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PRIMARY PRODUCTION OF PLOTS OF FIVE YOUNG CLOSE-SPACED FAST-GROWING TREE SPECIES, I. BIOMASS EQUATIONS

*Sarayudh Bunyavejchewin** and *Somboon Kiratiprayoon**

ABSTRACT

Biomass equations for the above-ground component of individual *Eucalyptus camaldulensis* Dehnh., *Leucaena leucocephala* de Wit, *Cassia siamea* Britt., *Azadirachta indica* Juss. var. *siamensis* Valeton and *Acacia auriculaeformis* Cunn. aged 1½, 3 and 5 years were developed for species trial plots in Ratchaburi Province. The mass of stems, of branches and of foliage are given as functions of d and d^2h. Pooled regression equations for the components of each species were then developed.

INTRODUCTION

Biomass is used in studies of productivity, nutrient removal and distribution in plantations and forests. Since measurement of biomass of all trees in a given area is impracticable, regression analysis of the relationships between biomass and easily-measured parameters is used; this is called "dimension analysis" (WHITTAKER & WOODWELL, 1971). Many biomss equations for tree species have been published (PETMAK & SAHUNALU, 1978; SAHUNALU *et al.*, 1981a, b; PETMAK, 1983; BUNYAVEJCHEWIN, 1984; BUNYAVEJCHEWIN & PURIYAKORN, 1985; CHAKRAPHOLWARARIT, 1985, and KIETVUTTINON, 1985) but all of them are presented for a given age. In this paper, we assess the biomass equations for *Eucalyptus camaldulensis* Dehnh., *Leucaena leucocephala* de Wit, *Cassia siamea* Britt., *Azadirachta indica* Juss. var. *siamensis* Valeton and *Acacia auriculaeformis* Cunn., age 1½, 3 and 5 years. The data of each species are then combined and biomass equations are presented for above-ground dry matter of each species for young stands (1 – 5 years old).

SITE

The site is located on the east side of Highway No. 3087, 10 km north-west of Ratchaburi town (latitude 13° 35′ N, longitude 99° 40′ E). Mean annual rainfall is 1,046 mm, whilst the mean maximum and minimum temperatures are 35.1°C and 23.2°C, respectively (climatic average from 1980 to 1986).

The experimental area consists of 12 blocks. Each block consists of five

* Forest Ecology Section, Silvicultural Research Sub-division Division of Silviculture, Royal Forest Department, Bangkhen, Bangkok 10900.

8×30-m plots, 4 m apart, with each plot planted with one of the 5 species of *E. camaldulensis, L. leucocephala, C. siamea, A. indica* var. *siamensis* and *A. auriculaeformis*. Spacing was 2 m between trees and 1 m between rows. The soil of the experimental site is reddish brown lateritic soil with a high percentage of gravel (>50%). Since some part of the experimental area is waterlogged, the area was stratified into typical soil and waterlogged area.

METHODS

Three plots of each species were randomly laid out in the typical soil. In December 1982, 1983 and in July 1984-1986 the diameter at breast height (*d*) of each tree was measured, excluding the two outer-most trees in each row. Nine to 16 trees of each species were felled in December 1982, June 1984 and 1986 (aged 1½, 3 and 5 years) (Table 1). The sample trees covered the *d* range presented. The felled trees were divided into stems (wood+bark), live branches and foliage. After the components were weighed, green samples were taken to dry at 105°C for 24 hours to obtain moisture content. From this, the dry weight of stems, live branches and foliage of individual trees was estimated.

Regression analysis was used to estimate oven-dry mass of separate tree components of each species at each age (1½, 3 and 5 years old). The equation used was the transformed allometric model: $\log y = a + b \log x$, where y = stem, live branch or foliage weight (kg) and $x = d$ (cm) or d^2h (cm^{2}m).

Pooled regression equations for each component of each species were then calculated. The effects of pooling all data were then tested using the change in the coefficient of determination (r^2) and regression standard deviation ($s_{y.x}$).

