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ASSESSMENT OF THREE ALLOMETRIC REGRESSION TECHNIQUES OF BIOMASS DETERMINATION IN TWO HARDWOOD SPECIES

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OLA-ADAMS, B.A. 1997. Assessment of three allometric regression techniques of biomass determination in two hardwood species. Biomass estimations using three allometric regression equations with different independent variables were carried out in 18-y-old *Tectona grandis* and 13-y-old *Terminalia superba* plantations established at Gambari Forest Reserve, Southwestern Nigeria. Biomass estimation with D (diameter) as the only variable did not differ much from the model based on either the product of the square of the mean diameter and mean height of trees (D^2H) or the product of the mean basal area and mean height of trees (BAH). Considering the computational work and time involved in using D^2H or BAH, the use of D only would save cost and time in estimation of biomass of the two species.

Key words: Allometric regression - independent variables - biomass - *Tectona grandis* - *Terminalia superba*

OLA-ADAMS, B.A. 1997. Taksiran tiga teknik regresi alometrik untuk menentukan biojisim dua spesies kayu keras. Anggaran biojisim menggunakan tiga persamaan regresi alometrik dengan pemboleh ubah bebas yang berbeza dijalankan di ladang *Tectona grandis* berumur 18 tahun dan ladang *Terminalia superba* berumur 13 tahun yang ditubuhkan di Hutan Simpan Gambari, Nigeria Barat Daya. Anggaran biojisim menggunakan D (diameter) sebagai satu-satunya pemboleh ubah tidak banyak berbeza daripada model yang berasaskan sama ada produk kuasa dua purata diameter dan purata ketinggian pokok (D^2H) ataupun produk purata luas pangkal dan ketinggian pokok (BAH). Dengan mengambil kira kerja-kerja pengiraan serta masa yang terlibat apabila menggunakan D^2H atau BAH, penggunaan D sahaja dapat menjimatkan kos dan masa dalam penganggaran biojisim kedua-dua spesies.

Introduction

Methods of measuring dry matter production and productivity of forest ecosystems have been fully discussed (Ovington *et al.* 1967, Egunjobi 1969, Newbould 1970, Egunjobi & Bada 1976). These methods fall into two main groups - non-regression and regression techniques.

The regression analysis method involves selecting either randomly or systematically a number of trees. The weight of these whole trees or those of individuals components (dependent variables), and one or more tree dimensions (independent variables) are commonly used to develop mathematical relationships that can be used for predictive purposes. Typical equations usually relate the biomass of tree components to readily measured parameters, viz. diameter at breast height (DBH), height and basal area, etc. Using these equations, the biomass of individual trees and hence that of the tree stand can be estimated (Ovington *et al.* 1967).

Regression techniques are widely used for prediction in production ecological studies and often involve logarithmic transformation. As Sprugel (1983) pointed out, logarithmic transformations are used routinely in dimension analysis to fit allometric equations to sample data. This transformation simplifies calculations and increases the statistical validity of the analysis by homogenising the variance over the entire range of the sample data. Log transformation tends to equalise the variance over the entire range of y-values, which satisfies one of the prerequisites for proper use of parametric regression.

A comparison of various regression models in even-aged plantations showed that log-transformed allometric model produced the best fit in which the diameter at breast height was the independent variable (Crow 1971), or in which height was included in the independent variable (Egunjobi 1976) or the product of the mean basal area and mean total height (*BAH*) (Ola-Adams 1993), or the product of the mean basal area and the mean total height squared (BAH^2).

This paper assesses the predictive strength of (1) diameter at breast height, (2) the product of the square of the mean diameter and mean height of *n* trees, and (3) the product of the mean basal area and height individually as independent variables for biomass determination in *Tectona grandis* and *Terminalia superba.*

Methods

Detailed reports of the site, tree sampling, harvesting and treatment of the sampled trees have already been published (Ola-Adams 1990, 1993, Ola-Adams & Egunjobi 1992).

Ten trees, based on proportional representation of girth frequency classes, were felled for dry matter production estimation in each spacing regime and a total of 40 trees were harvested for each species. This procedure conforms with all tree summation techniques of Attwill and Ovington (1968). The bole was cut into 2 m logs to facilitate rapid weighing and six 5 cm discs were also cut from each log at the ground line, breast height, mid-stem between breast height and base of live crown and middle of the crown.

All roots from each tree above 5 mm in diameter were carefully collected by excavation and the soil brushed off. Big roots were cut into manageable portions. Fine roots were excluded because of the difficulty of disinterment.

Weight of individual boles were estimated by the discount method. For the discount method, a mean rate of decrease in fresh and dry weights from the ground level disc to both merchantable height (measured to the first major branch) and total height discs was calculated thus:

$$\text{Groundlevel disc wt.} \times \frac{1}{(1 \times r)} \times n$$

where

r = mean rate of weight decrease per 5 cm disc
n = ranges from 1 to number of 5 cm discs in the bole

This rate was then used as a discount factor to estimate the weight of successive 5 cm discs. The sum of the weights of the discs gave the total weight of the bole. All sub-samples were oven-dried at 105 °C to constant weight.

