LINEAR EQUATIONS FOR ESTIMATING THE MERCHANTABLE WOOD VOLUME OF *GMELINA ARBOREA* IN SOUTH-WEST NIGERIA

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AKINNIFESI, F. K. & AKINSANMI, F. A. 1995. Linear equations for estimating the merchantable wood volume of *Gmelina arborea* in Southwest Nigeria. Wood volume equations were developed for gmelina (*Gmelina arborea*) in Gambari forest of Nigeria using several functional forms, in order to establish the relationships between merchantable wood volume and estimator variables. Result from this study showed that quadratic model was the most efficient for estimating merchantable wood volume in the entire *Gmelina* plantation as follows: $V = 0.0206 + 0.00004D^2H$ ($r^2 = 0.975$). Efficiency of equations was markedly depressed when ratios of volume (V), breast height diameter (D) and/or merchantable height (H) were used as dependent variables. Breast height diameter was the best single estimator variable. Although precisions were lost when height measurement was omitted in wood volume equations, estimates based on diameter measurement as single estimator variable were also presented for quick evaluation of standing trees and wood removed by illegal forest takers.

Key words: *Gmelina arborea* - functional forms - precision - volume table

AKINNIFESI, F. K. & AKINSANMI, F. A. 1995. Persamaan-persamaan linear untuk isipadu kayu *Gmelina arborea* yang boleh dipasarkan di Barat Daya Nigeria. Persamaan isipadu kayu telah dihasilkan untuk (*Gmelina arborea*) di hutan Gambari, Nigeria dengan menggunakan beberapa bentuk berfungsi untuk menubuhkan hubungan di antara isipadu kayu yang boleh dipasarkan dan pembolehubah penganggar. Hasil dari kajian ini menunjukkan bahawa model kuadratik paling efisien untuk menganggar isipadu kayu yang boleh dipasarkan di keseluruhan ladang *Gmelina* seperti berikut: $V = 0.0206 + 0.00004D^2H$ (r^2=0.97). Keefisienan persamaan menurun dengan ketara apabila nisbah isipadu (V), diameter aras dada (D) dan/atau tinggi yang boleh dipasarkan(H) digunakan sebagai pembolehubah bersandar. Diameter aras dada merupakan pembolehubah penganggar tunggal yang terbaik. Walaupun ketepatan hilang apabila ukuran tinggi ditinggalkan dari persamaan-persamaan isipadu kayu, anggaran yang berdasarkan ukuran diameter sebagai pembolehubah penganggar tunggal juga digunakan untuk menilai dengan pantas dirian pokok dan pokok-pokok yang dibalak secara haram.

Introduction

For some decades back, Nigeria has been experiencing acute depletion of the forest belt. The realization of potential wood requirements has compelled a gradual conversion of the natural forest to plantations of mainly exotic species in recent years. Gmelina *(Gmelina arborea)* and teak *(Tectona grandis)* dominate about 85% of plantations of exotic species in Nigeria (FORMECU 1984) and the two species were established at the rate of about 20 000 ha y^{-1} (Akindele 1987). Preference for *Gmelina* was probably due to its distinct fast growth and uses for fuelwood, as well as industrial raw material for pulp and paper production.

The use of appropriate, reliable and up-to-date wood volume estimating techniques is not yet a practice in most tree plantations in Nigeria. Most volume tables are obsolete and subjective approaches are often used in their constructions. The need for good wood volume estimates has become imperative for efficient management of the growing stock, valuation, and extraction purposes.

As Grossembaugh (1968) noted, trees assume a variety of shapes than can always be described by linear relationships. Misspecification of appropriate functional forms could be very catastrophic in volume table construction. The use of least square technique in fitting volume models has continued to receive considerable attention in the tropics (Nokoe & Okojie 1976, Akindele 1987). The objective of this study was to develop appropriate wood volume prediction equations and volume table for *Gmelina arborea* up to 5 cm diameter merchantability limit in the Gambari forest reserve of Nigeria, using several functional forms.

