Aboveground Biomass Equations for 7-year-old *Acacia mangium* Willd in Botucatu, Brazil

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Abstract.—The biomass of stems, leaves, and branches was determined for 152 sample trees of *Acacia mangium* Willd were in a 7-year-old experimental plantation in Botucatu, Sao Paulo State, Brazil. After felling, dimensional measurements were taken from each tree. Cross sections were collected in 125 sample trees at ground level (0 percent), 25 percent, 50 percent, 75 percent and at the merchantable diameter top of 4 cm outside bark (100 percent). They were processed in the laboratory to establish the wood basic density and the bark density by maximum moisture method. Another 27 trees were separated into the crown components of branches and leaves, which were weighed green. Samples were collected to determine the dry mass/green mass ratios for branches and leaves. With the obtained data, seven linear regression models, based on diameter at breast height outside bark (d_i) and tree total height (h_i), were tested for the following dependent variables: total-stem wood dry weight outside bark ($tswob_i$); total leaves dry weight (tlw_i); total branches dry weight (tbw_i); total crown dry weight (tcw_i). The selected tree weight equations, based on residue distributions and values of coefficient of determination (r^2) and coefficient of variation (CV), were the following:

$$tswob_i = -44897 + 21327d_i - 1973.229246d_i^2 - 704.590913d_ih_i + 107.485531d_i^2h_i$$
$$(r^2=0.9326,\ CV=16.60\%)$$

$$\log_e tlw_i = -2.036212 + 1.732941\log_e d_i + 1.903792\log_e h_i$$
$$(r^2=0.7584,\ CV=8.29\%)$$

$$tbw_i = 8397.141385 - 4064.638803d_i + 484.543145d_i^2 + 142.956321d_ih_i - 20.611713d_i^2h_i$$
$$(r^2=0.8338,\ CV=24.20\%)$$

$$\log_e tcw_i = 6.119424 + 2.242600\log_e d_i - 0.857497\log_e h_i$$
$$(r^2=0.8323,\ CV=3.07\%)$$

where weight is given in g, diameter in cm, and height in m.

Planted only in experimental plantations in Brazil, the forest leguminous *Acacia mangium* Willd shows rusticity and fast growth in tropical countries (Nitrogen Fixing Tree Association 1987).

Although there are only a few national papers about *A. mangium*, studies in different knowledge areas about the species are beginning to be published. Among them, Silva *et al.* (1996) compared 18 provenances; Daniel *et al.* (1997) analyzed the phosphorus effect in seedlings; Carvalho *et al.* (1997) determined equations for estimates of wood weight inside bark; and Veiga *et al.* (1998) selected volume equations for *A. mangium* and for *Eucalyptus grandis.*

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International scientific literature sums up some publications about the quantification of acacia biomass according to total dry weight: Lim (1985, 1986, 1988), Lim and Mohd-Basri (1985), Schubert and Whitesell (1985), Dudley and Fownes (1992), Bernhard-Reversat *et al.* (1993), Latif and Habib (1994), and Tanouchi *et al.* (1994). However, in some of these cases, the results came from small samples.

Schubert and Whitesell (1985) analyzed 28 species between 2 and 5 years old, verifying the good growth of *A. mangium* and its tendency to show multiple stems.

Lim (1985) selected samples from only six 3.5-year-old trees. He found a pattern of 64.1 kg total dry weight with a high correlation between the stem and the crown weight and the circumference at the breast height.

Lim and Mohd-Basri (1985) determined the biomass over the ground of a group of 3.5-year-old *A. mangium*, reaching the medium value of 54.4 t/ha.

Lim (1996), in a fertilization test, found an annual pattern of 18.2 t/ha for an 11-tree sample, and in analyzing 4-year-old trees (Lim 1988) found 80.4 t/ha of total biomass over the ground.

Bernhard-Reversat *et al.* (1993) found a good correlation between dbh and the 7-year-old species total dry weight. Total biomass over the ground was between 120 and 130 t/ha, which is similar to the eucalyptus plantations in the same kind of soil.

Dudley and Fownes (1992) selected equations for 2-year-old trees. The weight estimation over the ground was determined according to only the dbh variable, because the height variable does not contribute significantly to the regression.