RESULTS AND DISCUSSION

Regression equations for each component of the 5 species and for each age are given in Tables 2 to 6. Although a small sample size was used, analysis of variance of the regression equations showed highly significant and low standard deviation.

For the 1½ year-old trees, equations using d^2h as the independent variable gave a better fit than using *d* for all components of all species, except for *A. auriculaeformis*. For stem components of the 3 and 5-year old equations, there were no differences when d^2h and *d* were the independent variables. For branch and foliage the equations were a better fit using *d* as the independent variable.

For stem components, $s_{y.x}$ increased in moving from separate to pooled regressions, and there was loss of fit, especially in *A. indica* var. *siamensis* and *A. auriculaeformis*. While the other species showed negligible loss of fit. For branch and foliage there was increase in $s_{y.x}$ and loss of fit. Pooled regression equations for estimating the oven-dry mass of components of all species are given in Table 7.

Bias for estimated dry matter using pooled regression was calculated. The

Table 1. Range of dimensions of sample trees.

Age (years)	Sample trees	*Eucalyptus camaldulensis*	*Leucaena leucocephala*	*Cassia siamea*	*Azadirachta indica* var. *siamensis*	*Acacia auriculaeformis*
	No. of trees	10	10	10	9	10
1½	d*	3.2 – 5.8	1.8 – 5.8	1.2 – 5.1	0.5 – 4.9	1.3 – 5.9
	h**	5.47 – 8.77	2.66 – 7.70	1.95 – 6.10	1.36 – 5.15	2.40 – 6.36
	No. of trees	12	10	10	12	10
3	d	3.6 – 11.2	1.3 – 10.0	2.0 – 8.9	1.6 – 10.8	0.6 – 7.0
	h	6.39 – 14.80	2.12 – 9.90	2.71 – 9.20	2.08 – 7.30	1.83 – 8.19
	No. of trees	14	16	10	14	13
5	d	2.4 – 17.0	1.7 – 18.3	1.5 – 11.0	1.5 – 15.2	0.6 – 10.4
	h	4.53 – 20.22	3.67 – 15.60	3.96 – 9.80	2.05 – 12.70	1.90 – 11.30

* d = stem diameter over bark at breast height (cm)
** h = total height of tree (m).

Table 2. Regression constants for equations used to estimate the oven-dry mass of components of *Eucalyptus camaldulensis*. All regressions significant at $P < 0.01$.

Component	Age (years)	Dimension	b	a	r^2	$s_{y.x}$	F
Stem	1½	d	2.3239	−1.0552	0.9834	0.0286	475.07
		d^2h	0.9075	−1.5271	0.9936	0.0178	1243.49
	3	d	2.3676	−0.9467	0.9815	0.0539	529.57
		d^2h	0.8679	−1.3014	0.9877	0.0439	802.66
	5	d	2.5711	−1.0215	0.9887	0.0722	1049.35
		d^2h	0.9386	−1.4315	0.9967	0.0388	3666.84
Branch	1½	d	2.3507	−1.9797	0.8086	0.1086	33.78
		d^2h	0.8668	−2.3439	0.7284	0.1294	21.45
	3	d	2.1148	−1.9108	0.8855	0.1259	77.30
		d^2h	0.7764	−2.2307	0.8938	0.1212	84.15
	5	d	2.4849	−2.1564	0.9565	0.1392	263.54
		d^2h	0.8956	−2.5194	0.9398	0.1637	187.34
Leaf	1½	d	2.3566	−1.6786	0.9077	0.0714	78.66
		d^2h	0.9341	−2.1877	0.9449	0.0552	137.07
	3	d	1.7469	−1.4173	0.8509	0.1211	57.05
		d^2h	0.6343	−1.6629	0.8402	0.1253	52.56
	5	d	1.8882	−1.5902	0.9171	0.1491	132.75
		d^2h	0.6764	−1.8541	0.8902	0.1716	97.30

Table 3. Regression constants for equations used to estimate the oven-dry mass of components of *Leucaena leucocephala*. All regressions significant at $P < 0.01$.

