in determining the height of tree already cut in which the diameter at breast height (dbh) is no longer available as a result of illegal logging activities and subsequently be able to determine the volume of tree removed.

## METHODOLOGY

This study was carried out in Sokponba forest reserve located in the moist tropical rainforest zone of Nigeria. It lies on latitude $6^0$04'N and longitude $5^0$ 32'E.Sokponba forest reserve was first constituted on the 13th of March 1912. It occupies an area of 502.5km$^2$. The forest reserve is situated in Orhionmwon Local Government Area of Edo State, Nigeria (Figure 1)




Source: ESRI Data and Maps 2002.

It has common boundary with Ethiope West Local Government Area of Delta State, Nigeria. Sokponba forest reserve is divided into two main areas by River Jamieson, Area BC 29 and BC 32/4. It is gridded into 176 compartments. Of these, 101 are located in BC 29 and 75 in BC 32/4 (Isikhuemen, 1998).Eighteen temporary sample plots, each of size 20m x 20m, (0.04ha in size) were randomly established in a 42-year old *Terminalia ivorensis* plantation of 10.12 hectare of even aged stand. In each plot, the outside bark stump diameter ($D_{st}$) of the tree was measured at 15cm above ground, (since a survey of past exploitation shows that no tree is cut below this point), merchantable height (Ht) (which is the point between ground level and point of the first surviving whorl of branch/fixed top diameter of 7cm) and total height (H) of 216 trees of *Terminalia ivorensis* (randomly selected) were all measured using the Spiegel relascope and measuring tape. An average of twelve trees was measured in each plot.

**Model specification**

Several regression models have been used for estimating tree heights based on tree diameter (D) as the independent variable. Sharma and Parton (2007) derived height- diameter equations for boreal tree species using mixed effect modelling approach but involved a large sample size. Usually height – diameter equations are constructed from few samples (Okojie, 1985). Several equations investigated were assessed and compared on the basis of their correlation coefficient, coefficient of determination, variance ratio, and overall standard error of estimate. The following regression equations were tried for this study:

$LogH = a + blogD$…………….. ...(1)

$H = a + blogD$……………..............(2)

$InH = a + b(1/D)^{1/2}$……………........(3)

$H = a + b_0D + b_1D^2$…………….. .(4)

$InH = a + bD$…………………........(5)

$InH = a + bD^2$……………….........(6)

$H = ae^{bD}$ …………………..............(7)

Where a, $b_0$, and $b_1$ are coefficients to be determined, H is tree height in metre and D is stump diameter in metre.

**RESULTS AND DISCUSSION**

A total of 216 trees were measured in the eighteen sample plots. The data were divided into two such that a set, which is two–third of the number of trees measured were used for estimation of the parameters of the equations while one- third of the total number trees were used for the validation of the selected equations. Table 1 shows summary of estimation data set, which exhibited close variation in their growth attribute. The correlation coefficients between the variables are presented in Table 2. The table shows a linear relationship between the variables as indicated by the significant level of correlation. The negatively correlated variables of heights and stump diameters indicates that an increase in one variable leads to decrease in the other variable and vice versa while the positively correlated variables have a directly proportion relationship. The seven regression equations tried were fitted with the data generated, which finally resulted in the equations below with their coefficient parameters and statistics:

$LogH = 1.2493 + 0.005LogD$ ………………………………………… (1a)

($R^2$ = 0.9908; Adj. $R^2$ = 0.9907; F = 0.0861817; SE = 0.028285)

$H = 17.842 + 0.2451LogD$ ……………………………………….. (2a)

($R^2$ = 0.8018 ; Adj. $R^2$ = 079969; F = 0.02243 ; SE = 0.02243 )

$InH = 2.8723 – 0.06(1/D)^{1/2}$ …………………………………..….. (3a)

($R^2$ = 0.5868; Adj.$R^2$ = 0.5824; F = 0.11547; SE = 0.063525)