Latif and Habib (1994) selected weight equations, wishing to estimate the green weight of all the tree and the branches, stem, and leaves weights, and presenting conversion factors for total dry weight.

Tanouchi *et al.* (1994) determined the biomass of the 5-year-old trees, finding 147 t/ha.

In Brazil, there are a few studies about the subject. Among them are the work of Carvalho *et al.* (1997) about stem wood inside bark, and the research of Veiga *et al.* (1998) about volume equations.

Because of the lack of national studies, the studies that help to characterize *A. mangium* biomass total weight are very important. Thus, the importance of the present paper, about the selection of linear regression equations to estimate *A. mangium* total stem, leaves, and branches biomass weight, according to dbh outside bark and total height.

MATERIAL AND METHODS

A total of 152 sample trees were selected in a 7-year-old experimental plantation established in Botucatu, São Paulo State, with a 3- x 2-m original spacing.

Cross sections were collected in 125 sample trees at ground level (0 percent), 25 percent, 50 percent, 75 percent and at the merchantable diameter top of 4 cm outside bark (100 percent).

For each of the sample trees, the basic density of the wood was determined, based on correspondent values of total dry weight and the saturated volume, determined in a hydrostatic balance. The bark density was also calculated. From the field and laboratory data for each sample tree, the stem wood weight outside bark was calculated.

Another 27 trees were separated into the crown components of branches and leaves, which were weighed green. Samples were collected to determine dry mass/green mass ratios for branches and leaves.

For the selection of weight equations, the following dependent variables were studied: total-stem wood dry weight outside bark ($tswob_i$); total leaves dry weight (tlw_i); total branches dry weight (tbw_i); and total crown dry weight (tcw_i). The last one considers the sum of branches and leaves weights.

With obtained data, seven linear regression models, as showen in table 1, were used to estimate stem wood dry weight and crown components dry weight, as a function of tree diameter at breast height outside bark (d_i) and tree total height (h_i). The models were chosen among those used by Veiga (1984, 1992) and Timoni *et al.* (1997).

Table 1.—*Linear regression models tested for the estimate of tree biomass dry weight (y_i) as a function of the tree dbh outside bark (d_i) and the tree total height (h_i)*

Model	Equation
1	$y_i = b_0 + b_1 d_i^2 h_i$
2	$y_i = b_0 + b_1 d_i^2 + b_2 h_i + b_3 d_i^2 h_i$
3	$y_i = b_0 + b_1 d_i + b_2 d_i^2 + b_3 d_i h_i + b_4 d_i^2 h_i$
4	$y_i = b_0 + b_1 d_i^2 + b_2 d_i^2 h_i + b_3 d_i h_i^2 + b_4 h_i^2$
5	$\log_e y_i = b_0 + b_1 \log_e (d_i^2 h_i)$
6	$\log_e y_i = b_0 + b_1 \log_e d_i + b_2 \log_e h_i$
7	$\log_e y_i = b_0 + b_1 \log_e (d_i h_i^2)$

RESULTS AND DISCUSSION

The analysis of variance results corresponding to weight equations, i.e., linear regression models for estimates of total stem wood dry weight, total leaves dry weight and total crown dry weight, can be found in tables 2 and 3.

The estimated coefficients for the correspondent variables are in table 2. The values of coefficient of variation (CV) and coefficient of determinations (r^2) are in table 3. These results and observations about residue distributions were used to select the best model for each case.

The selected equations were the ones corresponding to Meyer's model, modified (equation 3), for the estimates of total stem wood dry weight outside bark, total leaves dry

Table 2.—*Parameter estimatives of linear regresssion models tested to determine the 7-year-old* A. mangium *biomass over the ground level in terms of total stem wood dry weight outside bark (tswob$_i$), total leaves dry weight (tlw$_i$), total branches dry weight (tbw$_i$), and total crown dry weight (tcw$_i$)*