The dry weights of other tree components were estimated using the method of Honer (1971). The dry weight was determined using the general relationship:

$$\text{Dry wt} = a(c/b)$$

where a = the fresh weight of the component
b = the fresh weight of the sample
c = the dry weight of the sample

The total oven-dry weight of each tree for the eight spacings was estimated using three different mathematical forms of the allometric model: (a) $Y = aD^b$, (b) $Y = a(D^2H)^b$ and (c) $Y = a\,(BAH)^b$.

where Y = total by weight ha^{-1}
D = diameter (mean)
D^2H = product of D^2 and mean height H
BAH = product of mean basal area BA and mean height
a, b = constants

In order to estimate the total biomass of all trees in the plantations on an area basis, the values for individual trees were summed.

The nature of the bias produced by log transformations has been explained in detail by several authors (Beuchamp & Olson 1973, Mountford & Bunce 1973, Lee 1982) and the biomass estimates were then corrected for error resulting from logarithmic transformation.

Results and discussion

The parameters measured are shown in Tables 1 and 2. The trees varied in their dimensions both within and between spacings. The variations can be attributed to random variation in the environment, genetic differences and spacing.

While some of the distributions of the different population parameters were close to normal, others differed significantly. As White and Harper (1970) pointed out, frequency distributions of plant girths, heights and weights change from normal to log-normal as density stress developed in a population and such changes occur more rapidly as density increases.

Comparison of regression for total weights are shown in Tables 3 and 4 for *Tectona grandis* and *Terminalia superba* respectively. In calculating total biomass, the independent variables improved the total estimate in all cases.

Table 1. Population parameters for *Tectona grandis* planted at various spacings in Gambari Forest Reserve

Population parameters	Spacing			
	1.37× 1.37 m	1.98 × 1.98 m	2.90 × 2.90 m	3.96 × 3.96 m
Density per hectare	5102	2500	1189	638
Mean diameter at breast height (DBH)	17.79	19.32	23.53	26.66
Range	10 - 120	12.5 - 127.2	9 - 146.5	10.5 - 148.6
Std. deviation	19.44	20.12	23.93	25.61
Skewness	0.4448	0.3720	0.1782	10.5711
Kurtosis	- 0.1098	0.0730	0.4310	0.3224
Coefficient of variation	0.348	3.02	3.09	3.27
Mean merchantable ht(m)	9.31	9.09	8.36	7.59
Range	0-15	0-15	0 - 16	0 - 13
Std. deviation	2.60	3.03	3.04	2.83
Skewness	- 1.4209	- 0.958	- 0.7641	- 0.4724
Kurtosis	2.7017	0.9581	0.4011	- 0.3069
Coefficient of variation	3.58	3.00	2.75	2.68
Mean total ht (m)	13.41	13.40	13.36	13.76
Range	3 -17	4 -16	2.5 - 17.5	3 - 19.5
Std. deviation	2.93	2.90	2.29	3.05
Skewness	- 0.6973	- 0.7672	- 1.3219	- 1.4335
Kurtosis	0.5513	0.4882	2.2868	2.3512
Coefficient of variation	4.58	4.62	5.83	4.51

Table 2. Population parameters for *Terminalia superba* planted at various spacings in Gambari Forest Reserve

Population parameters	Spacing			
	1.80 × 1.80 m	2.80 × 2.80 m	4.20 × 4.20 m	6.10 × 6.10m
Density per hectare	3086	1271	567	268
Mean diameter at breast height (DBH)	11.35	14.49	18.71	20.64
Range	1.9 - 97.5	10 - 108.5	15.5 - 103.5	14-103.5
Std. deviation	18.19	18.51	19.44	21.83
Skewness	0.7320	0.4945	0.0269	- 0.4381
Kurtosis	- 0.0497	0.1936	0.6239	- 0.5277
Coefficient of variation	1.96	2.46	3.02	2.97
Mean merchantable ht (m)	6.36	9.16	8.56	7.89
Range	0 - 17	0 - 14	0 - 12	2 - 11
Std. deviation	4.65	1.99	2.11	2.06
Skewness	- 0.3261	- 0.8909	- 0.8701	- 0.2320
Kurtosis	- 1.3584	0.5671	0.1558	- 0.8166
Coefficient of variation	1.37	4.60	4.60	3.83
Mean total ht (m)	8.99	9.73	10.23	10.46
Range	1 - 32	1.5 - 16	2 - 15	3 - 15
Std. deviation	3.62	2.86	2.34	2.34
Skewness	- 0.1189	- 0.9548	- 1.1972	- 1.0987
Kurtosis	0.8417	0.4833	1.2703	1.1758
Coefficient of variation	2.48	3.40	4.37	4.47

Table 3. Comparison of regression equations for total weight (kg ha^{-1}) on DBH(*D*), D^2H and *BAH* for *Tectona grandis* planted at various spacings in Gambari Forest Reserve