$H = 18.379 – 0.3311D + 0.0613D^2$ …………………………………………… (4a)

($R^2$ = 0.4058 ; Adj.$R^2$ = 0.39302 ; F = 0.026432 ; SE = 1.159249)

$InH = 2.8892 + 0.009D$ ……………………………………..….. (5a)

($R^2$ =0.9982 ; Adj.$R^2$ = 0.99818 ; F = 0.008735 ; SE = 0.63561)

$InH = 2.8918 + 0.008D^2$ ………………………………..…….. (6a)

($R^2$ = 0.9897 ; Adj.$R^2$ = 0.98959 ; F = 0.02819 ; SE = 0.063554)

$H=18.048e^{0.004D}$ …………………………………….. (7a)

($R^2$ = 1 ; Adj.$R^2$ = 1 ; F = 0.003024 ; SE = 1.15337)

From the regression statistics of the seven equations, equation (1a) was adjudged the best based on, it has one of the best coefficients of determination ($R^2$), the highest F – ratio and the lowest standard error (SE). The final models selected and others found with best goodness of fit are equations (1a), (5a), (6a), and (7a). The estimated coefficients were similar and consistent in sign and magnitude with results reported previously for other species (Larsen and Hann, 1987). The trend in this study was also in concert with models formulation proposed by several findings on the relationship of height and diameter (Krumland and Wensel ,1988; Tome, 1989; Canadas, 2000; Calama and Montero, 2004; Dieguez-Aranda *et. al*., 2005).

**Table 1: Summary statistics of estimated parameters**

| Variables | Minimum | Maximum | Mean ± Std. Error |
|---|---|---|---|
| Height (m) | 15.30 | 20.85 | 17.95±0.117 |
| Stump diameter (m) | 1.32 | 1.79 | 1.53±0.009 |
| Square of stump Diameter ($m^2$) | 1.43 | 3.20 | 2.34±0.032 |
| In height (m) | 2.73 | 3.04 | 2.89±0.006 |
| Log stump diameter (m) | 0.28 | 0.58 | 0.42±0.007 |
| Square root of inverse of stump diameter($m^{-1}$) | 0.71 | 0.87 | 0.81±0.003 |
| Log height (m) | 1.19 | 1.32 | 1.25±0.003 |

**Table 2: Correlation Matrix for the Tree Growth Variables**

| Variables | Height | Stump diameter | Log stump diameter | Square of stump Diameter | Ln height | Square root of inverse of stump diameter | Log height |
|---|---|---|---|---|---|---|---|
| Height | 1.000 | -.006 | .016 | -.013 | .999* | -.037 | .857* |
| Stump diameter | -.006 | 1.000 | .897* | .943* | -.010 | -.766* | -.058 |
| Log stump diameter | .016 | .897* | 1.000 | .899* | .015 | -.659* | -.029 |
| Square of stump Diameter | -.013 | .943* | .899* | 1.000 | -.017 | -.720* | -.061 |
| Ln height | .999* | -.010 | .015 | -.017 | 1.000 | -.034 | .851* |
| Square root of inverse of stump diameter | -.037 | -.766* | -.659* | -.720* | -.034 | 1.000 | .067 |
| Log height | .857* | -.058 | -.029 | -.061 | .851* | .067 | 1.000 |

*. Correlation is significant at the 0.01 level (2-tailed).

