

## UNEXPLAINED RELATIONSHIPS OF HEIGHT-DIAMETER OF THREE TREE SPECIES IN A TROPICAL FOREST

T.O. DAUDA<sup>1,\*</sup>  
L.O. OJO<sup>2</sup>  
S.K. NOKOE<sup>1</sup>

<sup>1</sup>Department of Mathematical Science  
University of Agriculture, Abeokuta, Nigeria

<sup>2</sup>Department of Environmental Management and Toxicology  
University of Agriculture, Abeokuta, Nigeria

\*to whom all correspondence should be addressed:

Received: 5/3/2004  
Accepted: 23/8/2004

Fax: +234-2-231267  
e-mail: taofikdaud@yahoo.com

### ABSTRACT

Associations between bivariate variables relative to the unexplained relationships of height-Dbh (diameter at breast height) models were investigated. Seven permanent sample plots measuring 40m by 250m at Omo Forest Reserve were used to assess the relationships between height and diameter at breast height of three tree species as affected by the variables of neighbouring trees. The result showed differences in the coefficient of determination of the bivariate models and multivariate models. The models arrived at for each of the species and for the bivariate models are:

*Scottelia coriacea*:  $Ht = 2.59 + 0.473D + 0.0012D^2$  for  $5\text{cm} \leq D \leq 100\text{cm}$  ( $R^2 = 0.70$ )

*Sterculia rhinopetala*:  $Ht = 5.96 + 0.467D + 0.00296D^2$  for  $5\text{cm} \leq D \leq 100\text{cm}$  ( $R^2 = 0.77$ )

*Strombosia pustulata*:  $Ht = 2.02 + 0.722D + 0.00581D^2$  for  $5\text{cm} \leq D \leq 60\text{cm}$  ( $R^2 = 0.81$ )

Where both Ht and D are height and Diameter at breast height.

While on the other hand the multivariate models that considered the effect of neighbouring trees are:

*Scottelia coriacea*:  $Ht = 3.74 + 0.41x_1 - 1.14x_2 + 0.205x_3 + 1.278x_4$  ( $R^2 = 0.723$ )

*Sterculia rhinopetala*:  $Ht = 6.18 + 0.2601x_1 + 1.163x_2 + 0.438x_3 - 0.442x_4$  ( $R^2 = 0.608$ )

*Strombosia pustulata*:  $Ht = 6.84 + 0.399x_1 - 0.318x_2 - 0.138x_3 - 0.838x_4$  ( $R^2 = 0.650$ )

$x_1$  = diameter at breast height,  $x_2$  = Mean neighbouring tree distance,  $x_3$  = Frequency of the neighbouring tree and  $x_4$  = Position of the crown.

**KEYWORDS:** Unexplained relationship, Neighbouring tree, Diameter at breast height (Dbh).

### INTRODUCTION

Associations in bivariate modeling are usually investigated in forestry to boost the reliability of prediction to save cost, minimize task and time

spent in data collection. These data are of prime importance for varying forest management techniques. According to Okojie (1985) and Vanclay (1989 and 1995), these models are useful

in investigating different rules for logging selection, silvicultural treatment and others. Regression analysis is one of the tools usually employed to investigate the nature of the association between two or more variables via models (equations). The degree or extent of the association is determined using coefficient of determination  $R^2$ . The coefficient of determination  $R^2$  is useful in determining the total variability accounted for by the regression equation. The closer the value is to one "1" the stronger the relationships and vice versa between the variables. That is "1" implies perfect relationships between bivariate models (which is a rare case, Zar, 1984). Coefficient of determination  $R^2$  therefore arrived at, explained relationships leaving behind some relationships unexplained. These unexplained relationships are those from variables not considered in the modeling. In height- Dbh modeling of tree species in a tropical forest for instance, other factors like those relating to neighbouring trees are examples of unexplained relationships.