Component	Age (years)	Dimension	b	a	r^2	$s_{y.x}$	F
	1½	d	2.3759	−1.1576	0.9830	0.0549	463.17
		d^2h	0.8593	−1.4042	0.9911	0.0397	893.02
Stem	3	d	2.3077	−0.9283	0.9943	0.0499	1391.27
		d^2h	0.8512	−1.2416	0.9938	0.0520	1282.53
	5	d	2.2374	−0.8466	0.9916	0.0628	1643.83
		d^2h	0.8629	−1.2684	0.9978	0.0321	6314.51
	1½	d	2.8046	−2.1319	0.9328	0.1322	111.11
		d^2h	0.9901	−2.3733	0.8963	0.1643	69.12
Branch	3	d	3.2549	−2.3863	0.9665	0.1728	231.12
		d^2h	1.1929	−2.8113	0.9537	0.2032	164.94
	5	d	2.6486	−1.8854	0.9122	0.2498	145.46
		d^2h	0.9985	−2.3210	0.8770	0.2956	99.85
	1½	d	2.2505	−1.7545	0.9399	0.0999	125.21
		d^2h	0.8102	−1.9805	0.9391	0.1006	123.41
Leaf	3	d	1.9756	−1.9562	0.9690	0.1008	250.27
		d^2h	0.7257	−2.2179	0.9607	0.1135	195.68
	5	d	1.9715	−1.8813	0.9413	0.1497	224.44
		d^2h	0.7483	−2.2197	0.9174	0.1775	155.53

estimated bias can be obtained by applying the equation to the original data (Table 8). D^2h was better estimated than d for the stem component of the youngest age in all species, but there were no differences in the older except for *A. indica* var. *siamensis*. With the exception of *E. camaldulensis*, there were no differences in estimating branch and foliage biomass between d and d^2h as the independent variables. The pooled regression should be useful, particularly for the stem component for survey purposes in Ratchaburi Province and similar sites.

The biomass equation can be developed by using other variables, for example, cross-sectional area at the base of the live crown or sapwood cross-sectional area, etc. However, these variables are more difficult to measure than the variables used in the present study.

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Table 4. Regression constants for equations used to estimate the oven-dry mass of components of *Cassia siamea*. All regressions significant at $P < 0.01$.

Component	Age (years)	Dimension	b	a	r^2	$s_{y.x}$	F
Stem	1½	d	1.8907	−0.7957	0.9771	0.0724	341.84
		d^2h	0.6812	−0.9455	0.9844	0.0599	504.15
	3	d	2.4145	−1.0765	0.9825	0.0712	448.38
		d^2h	0.8480	−1.2548	0.9856	0.0646	546.07
	5	d	2.2288	−0.9075	0.9982	0.0301	4530.66
		d^2h	0.8990	−1.3594	0.9989	0.0233	7554.11
Branch	1½	d	2.4972	−1.7545	0.9539	0.1376	165.36
		d^2h	0.9012	−1.9548	0.9640	0.1216	213.96
	3	d	2.7946	−1.9488	0.8835	0.2240	60.66
		d^2h	0.9606	−2.1095	0.8490	0.2550	44.96
	5	d	2.9786	−2.1750	0.9669	0.1771	233.63
		d^2h	1.1947	−2.7630	0.9566	0.2027	176.34
Leaf	1½	d	2.1923	−1.6342	0.9180	0.1641	89.59
		d^2h	0.7961	−1.8187	0.9394	0.1410	124.08
	3	d	2.1532	−1.8128	0.9121	0.1475	83.04
		d^2h	0.7472	−1.9519	0.8932	0.1626	66.88
	5	d	2.2831	−1.9076	0.9145	0.2243	85.52
		d^2h	0.9151	−2.3569	0.9036	0.2382	74.95

Table 5. Regression constants for equations used to estimate the oven-dry mass of components of *Azadirachta indica* var. *siamensis*. All regressions significant at P < 0.01.

