CLIMATE CHANGE AND FOREST RESOURCES MANAGEMENT: THE WAY FORWARD

Editors: J. C. Onyekwelu, V.A.J. Adekunle, D. O. Oke

Proceedings of the 2nd Biennial National Conference of the Forests and Forest Products Society
26th - 29th April, 2010

FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, NIGERIA

Comparison of Tree Volume Estimates Obtained by Different Methods for *Gmelina Arborea* in Omo Forest Reserve, Southwest Nigeria

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Abstract

Volume estimates obtained from four different methods of tree volume estimation were compared with a view to determining the most precise method. The major difference between the methods lies in the position where the diameter used in the volume estimation was obtained. The methods include the "Bolt method" which requires dividing the entire stem into "bolts" so that diameter measurements are made at both ends of each bolt. Other methods are the Huber's method which requires diameter measurement at the middle position along the stem, Smalian's method where diameter measurements are made at the base and top of the stem, and Newton's method which takes diameter at base, middle and top positions along the stem. Data for the study were collected from six different age series (13, 15, 19, 20, 24, and 25 years old) of Gmelina arborea plantations in Omo forest reserve, Nigeria. The determination of the volume of trees using the "Bolt method" requires tree felling so that the stem of each tree could be sectioned into bolts for detailed measurement. Due to the destructive nature of the procedure, only five trees per age series were selected. Prior to felling, the diameter of each tree at base, middle and top positions along the bole and the merchantable height were measured. Each sample tree was then felled and cross-cut into bolts whose length and diameter were measured for volume computation. The volume of the bolts that made up a bole and the stump volume were added to obtain the merchantable volume for the tree. For each felled tree, Huber, Smalian and Newton's formulae were also applied to the tree data obtained before felling in order to obtain volume estimates. One-way analysis of variance (ANOVA) was used to test for significant differences in tree volumes obtained by the four methods. The results indicate that there were significant differences in the volume obtained using the four methods. Bolt's method of tree volume estimation produced the most accurate tree volume in this study since it accommodates all irregularities along the stems of the trees.

Keywords: *Tree volume, Bolt'method, Gmelina arborea, diameter, height, volume estimation*

Introduction

Available statistics show that in 1995, the global plantation area without agricultural plantations of rubber oil palm or coconut was totaled 123.7 million ha, consisting about 3.5 % of the total forest (Brown ad ball, 2000) of which tropical and subtropical forest plantation accounted for nearly 45% (about 55 Million ha) (Pandey, 1997). A substantial proportion of this is made up of exotic species (Nair, 2003). According to Onyekwelu, (2001), eighteen (18) countries account for 87% of the world's plantation forests while in Nigeria, in 1996, a total of about 224,524.00 ha of plantations have been established in different parts of the country with about 79% of it concentrated in humid tropical rainforest of southwest Nigeria.

In the global world generally, some of the species planted as plantation are *Pinus spp. Gmelina arborea, Tectona grandis, Macrophyla spp and Eucalyptus spp* Pandey, (1997) among others. The first and the most dominant exotic plantation in Nigeria is *Gmelina arborea* (FDF, 1984;, Umeh, 1991; Akachukwu, 1997; Onyekwelu, 2001). *Gmelina arborea* is a fast growing tree species, usually raised in forest plantations to produce wood. It was primarily introduced into Nigeria for the production of pulp for paper industry. Over the years, foresters have adopted various methods of tree volume computation using Newton's, Smalian's and Huber's formulae. It is also believed that displacement method of tree volume estimation is most accurate since it will only displace water that is equals the precise volume of the tree. Displacement method nevertheless cannot accommodate a very large tree species especially in the natural forest thus, not making it practicable in the forest inventory of a large hectare of land. The "Bolt" method is considered to be close to water displacement method in terms of accuracy since the cross sectioning into bolts and aggregation of the volume of each bolt will take care of the taper and form of the tree. In this study, we compare volume estimates from each of the common analytical formulae (Huber, Smalian and Newton) with volume estimates obtained through the "Bolt" method. The aim is to see which of the volume estimates are closest to what were obtained with the "Bolt" method.