Similarly, two approaches to modeling have been stressed by Bruenig *et al.*, (1986) and are statistical and structural approaches. Statistical approaches established a relationship between observed output and known input of a system by their variables. Structural modeling approach, in addition, uses available structural knowledge about the system. However, the statistical modeling approach is described as often arbitrary and structurally invalid because it cannot reflect the possible structural changes in the system, (Bruenig *et al.*, 1986). Modeling unexplained relationship of height – diameter relationship can therefore meet these challenges of reducing errors in the prediction of height from diameter at breast height. Also, the pattern of growth of tree species according to Philip (1998) is affected by a number of factors among which is competition. It is therefore expedient to incorporate competition factors when modeling height-diameter relationship of tree species in a forest, which is the focus of this study. The objective of this study is thus to investigate the effects of neighbouring tree species parameter on the height-diameter models of some tree species in a natural forest. This will be done by modeling the relationships between height-diameter of some tree species based on the effects of neighbouring tree

parameters and find the intra-relationships of these variables within themselves.

## **MATERIALS AND METHOD**

### **The Study Area**

The study area (Figure 1) is located within Abeku sector of Omo Forest Reserves. It falls between  $6^{\circ}35'$  to  $7^{\circ} 05'$  N and  $4^{\circ} 19'$  to  $4^{\circ} 40'$  in the southwest of Nigeria (Okali and Ola Adams, 1987; Ola Adams *et al.*, 1998). Omo Forest Reserves, which covers 1167 km<sup>2</sup>, was established in 1916 but gazetted by order No 10 of 1925, (Weeks, 1996). The forest reserve, formerly part of Shasha forest reserve now shares boundaries with Shasha forest reserve, Oluwa forest reserve and Ondo state afforestation project. Topographically, the area is undulating and dominated by slopes which reaches between 15m and 150m above sea level, (Okali and Ola Adams, 1987). The area falls within the tropical wet and dry climate and is characterized by two (2) rainfall peaks with a less humid period usually in the month of August separating the two peaks, (Ola Adams *et al.*,1998). Mean Annual rainfall is about 1750mm and mean relative humidity is 80%, (Ola Adams, 1999). Again, the mean daily temperature is 26.4 °C and relative humidity is generally around 95% at dawn, usually the time of minimum temperature.

### **Vegetation of the Study Area**

The vegetation of the study area is mixed/moist semi evergreen rainforest. However, a dry green mixed deciduous forest in the northern part and a wet evergreen forest in the greater southern parts of the reserve were identified by Okali and Ola Adams (1987). More than 750 individual stems of 95 species were encountered during the sampling. These were mostly, *Strombosia pustulata*, *Terbanaemontana pachysiphon*, *Anthostema aubreyanum*, and *Diospyros iturensis*.

### **Data collection**

Data were collected from seven permanent sample plots of one hectare each established at the Abeku sector of Omo Forest Reserve by High Forest monitoring plots project (HFMP) of the Federal Department of Forestry. Each plot of one hectare was offset perpendicularly 50m from the reference baseline. The centreline of those plots was demarcated and marked into quadrats of 50m. Each quadrat is further subdivided in to 10

segments of 5m each. Tree height data comprising both merchantable and total height were collected at three levels.

- Small trees 50-200mm dbh within 2.5m either side of centerline.
- Medium trees 200-400mm dbh within 5m either side of centerline.
- Large trees > 400mm dbh in the entire plot.

Trees were recorded relative to their position on the quadrat in which they were found. This would enable locating the trees easily in subsequent re-measurement. Trees, which were 50mm dbh and above were enumerated appropriately for both total height and diameter at breast height.

