NAT. HIST. BULL. SIAM SOC. 37(1): 57–63, 1989

PRIMARY PRODUCTION OF PLOTS OF FIVE YOUNG CLOSE-SPACED FAST-GROWING TREE SPECIES, II. ABOVE-GROUND BIOMASS, NUTRIENT AND ENERGY CONTENT

*Sarayudh Bunyavejchewin**, *Somboon Kiratiprayoon**
and *Tanapong Kumpun***

ABSTRACT

Five-year-old *Eucalyptus camaldulensis, Leucaena leucocephala, Cassia siamea, Azadirachta indica* var. *siamensis* and *Acacia auriculaeformis* plots contained 109, 103, 48, 52 and 45 tonnes of above-ground biomass per ha, respectively. Energy content ranged from 443×10^6 kcal/ha for *E. camaldulensis* to 192 kcal/ha for *A. auriculaeformis*. In the 5 species, the nutrient content per unit of energy varied from the same order of magnitude for phosphorus to 2 times different for nitrogen, potassium and magnesium.

INTRODUCTION

In most rural areas, about 90 percent of the people depend on firewood as their main source of fuel. People in some areas are facing a critical firewood shortage, lacking wood for cooking and heating.

Energy plantations have been attempted by the Royal Forest Department, but sound planning for this programme needs more information on various fast-growing tree species. Since the potential of an energy programme depends on estimates of the dry matter content, the aims of the present study were to present data for dry matter, nutrient and energy content of the above-ground portions of 5 fast-growing tree species (*Eucalyptus camaldulensis* Dehnh., *Leucaena leucocephala* de Wit, *Cassia siamea* Britt., *Azadirachta indica* Juss. var. *siamensis* Valeton and *Acacia auriculaeformis* Cunn.). This work was carried out to provide a basis for estimating production of species suitable for growing firewood for rural needs. The data obtained are also applicable to plantations for fueling small industries or for pulp production.

METHODS

Field handling of samples was described in the preceding paper (BUNYAVEJCHEWIN & KIRATIPRAYOON, 1989). Dry weights of components of each species were

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

** Khao Soi Doa Seed Orchard, Silvicultural Research Sub-division Division of Silviculture, Royal Forest Department, Bangkhen, Bangkok 10900.

calculated from regression equations with diameter at breast height as the independent variable (Tables 2 – 6 in BUNYAVEJCHEWIN & KIRATIPRAYOON, 1989). Stem weights of 2½ and 4-year-old plots were estimated by using regression equations for 1½ and 3-year-old trees, respectively. Branch and foliage mass at ages 2½ and 4 years were estimated by using pooled equations (Table 7 in preceding paper).

For nutrient analysis, samples of stem, branch and foliage of each species at age 5 years were ground up to pass a 2 – mm mesh sieve. Subsamples were digested using mixed acids ($HNO_3 - H_2SO_4 - HClO_4$, 5:1:2). Nitrogen was determined by the Kjeldahl method and phosphorus by the vanadomolybdate method. Potassium was determined by flame photometer. Calcium and magnesium were determined by atomic absorption. Energy values were measured with an adiabatic bomb calorimeter.

RESULTS AND DISCUSSION

Trees in the 1½ to 3-year-old *L. leucocephala* plots had outgrown those in the other species plots in dbh while the largest dbh's were found in *E. camaldulensis* for ages 4 and 5. *L. leucocephala* attained the greatest height at all ages (Table 1).

The nutrient concentrations in the various components of the 5 species were broadly comparable and tended to decrease in the order of foliage, branch and stem (Table 2). The same ordering has been found in various species in other studies (MADGWICK *et al.*, 1981, 1982; PETMAK, 1983). All components of *E. camaldulensis* had lower nitrogen concentration than the other species and all foliage of legume species contained high concentrations of nutrients.

Dry matter, nutrient and energy content for components of all species are given in Tables 3 and 4. Stem and branch biomass were found to increase with age in all species. A similar trend is apparent in foliage biomass of *E. camaldulensis* and *A. auriculaeformis*. Foliage biomass of *L. leucocephala*, *C. siamea* and *A. indica* var. *siamensis* tend to remain constant across the age range.