Materials and methods

Study area

The Gambari forest reserve is located at 6° 50'N and 3° 50'E in Southwest Nigeria. It lies within the lowland rain forest belt and occupies a total land area of 12 090.4 ha. The general topography is undulating, with average altitude of about 120 m above sea level. Average rainfall is 1500 mm, with monthly maximum and minimum temperatures of 32 °C and 20.2 °C in January and June respectively. Relative humidity in the forest averages about 77.6% (Adeola 1983). The soil of the forest reserve is typical of ferruginous tropical soils and has been classified as Alfisol (Oxic Paleustalf), belonging to the Egbeda soil series (Smith & Montgomery 1962).

Sampling techniques

The Gambari forest reserve is made up of five zones: Mamu, Onigambari, Busogboro, Odo-Ona/Onipe and Olonde. Mamu and Onigambari were chosen for this study on the basis of their sizes, distribution and age of *Gmelina* plantations.

Four age series were selected for detailed study from Mamu (8 and 10 years old) and Onigambari (13 and 16 years old) plantation zones. Each age series is about 40 ha in area.

A sampling intensity of 1.2% was used in the work, as determined from pilot survey. This was within the range of minimum 1% used in most inventory works (Maimo 1987). Four quadrats of 25 × 25 m were randomly demarcated within each selected plantation series. A total of 75 sample trees were selected for detailed measurements in the following order: 14, 18, 18 and 25 trees were selected from the 16, 13, 10 and 8 y-old series respectively. Selection was based on within-stand variation in breast height diameter (D). Required number of sample plots (n) was estimated from the formula: $n = c.v.^2 \times t^2 \times E^{-2}$ (where t is the student-t value at desired error level (E). More variations in D were observed in younger plantations during the pilot survey.

Stump and breast height diameters over bark were taken respectively at 15 cm and 1.3 m above ground level. Merchantable height was taken up to a 5 cm top diameter using the spiegel relaskop. Four mean trees with basal area corresponding to average of all trees within each 25 × 25 m quadrat was selected for detailed measurements of their diameters at 0.1, 0.3, 0.5, 0.7 and 0.9 positions of the merchantable height. The form factor as well as tree volume were estimated using the Hohenadl's formula (Loetsch *et al.* 1973).

$$V = 0.2\,H.k.\,(d^2\,0.1 + d^2\,0.3 + d^2 0.5 + d^2\,0.7 + d^2\,0.9)$$

Where

V = merchantable volume (m^3)

H = merchantable height (m)

d = diameter (cm) at various positions of the merchantable height

k = $\pi/4$ and 0.2 are constants

Model construction and analysis

Homogeneity of data set from Mamu and Onigambari was tested by t-test and the result suggested that data could be pooled to obtain common regression models.

Simple and multiple regression models were constructed with the various functional forms including linear, hyperbolic, square root, quadratic, semi-log, and double-log functions. In addition to the primary variables of volume (V) and breast merchantable height, various ratios and or combinations of the inverse, quadratic or linear components of these variables were also tested in the regression analyses. Regression analysis was done using (statistical analysis system (SAS 1985). The size of cofficients of determination (r^2), coefficient of variation and furnival index (Furnival 1961) were used to select models.

Results and discussion

Multicollinearity and homogeneity tests

Table 1 shows the homogeneity between *Gmelina* growths at Onigambari and Mamu plantation zones. All the growth parameters measured were consistently higher at Mamu than the series at Onigambari. However, these differences between Mamu and Onigambari were only significant in stump diameter and crown depth at the 0.05 probability level. This suggests that data can be pooled based on D and merchantable height to develop merchantable volume equations.