Component	Age (years)	Dimension	b	a	r^2	$s_{y.x}$	F
Stem	1½	d	1.3026	−1.4844	0.9115	0.1446	72.10
		d^2h	0.5258	−0.6198	0.9401	0.1190	109.77
	3	d	2.0904	−0.9685	0.9963	0.0331	2687.48
		d^2h	0.7913	−1.1355	0.9943	0.0412	1732.57
	5	d	2.4103	−1.0388	0.9956	0.0491	2690.42
		d^2h	0.8598	−1.2525	0.9943	0.0554	2110.37
Branch	1½	d	1.5538	−1.5012	0.7950	0.2811	27.13
		d^2h	0.6350	−1.6742	0.8403	0.2481	36.83
	3	d	3.1540	−2.8360	0.9430	0.2011	165.46
		d^2h	1.1893	−3.0781	0.9338	0.2168	141.09
	5	d	3.1695	−2.6198	0.9542	0.2117	249.77
		d^2h	1.1257	−2.8881	0.9447	0.2325	205.08
Leaf	1½	d	1.1139	−0.9098	0.8374	0.1748	36.05
		d^2h	0.4536	−1.0314	0.8790	0.1508	50.84
	3	d	1.6093	−1.2703	0.9806	0.0587	505.20
		d^2h	0.6078	−1.3958	0.9740	0.0679	375.16
	5	d	1.9999	−1.6132	0.9598	0.1247	286.74
		d^2h	0.7083	−1.7774	0.9451	0.1458	206.59

Table 6. Regression constants for equations used to estimate the oven-dry mass of components of *Acacia auriculaeformis*. All regressions significant at P < 0.01.

Component	Age (years)	Dimension	b	a	r^2	$s_{y.x}$	F
Stem	1½	d	2.0718	−1.0101	0.9968	0.0276	2528.13
		d^2h	0.7908	−1.2868	0.9916	0.0451	940.37
	3	d	2.0634	−0.7945	0.9922	0.0645	1014.95
		d^2h	0.7745	−1.0868	0.9895	0.0747	756.75
	5	d	2.1243	−0.7544	0.9853	0.1006	738.95
		d^2h	0.7971	−1.0920	0.9844	0.1038	693.78
Branch	1½	d	2.2844	−1.5071	0.8622	0.2163	50.05
		d^2h	0.8524	−1.7830	0.8197	0.2474	36.36
	3	d	2.1857	−1.3123	0.9754	0.1222	317.58
		d^2h	0.8213	−1.6234	0.9749	0.1237	310.15
	5	d	1.6870	−1.0003	0.7032	0.4256	26.06
		d^2h	0.6243	−1.2510	0.6833	0.4396	23.73
Leaf	1½	d	1.8718	−1.2431	0.8958	0.1512	68.81
		d^2h	0.7012	−1.4732	0.8583	0.1763	48.44
	3	d	1.4131	−1.1481	0.9129	0.1538	83.83
		d^2h	0.5302	−1.3479	0.9097	0.1566	30.55
	5	d	2.0798	−1.5826	0.9409	0.2025	174.98
		d^2h	0.7746	−1.9016	0.9260	0.2264	137.72

Table 7. Pooled regression constants for equations used to estimate the oven-dry mass of components of the 5 species. All regressions significant at $P < 0.01$.