Methodology

The Study Area

This study was carried out in the *Gmelina arborea* plantation established at Omo forest reserve in Ogun State, Nigeria between latitude 6⁰ 352 and 7⁰ 052 N and longitude 4⁰ 40'E (Akindele, 1991 and Onyekwelu, 2001). The average elevation is 123 m above sea level, though it may reach 154 m in the northern parts due mainly to occasional link and rocky out crops and could be as low as 30 m along the valley of the main river (Onyekwelu, 2001) . The parent rock materials were formed from sedimentary rocks, mainly crystalline rocks of the undifferentiated basement complex of the pre-Cambrian series with outcrops of older granite in same place (Onyekwelu, 2001) while the soil comprises of well drained mature red stony and gravely soil in the upper part of the sequences. The texture of the sub-soil consists of clay with gravel at 30 – 60 cm depth (Onyekwelu *et al*, 2006) and the top soil at 0 – 30 cm depth consists of loan and silts clay loam. Since Omo forest reserve is in the tropical rain forest zone of Southwestern Nigeria, there are two distinct seasons namely, the rainy and the dry season. The rainy season spans from March through November while dry season is normally from December to February. Annual rainfall ranges from 1,250 mm to 2,200 mm while the mean annual temperature and average relative humidity are 26.5⁰C and 80%, respectively (Onyekwelu, 2001).

Data collection

Prior to stand enumeration, a reconnaissance survey to the plantation was carried out to assess the condition of the stand. Only fully stocked stands of the species, with no evidence of past cutting were selected for enumeration. Three temporary sample plots of 20 x 20 were selected from each age series because there were no permanent sample plots in the study area as was suggested by Omiyale and Joyce (1982) and Clutter *et al*, (1983), and done by Akindele (1989) and Adekunle and Alo (2005). The diameter at breast height of all trees in each sample plot was measured and the trees were grouped into five diameter classes (< 20 cm, 20 – 30 cm, 30 – 40 cm, 40 – 50 cm and > 50 cm). The determination of the volume of trees using the "Bolt method" requires tree felling so that the stem of each tree could be sectioned into bolts for detailed measurement. Due to the destructive nature of the procedure, only five trees per age series were selected (i.e. the mean tree in each dbh class). Prior to felling of each mean tree, the diameter of each tree at base, middle and top positions along the bole and the merchantable height were measured. Each mean tree was then felled and cross-cut into bolts whose length and diameter were measured for volume computation.

Data Analysis

The volume of the tree was calculated using Huber's, Smalian's and Newton's formulae. The formulae are as follows:

Newton's formula (Avery and Burkhart, 1994)

$$V = \frac{h}{6}(A_b + 4A_m + A_t) \quad \ldots\ldots\ldots\ldots \quad (1)$$

Smalian's formular (Clutter et al., 1983; Avery and Burkhart, 1994)

$$V = \frac{h}{2}(A_b + A_t) \quad \ldots\ldots\ldots\ldots \quad (2)$$

Huber's formula (Avery and Burkhart, 1994).

$$V = h\,A_m \quad \ldots\ldots\ldots\ldots \quad (3)$$

where	V	=	Volume of the tree (m^3)
	H	=	Total height of the tree (m)
	A_b	=	Cross sectional area of the tree at the base (m^2)
	A_m	=	Cross sectional area of the tree at the middle (m^2)
	A_t	=	Cross sectional area of the tree at the top (m^2)

Volume computation of the various bolts, the diameters were taken at various length along the stem and more diameter measurements were taken at areas where there were inflection points with length as small as 0.1 (m) long. The volume of these various bolts were summed together for individual tree. The formula for calculating the volume of each bolt was the formula for calculating the volume of a cylinder, which is expressed as follows:

$$V = Area \ x \ h$$

$$V = \pi r^2 h \text{ where } r = \left(\frac{d}{2}\right).$$

Thus, $V = \frac{\pi h \bar{d}^2}{4}$ .... (4)

Where $\bar{d} = \left(\frac{d_b + d_t}{2}\right)$ this is to accommodate the differences in the diameter at the base and at the top where the differences were more than 0.5 cm.

The volumes obtained with the different formulae were compared with volume obtained by summing up the volume of all the bolts of each felled tree using one-way Analysis of Variance technique in SPSS 13.0 for Windows.

Results and Discussion

Tree volume estimation

The summary of tree volume computed using different formulae is shown in table 1. The table shows the mean volume and standard error for each dbh class. The volume of *Gmelina arborea* increases with increase in dbh for all formulae used in this study. Generally, the highest volume for all the diameter class was obtained from Huber's formula, followed by Smalian's and Newton's while bolt's produced the least values. Standard error of estimate for a particular diameter class was the same for all the different formulae used and increased with increase in dbh (Table 1) also, standard error of the volumes increased with dbh, with Smalian's formula giving highest standard error values.

Table 1: The result of volume estimation obtained from different volume formulae.