Table 1. Homogeneity test between Onigambari and Mamu *Gmelina* plantation zones

Variable	Plantation zone		t-test
	Onigambari	Mamu	
D (m)	23.42	25.94	ns
Stump diameter (cm)	29.14	33.46	*
Merchantable height (m)	17.54	18.27	ns
Crown depth (m)	5.30	7.08	**
Merchantable wood volume (m^3)	0.48	0.55	ns

D - Diameter at breast height
* Significant at 0.05 probability level,
** Significant at 0.01 probability level,
ns No significant difference at 0.05 probability level.

Table 2 shows the collinearity test between merchantable volume and estimator variables. Highly significant correlation ($r= 0.93$; $p < 0.05$) was found between D and stump diameter, suggesting that inclusion of both variables in the same volume equation will result in multicollinearity. Crown depth gave significantly low correlations with D ($r = 0.19$), stump diameter ($r = 0.22$), and merchantable height ($r = - 0.14$). Inclusion of crown depth in merchantable wood volume equations would therefore be superfluous.

Merchantable wood volume equations

The tested tree volume equations for *Gmelina* and the corresponding regression statistics are shown in Table 3. For both single and double-variable models, the highest precisions were obtained in quadratic and lowest in inverse functions. Precisions of equations were in the following decreasing order of magnitude for single-variable models: quadratic > semi-log > double log > simple linear > square root > inverse functions, with r^2 ranging from 0.936 to 0.773. The best single-variable model is as follows:

$$V = 0.0345 + 0.0008 D^2 \quad (r^2=0.936; \text{equation no.2})$$

Table 2. Multicollinearity between *Gmelina* wood volume predictor variables in Gambari reserve

Variable	Correlation
D x STD	0.93**
D x MHT	0.67*
D x Crown depth	0.19ns
STD x MHT	0.63*
STD x Crown depth	0.22ns
Merchantable height x Crown depth	- 0.14ns

D - Diameter at breast height, STD - stump diameter, MHT - Merchantable height
** Strongly collinear at 0.05 probability level,
* Slightly collinear at 0.05 probability level,
ns Non-collinear at 0.05 probability level.

Table 3. Constructed merchantable wood volume equations for *Gmelina arborea*

No	Equation	r^2 (%)	C.V. (%)	Furnival index
1	$V = a + bD$	80.70	25.51	0.14
2	$V = a + bD^2$	93.57	16.94	0.09
3	$V = a + bD^{-1}$	72.51	34.97	0.16
4	$V = a + b/D^2$	77.29	36.02	0.17
5	$LnV = a + bD$	82.46	35.11	0.13
6	$V = a + bLnD$	83.30	24.62	0.12
7	$LnV = a + bLnD$	85.72	31.51	0.11
8	$LnV = a + b/LnD$	79.90	36.84	0.14
9	$V = a + bLnD$	86.83	25.21	0.10
10	$V = a + bD + cD^2$	93.62	16.99	0.09
11	$VD^2 = a + bD$	17.84	17.97	0.17
12	$V/D = a + b/D^2 + cD$	17.83	18.09	0.0001
13	$V = a + bD + cH$	88.15	23.02	0.10
14	$V = a + bD^{-1} + cH^{-1}$	70.81	19.24	0.16
15	$LnV = a + bD + cH$	91.40	23.91	0.09
16	$LnV = a + bLnD + cLnH$	90.89	24.56	0.09
17	$V = a + bLnD + cLnH$	88.84	22.50	0.10
18	$V = a + bD + cH$	85.23	27.92	0.11
19	$LnV = a + bD + cH$	84.63	31.60	0.12
20	$V = a + bLnD + cLnH$	78.46	34.29	0.15
21	$V = a + bD^2H$	97.51	10.55	0.05
22	$V = a + bD^2 + cH + dD^2H$	97.54	10.63	0.05
23	$V = a + bD^2 + cDH + dD^2H$	97.57	10.57	0.05
24	$V/D^2 = a + bD^2 + cH^{-1}$	17.83	18.09	0.0001
25	$V/D^2H = a + bD^{-2}H^{-1}$	3.55	14.25	0.00001
26	$V/D^2H = a + bD^{-2} + cD^2H + dH$	6.29	14.24	0.00001
27	$V/D^2 = a + bD^{-2} + cD^{-1}H + dH$	59.22	12.84	0.0001
28	$V/D^2H = a + bD^{-2}H^{-1} + cH^{-1} + dD^{-1}$	6.88	14.20	0.00001

V = Merchantable wood volume (m^3), D = breast height diameter (cm), H = merchantable height (m), a, b, and c are constants.