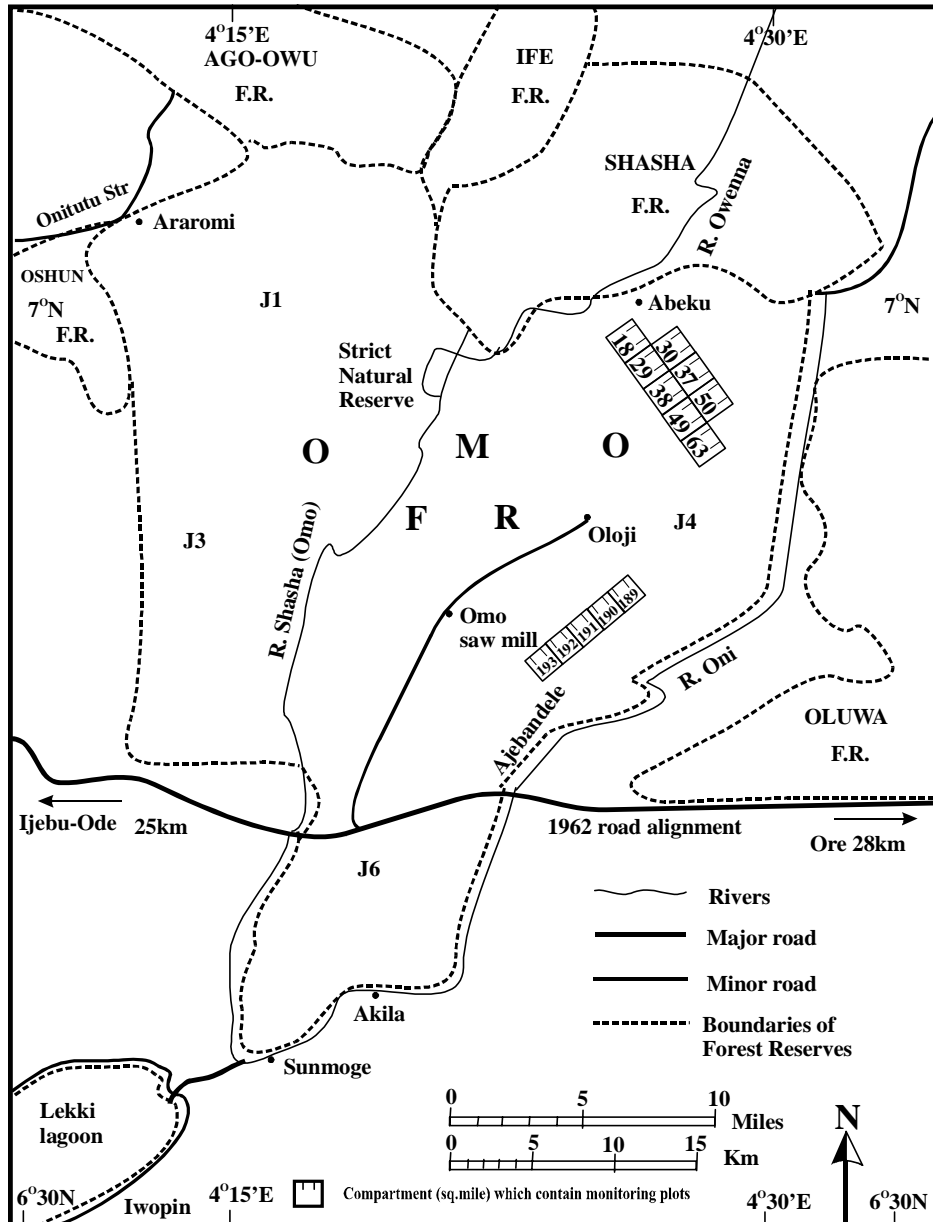


Figure 1. Map of Omo Forest Reserve showing the position of Abeku, the study site

### Data analysis

All the tree species found in the study area were first screened to the ten species used for the bivariate models based on their frequency and economic importance concerning wood production. These were *Strombosia pustulata*, *Terbanaemontana pachysiphon*, *Anthostema aubreyanum*, and *Diospyros iturensis*, *Octolobus spectabilis*, *Sterculia rhinopetala*, *Diopyros dendo*, *Diospyros suaveolense*, *Hunteria umbellate* and *Scottelia coriacea*. These ten species were further screened to the three species for the multivariate models. For the bivariate model (that is height-diameter model) both linear, non-linear and logarithm transformed model were employed to investigate the relationships.