Stem biomass of *L. leucocephala* plots was 24, 38 and 57 t/ha at ages 1½, 2½ and 3 years, respectively, which was the highest of all species. At age 5 years, *E. camaldulensis* achieved the highest biomass 97 t/ha. Stem biomass of a 5-year-old plot of *E. camaldulensis* was about 3 times that of *A. auriculaeformis* and about twice those of *C. siamea* and *A. indica* var. *siamensis*. Stem biomass of a 4-year-old plot of *E. camaldulensis* in this study was 71 t/ha which was greater than that found for *E. fastigata* and *E. nitens* of the same age and planting distance in New Zealand (Madgwick *et al.*, 1981), and also greater than for a 5 to 11-year-old plantation of *E. grandis* in New South Wales (BRADSTOCK, 1981). The stem weight was also greater than that of *E. camaldulensis* in an intercropping trial plot with spacing of 2 × 4 m in northeast Thailand (CAKRAPHOLWARARIT, 1985).

Although *L. leucocephala* carried more branch biomass than other species, *A. auriculaeformis* had the highest ratio of branch to stem (0.35), compared with *C. siamea* (0.26), *L. leucocephala* (0.25), *A. indica* var. *siamensis* (0.12) and

Table 1. Mean dbh (cm) ± standard deviation, and mean total height (m) ± standard deviation, in plots of 5 species at various ages.

Species	Dimen-sion	Age (years) 1½	2½	3	4	5
Eucalyptus camaldulensis	dbh	3.69±0.93	5.32±1.25	5.37±1.34	6.46±1.72	6.62±1.81
	h	N.D.	N.D.	7.19±1.90	8.40±1.16	9.49±2.97
Leucaena leucocephala	dbh	4.55±1.14	5.51±1.45	5.64±1.30	6.04±1.40	6.20±1.67
	h	N.D.	N.D.	7.59±1.68	9.01±1.45	10.47±1.82
Cassia siamea	dbh	3.80±1.29	4.48±1.49	4.51±1.53	4.82±1.79	5.37±1.80
	h	N.D.	N.D.	5.54±1.68	5.58±1.50	6.47±1.63
Azadirachta indica var.	dbh	3.38±1.44	4.59±1.68	4.69±1.66	5.22±1.88	5.29±1.73
siamensis.	h	N.D.	N.D.	4.31±1.21	5.24±1.14	5.98±1.56
Acacia auriculaeformis	dbh	2.25±1.06	3.11±1.53	3.16±1.59	4.16±1.80	4.24±1.91
	h	N.D.	N.D.	4.55±1.50	5.00±1.45	5.61±1.85

N.D. = not determined.

Table 2. Nutrient concentrations (percent of dry mass) and energy values (kcal/g) of 5-year-old plant tissues.

Plant tissue	N	P	K	Ca	Mg	Energy
Eucalyptus camaldulensis						
Stem	0.21	0.025	0.262	0.62	0.06	4.006
Branch	0.332	0.066	0.563	0.97	0.12	4.150
Leaf	1.627	0.083	1.063	1.97	0.21	4.694
Leucaena leucocephala						
Stem	0.542	0.025	0.500	0.47	0.06	3.801
Branch	0.612	0.033	0.750	0.42	0.08	3.931
Leaf	3.202	0.157	2.062	2.37	0.44	4.271
Cassia siamea						
Stem	0.385	0.033	0.406	0.72	0.03	4.238
Branch	0.602	0.056	0.500	1.12	0.08	3.881
Leaf	2.222	0.165	1.063	1.75	0.18	4.484
Azadirachta indica var. *siamensis*						
Stem	0.402	0.025	0.531	0.57	0.08	3.969
Branch	0.507	0.041	0.688	0.85	0.15	4.012
Leaf	1.855	0.115	1.250	1.75	0.50	4.237
Acacia auriculaeformis						
Stem	0.402	0.012	0.250	0.75	0.02	4.308
Branch	0.682	0.041	0.375	1.10	0.06	4.007
Leaf	2.695	0.132	1.250	1.22	0.26	4.796

Table 3. Oven-dry mass of various components of plots of 5 species at various ages in t/ha.