Model	b_i	$tswob_i$	tlw_i	tbw_i	tcw_i
1	b_0	3435.408873	-193.501403	1423.520486	1230.019083
	b_1	15.046066	1.090259	3.248577	4.338835
2	b_0	13004	1139,724708	-277,115670	862,609038
	b_1	-63.013955	-39.020618	172.052003	133.031385
	b_2	-991.749450	-79.157732	-42.149921	-121.307653
	b_3	23.514248	3.488052	-6.300197	-2.812145
3	b_0	-44897	1698.027993	8397.141385	10095
	b_1	21327	-358.203968	-4064.638803	-4422.842771
	b_2	-1973.229246	-9.743085	484.543145	474.800060
	b_3	-704.590913	-1.026198	142.956321	141.930123
	b_4	107.485531	2.824350	-20.611713	-17.737363
4	b_0	12058	455.301419	-750.123922	-294.827503
	b_1	-310.823595	-74.156462	163.671762	89.515301
	b_2	23.458598	8.068715	-5.040747	3.027968
	b_3	15.268779	-2.992780	-0.979585	-3.972365
	b_4	-108.668268	12.274995	4.336672	16.611667
5	b_0	3.243866	-1.015015	4.321430	4.171388
	b_1	0.946525	1.113090	0.603098	0.650848
6	b_0	4.204248	-2.036212	6.487374	6.119424
	b_1	2.543616	1.732941	2.252351	2.242600
	b_2	0.069457	1.903792	-1.073971	-0.857497
7	b_0	3.753327	-1.907177	3.975191	3.778095
	b_1	0.807648	0.900005	0.473289	0.512817

Table 3.—*Results of coefficient of determination (r^2) and coefficient of variation (CV) for the models tested to estimate the 7-year-old* A. mangium *biomass over the ground level in terms of total stem wood dry weight outside bark (tswob$_i$), total leaves dry weight (tlw$_i$), total branches dry weight (tbw$_i$), and total crown dry weight (tcw$_i$)*

Model	$tswob_i$		tlw_i		tbw_i		tcw_i	
	r^2	CV%	r^2	CV%	r^2	CV%	r^2	CV%
1	.7324	32.68	.6499	54.11	.7448	28.13	.7908	27.09
2	.8967	20.47	.6753	54.32	.8216	24.52	.8239	25.92
3	.9326	16.60	.6817	54.99	.8338	24.20	.8332	25.78
4	.9305	16.87	.6859	54.64	.8215	25.08	.8247	26.43
5	.8276	3.00	.7531	8.21	.7221	3.80	.7750	3.48
6	.8994	2.30	.7584	8.29	.7990	3.29	.8323	3.07
7	.5673	4.76	.7583	8.12	.6848	4.04	.7409	3.74

weight, and total branches dry weight; and Shumacher-Hall's model (equation 6) for the total leaves dry weight and the total crown dry weight.

The weight equations selected in the conditions of the present study for biomass estimates of the 7-year-old *A. mangium* were the following:

$$tswob_i = -44897+21327d_i-1973.229246d_i^2-704.590913d_ih_i+107.485531d_i^2h_i$$
$$(r^2=0.9326,\ CV=16.60\%)$$

$$\log_e tlw_i=-2.036212+1.732941\log_e d_i+1.903792\log_e h_i$$
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$$tbw_i=8397.141385-4064.638803d_i+484.543145d_i^2+142.956321d_ih_i-20.611713d_i^2h_i$$
$$(r^2=0.8338,\ CV=24.20\%)$$

$$\log_e tcw_i=6.119424+2.242600\log_e d_i-0.857497\log_e h_i$$
$$(r^2=0.8323,\ CV=3.07\%)$$

where the weight is given in g, diameter in cm, and height in m.

This results complement others found by the authors for the same species and age, corresponding to volume equations (Veiga *et al.* 1998) and total and merchantable stem wood weight inside bark equations (Carvalho *et al.* 1997).

CONCLUSION

The correspondent model to the Meyer's equation, modified,

$$y_i=b_0+b_1d_i+b_2d_i^2+b_3d_ih_i+b_4d_i^2h_i$$

was selected to estimate total stem wood dry weight outside bark and the total branches dry weight.

The correspondent model to the Schumacher-Hall's equation logarithmic combined variable

$$\log_e y_i=b_0+b_1\log_e d_i+b_2\log_e h_i$$

was selected to estimate total leaves dry weight and total crown dry weight.

ACKNOWLEDGMENTS

To FAPESP (Fundacao de Amparo a Pesquisa do Estado de Sao Paulo) and CNPq (Conselho Nacional de Desenvolvimento Cientifico e Tecnologico).

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