The model that performs best for each of the species was chosen using F-test and based on the magnitude of coefficient of determination,  $R^2$ . This was used to screen the ten species to the three species used for the multivariate modeling. For the Multiple linear regression analysis, additional variables to the height and diameter at breast height were;

1. Neighbouring tree distance: This represents the mean distance of the trees within 2.5m radius to any of the three selected tree species, (Vanclay, 1995).
2. Crown position of neighbouring tree: This considers the crown position of the neighbouring tree relative to any of the selected tree species. If it is above reference tree, it is allotted a coefficient of one but if it is below it is zero.
3. Frequency of the neighbouring tree: This is the number of trees within 2.5m radius to the reference tree, regardless of the species.

The datasets collected from the experiment designed in a complete randomized design were subjected to the various analysis using MINITAB and STATISTICA

### RESULTS

The frequencies of the selected trees are 15, 22 and 50 for *Scottelia coriacea*, *Sterculia rhinopetala* and *Strombosia pustulata* respectively (Table 1). Table 2 shows some descriptive statistics (that is the minimum and maximum values) of the variables for each of the three species used in the models. Highest values of all the variables (DBH, Height, Mean distance, frequency and crown

nature of neighbouring trees) were recorded in *Sterculia rhinopetala*, while the lowest diameter at breast height (dbh) was also recorded in *Sterculia rhinopetala*, (Table 2). Correlation coefficient, which establish the relationship between the variables and Dbh and among all the other variables for each specie are presented in table 4-6. For *Scottelia coriacea*, highest relationships was observed between Dbh and height and which was significant at 1% significance level. This was followed by the relationship between Dbh and Mean neighbouring trees' distance, which is only significant at 5% significance level. The lowest and inverse relationships exist between Dbh and crown position. This relationship (that is Dbh and crown position) was not significant at 5% significance level, judging by the coefficient of determination,  $R^2$ , (Table 3 and 6).

Similarly, for *Sterculia rhinopetala*, highest relationships exist between Dbh and height, which was significant at 1% significance level using the coefficient of determination,  $R^2$ . Also, the relationship between the crown position and frequency of the neighbouring tree was significant at 1% significance level. Lowest and inverse relationship exists between crown position and Dbh and it was not significant at 5% significance level, (Table 4 and 6).

The relationships between height and Dbh of *Strombosia pustulata* was the highest and it was significant at 1% significance level. This was followed by that (the relationship) existing between the frequency and crown position of the neighbouring trees to the specie (*Strombosia pustulata*) The weakest relationship according to the value of coefficient of determination  $R^2$  exist between mean distances of neighbouring trees. This is also significant at 1% significance level. Least and inverse relationship exist between the crown position of the neighbouring tree and the height of *Strombosia pustulata*. These relationships as well as the other not stress are not significant at 5% significance level when judged by the coefficient of determination,  $R^2$  (Table5 and 6).

Two bivariate models chosen for these species are of the form:

$$Ht = a + b_1x + b_2x^2 \quad (1)$$

$$Ht = a + b + \log_e D \quad (2)$$

Where a = the intercept, Ht = height,  $b_1$  and

$b_2$ = regression coefficient and  $x = \text{Dbh}$ .