Age (years)	Components	*Eucalyptus camaldulensis*	*Leucaena leucocephala*	*Cassia siamea*	*Azadirachta indica* var. *siamensis*	*Acacia auriculaeformis*
	Stem	13.842	24.373	14.457	10.625	6.012
	Branch	1.710	5.144	3.911	1.469	2.419
1½	Leaf	3.420	5.011	3.261	3.116	2.822
	Total	18.972	34.528	21.529	15.210	11.253
	Stem	31.800	38.692	19.841	17.098	9.934
	Branch	3.435	10.507	5.963	2.867	5.087
2½	Leaf	3.248	4.079	3.412	4.882	3.176
	Total	38.483	53.278	29.216	24.847	18.197
	Stem	45.952	56.846	23.995	19.993	16.015
	Branch	3.179	11.109	6.134	1.741	5.815
3	Leaf	5.161	2.935	2.842	4.435	2.840
	Total	54.292	70.890	32.917	26.169	24.670
	Stem	71.471	68.319	28.447	27.307	23.154
	Branch	5.508	12.890	7.123	3.917	7.244
4	Leaf	4.537	4.661	3.786	5.985	4.320
	Total	81.516	85.870	39.356	37.209	34.718
	Stem	96.772	79.093	34.846	41.847	30.104
	Branch	5.958	19.529	9.199	5.031	10.676
5	Leaf	6.634	4.374	3.851	5.233	4.143
	Total	109.364	102.996	47.896	52.111	44.923

E. camaldulensis (0.06).

Foliage mass for 5-year-old *E. camaldulensis* plots was about 6.6 t/ha which was higher than that for the other species. This is close to foliage mass of 5 to 27-year-old *E. grandis* plantations in northern New South Wales (BRADSTOCK, 1981). Foliage mass of 3-year-old *L. leucocephala* plots in this study was higher than that measured in northeast Thailand (PETMAK, 1983; BUNYAVEJCHEWIN, 1984).

Mean net above-ground biomass was 21.9, 20.6, 10.4, 9.6 and 9.0 t/ha/yr for *E. camaldulensis*, *L. leucocephala*, *A. indica* var. *siamensis*, *C. siamea* and *A. auriculaeformis*, respectively (Table 5). All species produced wood material more than 90%. Net above-ground energy accumulation was 88.7×10^6 kcal/ha/yr for *E. camaldulensis* which was slightly higher than for *L. leucocephala* (79.2×10^6 kcal/ha/yr) and much higher than for the other three species. Mean annual

Table 4. Nutrient and energy content of 5-year-old plots.

Species and component	Nutrient content (kg/ha)					Energy (kcal/ha)
	N	P	K	Ca	Mg	
Eucalyptus camaldulensis						
Stem	203.2	24.2	253.5	600.0	58.1	287.67×10^6
Branch	19.8	3.9	33.5	57.8	7.1	24.73×10^6
Leaf	107.9	5.5	70.5	130.7	13.9	31.14×10^6
Total	330.9	33.6	357.5	788.5	79.1	443.54×10^6
Leucaena leucocephala						
Stem	428.7	19.8	395.5	371.7	47.5	300.63×10^6
Branch	119.5	6.4	146.5	82.0	15.6	76.77×10^6
Leaf	140.0	6.9	90.2	103.7	19.2	18.69×10^6
Total	688.2	33.1	632.2	557.4	82.3	396.09×10^6
Cassia siamea						
Stem	134.2	11.5	141.5	250.9	10.4	147.68×10^6
Branch	55.4	5.1	46.0	103.0	7.4	35.70×10^6
Leaf	85.6	6.3	40.9	67.4	6.9	17.27×10^6
Total	275.2	22.9	228.4	421.3	24.7	200.65×10^6
Azadirachta indica var. *siamensis*						
Stem	168.2	10.5	222.2	238.5	33.5	166.09×10^6
Branch	25.5	2.1	34.6	42.8	7.5	20.18×10^6
Leaf	97.1	6.0	65.4	91.6	26.2	22.17×10^6
Total	290.8	18.6	322.2	372.9	67.2	208.44×10^6
Acacia auriculaeformis						
Stem	121.0	3.6	75.3	225.8	6.0	129.69×10^6
Branch	72.8	4.4	40.0	117.4	6.4	42.78×10^6
Leaf	111.6	5.5	51.8	50.5	10.8	19.87×10^6
Total	305.4	13.5	167.1	393.7	23.2	192.34×10^6

increment and energy content of *E. camaldulensis* were slightly higher than those of *E. nitens* and *Pinus radiata* (Table 6). *E. camaldulensis* had the highest mean annual increment of all species at age 5 years while for 3-year-old plots the highest mean annual increment was shown by *L. leucocephala*.