Spacing	Y	Linearly transformed model	Coefficient of determination (R^2)	Standard Error of estimate (SEE)	Standing crop uncorrected for error	Standing crop corrected for error	Pecentage difference between corrected and uncorrected stand
1.37 x 1.37 m	Total biomass	log y = 4.2316 + 2.5556 log *D*	0.9892	0.0520	316 271	317 257 ± 171.03	0.31
		log y = 2.5521 + 0.9245 log D^2H	0.9895	0.0512	316 286	317 242 ± 168.39	0.30
		log y = 2.6491 + 0.9252 log *BAH*	0.9897	0.0506	316 261	317 195 ± 166.42	0.29
1.98 x 1.98 m	Total biomass	log y = 4.1042 + 2.2685 log *D*	0.9793	0.0698	293 139	294 788 ± 189.15	0.56
		log y = 2.5913 + 0.8250 log D^2H	0.9897	0.0618	293 061	294 353 ± 167.47	0.44
		log y = 2.6773 + 0.8247 log *BAH*	0.9833	0.0622	293 062	294 370 ± 168.55	0.44
2.90 x 2.90 m	Total biomass	log y = 4.1250 + 2.1995 log *D*	0.9440	0.0829	379 217	382 230 ± 127.69	0.79
		log y = 2.7248 + 0.8570 log D^2H	0.9321	0.0913	379 214	382 871 ± 140.85	0.96
		log y = 2.8080 + 0.8448 log *BAH*	0.9322	0.0912	379 215	382 864 ± 140.69	0.95
3.96 x 3.96 m	Total biomass	log y = 4.2164 + 2.4547 log *D*	0.9485	0.1053	222 711	225 573 ± 97.90	1.27
		log y = 2.6649 + 0.8819 log D^2H	0.9710	0.0791	222 714	224 324 ± 73.54	0.72
		log y = 2.7574 + 0.8818 log *BAH*	0.9710	0.0797	222 713	224 323 ± 73.54	0.72

Table 4. Comparison of regression equations for total weight (kg ha^{-1}) on DBH(D), D^2H and BAH for *Terminalia superba* planted at various spacings in Gambari Forest Reserve

Spacing	Y	Linearly transformed model	Coefficient of determination (R^2)	Standard Error of estimate (SEE)	Standing crop uncorrected for error	Standing crop corrected for error	Pecentage difference between corrected and uncorrected stand
1.80 x 1.80 m	Total biomass	log y = 4.0844 + 2.3472 log D	0.9863	0.0483	140 090	140 777 ± 158.87	0.27
		log y = 2.5331 + 0.8971 log D^2H	0.9878	0.0456	140 400	140 757 ± 149.98	0.30
		log y = 2.6412 + 0.8855 log BAH	0.9898	0.0475	140 398	140 763 ± 156.23	0.26
2.80 x 2.80 m	Total biomass	log y = 3.9748 + 2.1647 log D	0.9600	0.0880	126 198	127 328 ± 165.02	0.59
		log y = 2.5886 + 0.0853 log D^2H	0.9739	0.0711	126 199	126 933 ± 133.33	0.58
		log y = 2.6769 + 0.8520 log BAH	0.9749	0.0897	126 198	126 906 ± 130.70	0.56
4.20 x 4.20 m	Total biomass	log y = 3.8396 + 2.0046 log D	0.9786	0.0512	90 491	90 765 ± 41.92	0.40
		log y = 2.5499 + 0.7454 log D^2H	0.9747	0.0516	90 492	90 821 ± 45.94	0.32
		log y = 2.6266 + 0.7532 log BAH	0.9752	0.0550	90 491	90 807 ± 49.04	0.33
6.10 x 6.10 m	Total biomass	log y = 4.1749 + 2.3952 log D	0.9612	0.0836	85 136	86 150 ± 36.31	0.40
		log y = 2.6798 + 0.8487 log D^2	0.9845	0.0529	85 467	85 743 ± 22.97	0.30
		log y = 2.7688 + 0.8590 log BAH	0.9859	0.0539	85 468	85 754 ± 23.41	0.33

Biomass estimation model with *D* (diameter) as the only variable did not differ significantly from the models with D^2H or *BAH* (product of mean basal area and mean height). The models involving D^2H and *BAH* were identical. Considering the computational work and time involved in using D^2H or *BAH*, the use of *D* only would give a good estimate of biomass and would save cost and time in estimation of biomass of the two species. Egunjobi (1976) made a similar observation in estimating biomass of an even-aged plantation of *Pinus caribaea*. Kasile (1986) also observed that diameter at 0.5 m above ground was the easiest to use as independent variable for biomass determination of some sub-tropical dry forest species. However, for predicting the weight of trees in stands consisting of mixed-species small diameter trees, Kasile (1986) suggested the use of the product of basal area at knee height (0.5 m) and total height because it showed the highest correlation to stem biomass and provided accurate biomass estimates of tree species commonly used for firewood and charcoal production in the native dry forests of Mao in the Dominican Republic. As Madgwick (1971) also pointed out, the use of D^2H rather than D as the independent variable had little effect either on the accuracy or precision of the estimates of dry matter in *Pinus virginiana* stand.

The biomass values for the three models were quite close. In the absence of direct measurements to compare with, it is difficult to indicate which of the models gave the best fit. The ultimate, however, will be to use D for the simple reasons of ease and reliability in computation.

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