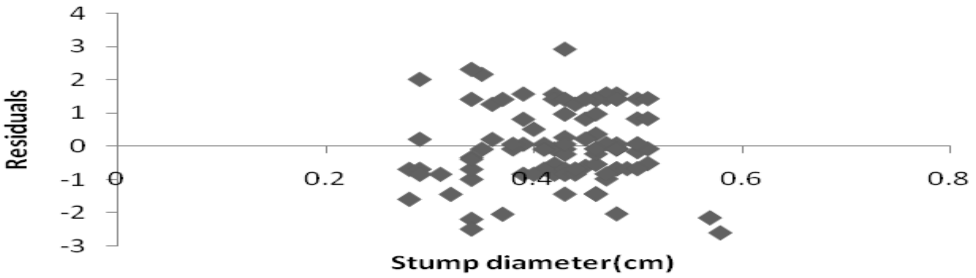



Fig.1: Residual Plot for equation 1a

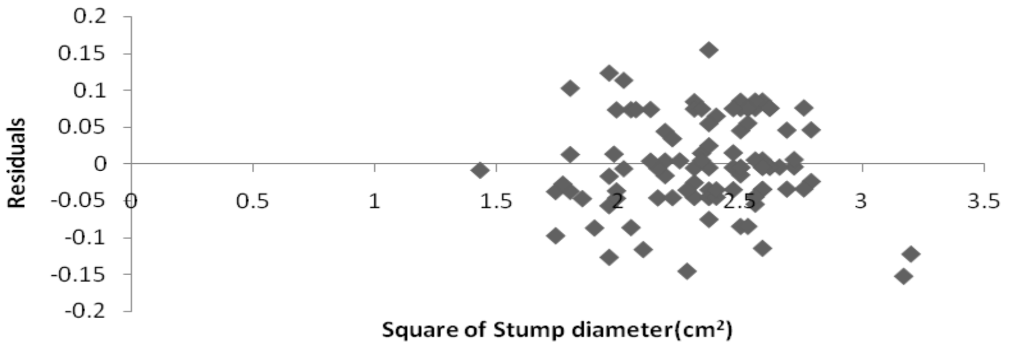



Fig.2: Residual Plot for equation 5a

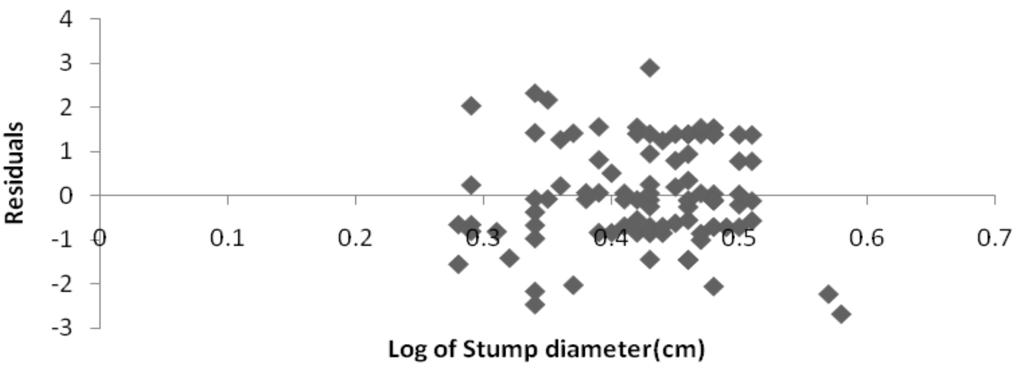



Fig.3: Residual Plot for equation 6a

A scatter diagram of the residuals of the selected models over the range of the independent variable is presented in Figure 1 to Figure 3. The figures revealed that the assumption of independence of residual is valid and there is no evidence of an outlier. The selected models were used to generate predicted volume for the validation data consisting of one – third of the observations. Validation of the equations was done by testing for significant difference between the predicted tree height and the actual tree height. Analysis of variance (ANOVA) and Duncan Multiple Range test showed that there was no significant difference ($p > 0.05$) between the predicted tree height and the observed tree height.

## CONCLUSION

The height – diameter model developed in this study gave reasonable and precise estimates of tree heights and the model is recommended for use for *Terminalia ivorensis* in similar ecological conditions. Where a tree has being removed, a forest manager can still calculate the height of tree removed for subsequent volume estimation,especially if the tree felled was illegal,thus, offenders can be appropriately charged by relevant authority. The models will be valuable in evaluating and preparing detailed management plans for stands of this species.

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