Similarly, precisions of double-variable models were in the following decreasing order of magnitude: quadratic > double-log > semi-log > multiple linear > square root > inverse functions with r^2 ranging from 0.976 to 0.708. The following model was selected as the overall most efficient merchantable volume equation within the range of trees measured in the plantation: $V=0.0206 + 0.00004D^2H$ ($r^2=0.975$, equation no. 21). Selection was based on regression statistics as well as ease of measurement of required estimator variables.

In general, the fits of equations were consistently improved by combining breast height diameter (D) and merchantable height compared to direct estimation of wood volume using only diameter measurements. This suggests that precision is lost when wood volume is estimated without height measurements.

Models developed by combining ratios of volume and diameter and/or height were least efficient with r^2 ranging from 0.036 to 0.592. However, furnival index (Furnival 1961) could not account for the large unexplained variation in such models.

Wood volume table

Tables 4 and 5 show the wood volume estimates based on the selected best single and double-variable models within range of trees measured in these plantations. Standing tree wood volume estimates ranged from 0.16 m^3 to 2.58 m^3 and 0.07 m^3 to 1.25 m^3 in double- and single-variable models respectively. Merchantable wood volumes of trees with stump diameter below 20 cm might be underestimated in these models due to the neiloidal shape of *Gmelina* stumps in the plantations.

Table 4. Merchantable tree volume (m^3)[a] of *Gmelina arborea* estimated from merchantable height (H) and breast height diameter (D)

	Merchantable height H (m)					
D (cm)	15	20	25	30	35	40
15	0.16	0.20	0.25	0.29	0.34	0.36
20	0.26	0.34	0.42	0.50	0.59	0.66
25	0.40	0.52	0.65	0.77	0.90	1.02
30	0.56	0.74	0.92	1.10	1.28	1.46
35	0.76	1.00	1.25	1.49	1.74	1.98
40	0.98	1.30	1.62	1.94	2.26	2.58

a, Estimated from $V = 0.0206 + 0.00004D^2H$ (r^2 =97.51, C.V. = 10.55).

Table 5. Merchantable tree volume (m^3) of *Gmelina arborea* estimated from stump diameter (S)[a] and breast height diameter (D)[b] as single estimator variables

Diameter (cm)	15	20	25	30	35	40
Stump diameter	-	0.16	0.27	0.41	0.57	0.76
D	0.15	0.29	0.53	0.69	0.95	1.25

a, $V = -0.0394 + 0.0005 S^2$ (r^2 = 86.12, C.V. = 24.89)
b, $V = -0.0345 + 0.0008D^2$ (r^2 = 93.57, C.V. = 16.94)

Conclusion

From this study it was demonstrated that curvilinear regression modelling could produce highly efficient equations for estimating merchantable wood volume of *Gmelina arborea* in plantations. The best equation developed in the Gambari forest was in quadratic form. Although breast height diameter (D) gave the most efficient single-variable model, precision was improved when stem diameter was combined with merchantable height suggesting that some precision is lost by omitting merchantable height measurement in wood volume estimations.

Prediction of wood volume from D or stump diameters could be useful when quick estimation of wood removed by illegal forest takers is necessary in forest inventory management.

The volume equations and volume estimates developed for *Gmelina arborea* in this study when carefully tested could be used for plantations with similar ecological conditions as the Gambari forest.

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