Volume formulae	Dbh Class (cm)	Mean (m^3)	Standard Error
Huber's	10 – 20	0.217	0.138
	20 – 30	1.011	0.145
	30 – 40	2.253	0.145
	40 – 50	4.316	0.160
	50 – above	5.633	0.181
Smalian's	10 – 20	0.284	0.138
	20 – 30	1.126	0.145
	30 – 40	1.929	0.145
	40 – 50	4.183	0.160
	50 – above	5.422	0.181
Newton's	10 – 20	0.167	0.138
	20 – 30	0.704	0.145
	30 – 40	1.311	0.145
	40 – 50	2.435	0.160
	50 – above	3.347	0.181
Bolt's volume summation	10 – 20	0.155	0.138
	20 – 30	0.557	0.145
	30 – 40	1.094	0.145
	40 – 50	1.812	0.160
	50 – above	2.213	0.181

Comparison of volume estimates from the various volume formulae

Huber's formula gave the highest volume followed by Smalian's and Newton's formulae. The tree volume obtained by summing up the individual bolt was least. The result of the analysis of variance (ANOVA) presented in Table 2 indicate that there are significant differences in the common formulae used for tree volume estimation using data form *Gmelina arborea* Plantations in Omo forest reserve. There were also significant differences in the mean volume of the diameter classes. There were also significant differences in the mean volume of the diameter classes. The results of mean separation are presented in tables 3 and 4. The volumes of tree obtained by Huber's and Smalian's formulae were not significantly higher than those obtained from Newton formula and the summation of individual bolt volume (table 4). The volume obtained by using Newton's formula was significantly higher than that obtained from the summation of individual bolt volume.

Table 2: ANOVA table for comparison of volume from the various computation formulae.

Sources of Variation	df	Sum of Squares	Mean Squares	F	Sig.
Volume Formulae (VF)	3	80.813	26.938	117.229	0.000
Diameter	4	386.693	96.673	420.708	0.000
Diameter x VF	12	50.253	4.188	18.225	0.000
Error	180	41.362	0.230		
Total	199	540.004			

Table 3: Summary of the follow up analysis for the computed volume for dbh classes

Dbh Classes (cm)	Mean Volume (m^3)
50 and above	4.15^a
40 – 50	3.19^b
30 – 40	1.65^c
20 – 30	0.85^d
10 – 20	0.21^e

Means with different superscripts are significantly different ($p < 0.05$).

Table 4: Summary of the follow up analysis of volume of *Gmelina arborea* with respect to common formulae used for volume computation

Formulae	Mean Volume (m^3)
Huber's	2.689^a
Smalian's	2.589^a
Newton's	1.593^b
Bolt's	1.166^c

Means with the same superscript are not significantly different (p e" 0.05) while those with different superscripts are significantly different ($p< 0.05$).

The results of this study indicate that Huber's formula produced the highest volume (2.689 m^3), while the least volume computed was obtained by summing up the volume of bolts along the stem (1.166 m^3). The very high volume obtained from Huber's formula could be attributed to the single diameter value (dbh) used in its estimation, which tends to assume that the tree is cylindrical from the base to the top. This deficiency in Huber's formula has been buttressed by Avery and Burkhart, (1994). Though, Smalian's formula required the input of diameter measurements at both ends of the log (base and top), it produced volume that is not significantly different from that of Huber's formula (Table 4). However, Newton's formula produced a significantly lower volume than both Huber's and Smalian's probably because it incorporated diameter measurement at base, middle and top thus capturing the tapering nature of *Gmelina* tree. Consequently, bearing in mind that *Gmelina arborea* trees are not cylindrical (Onyekwelu, 2001), the volume computed using Newton's formula used in this study. This is similar to the conclusions of Avery and Burkhart (1994); Bi (2000); Yujia et al. (2002); Laura and Andrew (2004). However, a more accurate volume estimate for *Gmelina arborea* trees could be obtained through the use of bolt method of volume computation since it involved diameter measurement at various points along the length of trees, thus capturing diameter variation more accurately than the Newton's formula. The significantly lower volume estimate from bolts method in comparison to Newton's formula (Table 4) further suggests a more accurate volume is obtained from the former than the latter.

From the fore going, the most accurate method for computing volume of *Gmelina arborea* tree is the bolt's method since it takes irregularities along the stem of the tree into consideration. This was similar to the conclusions of Hakki, (1999), who compared centroid method and four standard formulae for estimating log volume.

Conclusion

The volume computed using bolt's method of tree volume estimation produced the most precise volume estimate for *Gmelina arborea* tree in the study area because it took into consideration the tapering tendency of the species as well as the irregularities in the tree (e.g butts, knots and branched points). In comparison to the volume that resulted from the bolt's method, all the conventional volume estimation formulae considered in this study led to over-estimation of tree volume. The Newton's formula gave the closest volume estimate to the volume obtained through the Bolt's method. Its volume estimates were significantly different from those obtained through Huber's and Smalian's formulae. The Newton's formula is therefore recommended as the most preferred for volume estaimation in the *Gmelina arborea* plantations. It is not as destructive as the "Bolt" method, and the requirement for diameter measurements at base, middle and top is sufficient enough to capture the stem taper and form in volume estimation.

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