Species	Component	Dimension	b	a	r^2	$s_{y.x}$	F
Eucalyptus camaldulensis	Stem	d	2.6986	−1.2095	0.9716	0.0965	1164.96
		d^2h	0.9811	−1.6073	0.9831	0.0745	1980.06
	Branch	d	2.3182	−2.0173	0.9303	0.1328	454.04
		d^2h	0.8325	−2.3321	0.9184	0.1437	382.77
	Leaf	d	1.6802	−1.3426	0.8563	0.1441	202.67
		d^2h	0.5983	−1.5575	0.8312	0.1562	167.46
Leucaena leucocephala	Stem	d	2.3761	−1.0227	0.9751	0.1057	1332.10
		d^2h	0.8860	−1.3636	0.9877	0.744	2720.52
	Branch	d	2.9060	−2.1462	0.9383	0.2076	516.63
		d^2h	1.0661	−2.5208	0.9198	0.2366	389.93
	Leaf	d	1.8867	−1.7524	0.8776	0.1962	243.83
		d^2h	0.6864	−1.9817	0.8461	0.2200	186.94
Cassia siamea	Stem	d	2.2142	−0.9359	0.9804	0.0819	1400.08
		d^2h	0.8183	−1.1818	0.9815	0.0796	1482.29
	Branch	d	2.7409	−1.9330	0.9381	0.1841	424.12
		d^2h	0.9975	−2.2051	0.9107	0.2211	285.47
	Leaf	d	2.1035	−1.7128	0.8881	0.1952	222.23
		d^2h	0.7657	−1.9220	0.8626	0.2163	175.80
Azadirachta indica var. *siamensis*	Stem	d	2.0309	−0.8230	0.9265	0.1815	415.72
		d^2h	0.7416	−0.9730	0.9589	0.1357	769.99
	Branch	d	2.5253	−2.1579	0.8404	0.3491	173.82
		d^2	0.9155	−2.3303	0.8574	0.3299	198.48
	Leaf	d	1.5288	−1.1903	0.8948	0.1663	280.58
		d^2h	0.5470	−1.2793	0.8892	0.1707	264.85
Acacia auriculaeformis	Stem	d	2.1713	−0.8849	0.9618	0.1397	780.68
		d^2h	0.8137	−1.1936	0.9726	0.1182	1102.38
	Branch	d	1.9878	−1.2479	0.8116	0.3091	133.55
		d^2h	0.7366	−1.5157	0.8025	0.3165	125.96
	Leaf	d	1.7804	−1.3240	0.8838	0.2084	235.79
		d^2h	0.6527	−1.5516	0.8554	0.2325	183.37

Table 8. Bias of estimated biomass (using equations from Table 7) expressed as percentage of measured biomass for components of sample trees.

Age (years)	Component	*Eucalyptus camaldulensis*		*Leucaena leucocephala*		*Cassia siamea*		*Azadirachta indica* var. *siamensis*		*Acacia auriculaeformis*	
		d	d^2h	d	d^2h	d	d^2h	d	d^2h	d	d^2h
1½	Stem	27.82	22.44	36.22	24.93	18.12	9.75	24.85	6.15	52.69	34.82
	Branch	−14.92	−17.18	6.88	−3.40	−3.26	−12.25	−22.79	−36.71	5.96	−5.47
	Leaf	−55.03	−27.16	−45.74	−48.92	−29.37	−34.11	−13.53	−23.04	−28.00	−34.95
3	Stem	8.29	4.22	−7.87	−11.11	−5.52	−3.70	21.64	5.99	−4.60	−5.75
	Branch	17.81	13.20	−22.66	−27.87	−14.58	−14.58	13.65	−5.47	−21.40	−22.99
	Leaf	−38.56	−2.25	28.52	25.06	10.72	11.59	0.80	−9.54	14.28	11.35
5	Stem	−9.07	−7.91	−1.99	−4.73	−8.39	−11.25	−32.89	−22.12	−25.31	−21.11
	Branch	−24.50	−24.68	−21.39	−28.27	−17.58	−23.83	−43.19	−33.55	−40.96	−38.90
	Leaf	−42.50	−5.88	1.12	−3.20	−16.03	−19.92	−16.98	−8.55	−9.77	−8.33

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