These bivariate models are:

$$\textit{Scottelia coriacea}: Ht = 2.59 + 0.473D + 0.0012D^2 \text{ for } 5\text{cm} \leq D \leq 100\text{cm} (R^2 = 0.70) \quad (3)$$

$$\textit{Sterculia rhinopetala}: Ht = 5.96 + 0.467D + 0.00296D^2 \text{ for } 5\text{cm} \leq D \leq 100\text{cm} (R^2 = 0.77) \quad (4)$$

$$\textit{Strombosia pustulata}: Ht = 2.02 + 0.722D + 0.00581D^2 \text{ for } 5\text{cm} \leq D \leq 60\text{cm} (R^2 = 0.81) \quad (5)$$

Table 1. The selected species used for the study and their utility according to Ward (1974)

Spp no	Species names	Total Freq.	Utility.
1	Strombosia pustulata	50	For heavy construction, (Group 2 Utility class)
2	Sterculia rhinopetala	22	Veneers and Furniture timber Species.
3	Scottelia coriacea.	15	For heavy construction, (Group 2 Utility class)
	Total	87	

Table 2. Minimum and maximum values of the variables used in the models.

Spp	DBH (cm)		HEIGHT (m)		MEAN NT. (m)		FREQ.OF NT.		CROWN POSITION	
	Min	Max	Min	Max	Min	Max	Min.	Max	Min	Max
Scottelia coriacea	8.0	52.8	3.5	25.0	0.3	1.7	0	6	0	3
Sterculia rhinopetala	6.8	58.3	7.5	26.0	0.4	3.2	1	9	0	4
Strombosia pustulata	7.0	43.3	4.0	25.0	0.2	2.2	0	6	0	3

DBH = Diameter at breast height

NT. = Neighbouring Tree

FREQ.= Frequency

Table 3. Correlation matrix between the variables for neighbouring tree analysis for *Scottelia coriacea* in Omo Forest Reserve, Nigeria

	DBH	Mean NTD	Freq of neighbouring tree.	Crown position	Height
DBH	1.000				
Mean NTD	0.531*	1.000			
Freq of neighbouring tree.	0.350	0.444	1.000		
Crown position	-0.277	0.350	0.405	1.000	
Height	0.829**	0.432	0.407	-0.049	1.000

$R_{15(0.05)} = 0.521$ ,  $R_{15(0.01)} = 0.654$

Crown P.= Crown Position, whether above or below the reference tree

DBH = Diameter at breast height

NT. = Neighbouring Tree

FREQ.= Frequency

Table 4. Correlation Matrix between the Variables for Neighboring tree Analysis for *Sterculia rhinopetala* in Omo Forest Reserve, Nigeria

	DBH	Mean NTD	Freq of neighboring tree.	Crown position	Height
DBH	1.000				
Mean NTD	-0.277	1.000			
Freq of neighbouring tree.	-0.048	-0.420	1.000		
Crown position	-0.354	-0.067	0.651**	1.000	
Height	0.770**	-0.129	-0.017	-0.281	1.000

$R_{22(0.05)} = 0.452$ ,  $R_{22(0.01)} = 0.544$ .

Crown P.= Crown Position, whether above or below the reference tree.

DBH = Diameter at breast height.

NT. = Neighbouring Tree.

FREQ.= Frequency.

Table 5. Correlation Matrix between the Variables for Neighboring tree Analysis for *Strombosia pustulata* in Omo Forest Reserve, Nigeria

	DBH	Mean NTD	Freq of neighbouring tree.	Crown position	Height
DBH	1.000				
Mean NTD	0.131	1.000			
Freq of neighbouring tree.	0.073	0.485**	1.000		
Crown position	-0.291	0.274	0.660**	1.000	
Height	0.782**	-0.005	-0.107	-0.407	1.000

$R_{50(0.05)} = 0.279$ ,  $R_{50(0.01)} = 0.363$

Crown p.= Crown Position, whether above or below the reference tree

DBH = Diameter at breast height

NT. = Neighbouring Tree

FREQ.= Frequency

Table 6. Summaries of bivariate and multivariate models for the three selected species.

S/n	Species	Models.	N	K	P		R <sup>2</sup>	F-test
					0.05	0.01		
1	Scottelia coriacea	Ht = 2.59 + 0.473D + 0.0012D <sup>2</sup> . for 5cm ≤ D ≤ 100cm. (Bivariate model)	15	2	0.62	0.732	0.70*	16.52**
2	Sterculia rhinopetala	Ht = 3.74 + 0.41x <sub>1</sub> - 1.14x <sub>2</sub> + 0.205x <sub>3</sub> + 1.278x <sub>4</sub> (Multivariate model).	15	4	0.763	0.840	0.723*	6.63**
		Ht = 5.96 + 0.467D + 0.00296D <sup>2</sup> . for 5cm ≤ D ≤ 100cm. (Bivariate model)	22	2	0.520	0.620	0.77**	31.52**
3	Strombosia pustulata	Ht = 6.18 + 0.261x <sub>1</sub> + 1.163x <sub>2</sub> + 0.438x <sub>3</sub> - 0.442x <sub>4</sub> (Multivariate model).	22	4	0.641	0.724	0.608	6.59**
		Ht = 2.02 + 0.722D + 0.00581D <sup>2</sup> . for 5cm ≤ D ≤ 60cm. (Bivariate model)	50	2	0.346	0.422	0.81**	170.3**
		Ht = 6.84 + 0.399x <sub>1</sub> - 0.318x <sub>2</sub> - 0.138x <sub>3</sub> - 0.838x <sub>4</sub> (Multivariate model).	50	4	0.432	0.501	0.650**	20.82**

NB: D and x<sub>1</sub> = diameter at breast height. X<sub>2</sub>= Mean neighbouring tree distance, x<sub>3</sub> = Frequency of the neighbouring tree and x<sub>4</sub> = Position of the crown.

These models, (except that for the *Scottelia coriaceae*) which are of the second order polynomials are all significant at 1% significance level using both coefficient of determination  $R^2$  and the F-statistics. The model for the *Scottelia coriaceae* is significant only at 5% probability level. However, the multivariate models, which

were computed through the structural modeling approach, are of the form:

$$Ht = a + b_1x_1 - b_2x_2 + b_3x_3 + b_4x_4 \quad (6)$$

Where  $a$  = the intercept,  $b_1$  to  $b_4$  = regression coefficient and  $x_1, x_2, x_3, x_4$  are respectively the various variables including the diameter at breast height. These models are:

$$\textit{Scottelia coriaceae}: \quad Ht = 3.74 + 0.41x_1 - 1.14x_2 + 0.205x_3 + 1.278x_4 (R^2 = 0.723) \quad (7)$$

$$\textit{Sterculia rhamnifolia}: \quad Ht = 6.18 + 0.261x_1 + 1.163x_2 + 0.438x_3 - 0.442x_4 (R^2 = 0.608) \quad (8)$$

$$\textit{Strombosia pustulata}: \quad Ht = 6.84 + 0.399x_1 - 0.318x_2 - 0.138x_3 - 0.838x_4 (R^2 = 0.650) \quad (9)$$

The models are all significant at 1% significance level using the F-test. The F values of 6.63, 6.59 and 20.82 were computed respectively for *Scottelia coriaceae*, *Sterculia rhamnifolia* and *Strombosia pustulata*. However, when the multiple coefficient of determination  $R^2$  is used the multi variate linear models for *Strombosia pustulata* only is significant at 1% level while those for *Scottelia coriaceae* and *Sterculia rhamnifolia* are not significant. The multi variate model for *Scottelia coriaceae* was not significant at 5% significance level. The absolute differences existing between the coefficient of determination  $R^2$  for the bivariate and multivariate models are 0.015, 0.10 and 0.094 for *Scottelia coriaceae*, *Sterculia rhamnifolia* and *Strombosia pustulata* respectively (Table 6). Although, these are due to differences in the number of variables involved (that is K) but the differences are of both positive and negative value.

## DISCUSSION AND CONCLUSION

Highest relationships existed between Dbh and height of the three selected species. This corroborates the validity of the height-Dbh models used to screen the ten species for the multivariable models. The relationship between the crown position and the mean distance of neighbouring tree is said to be positive for *Strombosia pustulata*. This may be due to the fact that the specie is to some degree exhibit some level of allelopathy (Vanclay, 1989). Thus, the farther the distance away from the tree, the more neighbouring trees that can be found. The same reason in addition to the effect of shade on understory can be adduced for the relationship between crown position and frequency of the neighboring tree of the

*Strombosia pustulata*. For the other species (*Scottelia coriaceae*, and *Sterculia rhamnifolia*), the reason can simply be hinged on the effects of shade on understory (Phillips,1998).

The bivariate model (equation *iii* to *v*) can predict height when information on diameter at breast height is available and within the stipulated range. However, when information on the neighbouring tree is available in addition to the diameter at breast height, the following multivariate models (equation *vii* to *ix*) can be used. The non-significance of the multivariate models for some of the species does not imply that the neighbouring tree parameters are not important. The significance or otherwise of the models can be linked with the number of the significant relationship of the variables and also the level of such significance. For instance, *Strombosia pustulata* whose multivariate models is significant at 1% significance level has three (3) of the four variables for the multivariate models are significant at 1% significance level (table 3-5). Similarly, it can be hinged on the frequency of the observation.

The absolute differences existing between the coefficients of determination,  $R^2$  of bivariate and multivariate model can imply the unexplained relationships. This is because the difference is of both negative and positive value.

It is recommended that non-linear multi-variate model should be employed to investigate the effects of neighbouring trees' variable of the model. Also, the scope of this study can be expanded to cover most other vegetation types within and outside the country.



**REFERENCES**

- Bruenig E.F., Bossel H., Elpel P., Grossmann W-D., Schneider T.W., WangZhu-hao and Yuzuoyue (1986), *Ecologic-Socioeconomic System Analysis and Simulation: A Guide for Application of system Analysis to the Conservation, Utilization and Development of Tropical and subtropical Land Resources in China*, CRCUDS, 388.
- Okali D.U. and Ola Adams B.A. (1987), Tree Population Changes in treated Rainforest at Omo Forest Reserve, South Western Nigeria, *Journal of Tropical Ecology*, **3**, 291-312.
- Okojie J.A. (1985), Height-Diameter Model for Taungya Plantation of *Nauclea dideriichi*, *Journal of Tropical Forest Resources*, 75-83.
- Ola Adams B.A., Ojo L.O. and Adetunji M.T. (1998), Accumulation of Soil Nutrients under different Forest Land uses, *Nigeria Journal of Forestry*, **28**, 5-14.
- Ola Adams B.A. (1999), Biodiversity Inventory Of Omo Biosphere Reserve, Nigeria - Country Report on Biosphere Reserves for Biodiversity Conservation and Sustainable Development, Abeokuta, Gbemi Sodipo Press, pp 351.
- Philip S.M. (1998), *Measuring Trees and Forest*, New York: University Press, 2<sup>nd</sup> edition, pp309.
- Vanclay J.K. (1989), A growth Model North Queensland Rainforest, *Forest Ecology and Management*, **27**, 245-271.
- Vanclay J. K. (1995), Growth Models for Tropical Forest: A synthesis of Models and Methods, *Forest Science*, **41**, 7-33.
- Ward D.W. (1974), Grouping of Nigerian Wood According to General Properties and End use performance, Federal Department of forestry, pp36.
- Weeks (1996), Omo Forest Reserve Enumeration Survey" In: *Biosphere Reserves for Biodiversity Conservation and Sustainable Development in Anglophone Africa: Assessment and Monitoring*, Ola Adams B.A and Ojo L.O. (eds), pp 45-49.
- Zar J.H. (1984), *Biostatistical Analysis*, New Jersey: Prentice- Hall Inc., 2<sup>nd</sup> editon, pp 718.