Total nutrient and energy content reflects the nutrient concentrations, total biomass and age of tissues. *E. camaldulensis* and *L. leucocephala* plots contained greater quantities of all elements than the other three species plots, due to the faster growth rates of these two species. The total phosphorus and magnesium contents in the *E. camaldulensis* and *L. leucocephala* plots were the same order of magnitude. The *L. leucocephala plots* contained about twice the nitrogen and potassium contents but less calcium content than the *E. camaldulensis* plots (Table 4). *C. siamea*,

Table 5. Mean annual increment and nutrient cost of energy.

	E. camaldulensis		*L. leucocephala*		*C. siamea*		*A. indica* var. siamensis		*A. auriculaeformis*	
	Stem + branch	Total	Stem + branch	Total	Stem + branch	Total	Stem + branch	Total	Stem + branch	Total
Age (years)	5	5	5	5	5	5	5	5	5	5
Mean annual increment oven-dry (t/ha)	20.546	21.873	19.724	20.599	8.809	9.579	9.376	10.422	8.156	8.985
Energy (10^6 kcal/ha/year	82.480	88.708	75.48	79.218	36.676	40.130	37.254	41.688	34.494	38.468
Nutrient cost per 10^7 kcal										
N (kg)	5.41	7.46	14.53	16.87	10.34	13.71	10.40	13.95	11.24	15.88
P (kg)	0.68	0.76	0.69	0.84	0.90	1.14	0.68	0.89	0.46	0.70
K (kg)	6.96	8.06	14. 36	15.96	10.22	11.38	13.79	15.46	6.68	8.69
Ca (kg)	15.95	17.78	12.02	14.07	19.30	21.00	15.10	17.89	19.90	20.47
Mg (kg)	1.58	1.78	1.67	2.08	0.97	1.23	2.20	3.22	0.72	1.21
Age (years)	3	3	3	3	3	3	3	3	3	3
Mean annual increment oven-dry (t/ha)	16.377	18.097	22.652	23.630	10.043	10.990	7.245	8.723	7.277	8.233
Energy (10^6 kcal/ha/year)	64.074	72.212	90.387	90.633	39.717	43.737	30.022	36.615	30.373	36.643

Table 6. Mean annual increment and nutrient cost of energy for 3 species in New Zealand (data from Madgwick *et al.*, 1981).

	Pinus radiata		*E. nitens*		*E. fastigata*	
	Stem + branch	Tatal	Stem + branch	Total	Stem + branch	Total
Age (years)	17	17	4	4	4	4
Mean annual increment oven-dry (t/ha)	16	17	18	20	13	15
Energy (10^6 kcal/ha/year)	69.7	72.79	77.80	89.97	56.80	71.12
Nutrient cost per 10^7 kcal						
N (kg)	1.93	3.10	5.11	9.22	5.66	11.23
P (kg)	0.46	0.59	0.42	0.63	0.38	0.71
K (kg)	2.72	3.35	7.21	8.51	6.58	8.67
Ca (kg)	2.09	2.30	8.38	9.22	7.12	8.63
Mg (kg)	0.67	0.71	1.47	1.76	1.55	2.14

A. indica var. *siamensis* and *A. auriculaeformis* contained the same magnitude of total nitrogen, phosphorus and calcium, while *A. indica* var. *siamensis* contained greater quantities of potassium and magnesium. Mean annual increment of both total above-ground biomass and stem-plus-branch, and energy decreased in the order *E. camaldulensis*, *L. leucocephala*, *A. indica* var. *siamensis*, *C. siamea* and *A. auriculaeformis*.

Use of biomass as an energy source must concern the ecological impact of harvesting. The impact can be estimated by using "nutrient cost" of the energy value, the amount of nutrients removed per unit of energy harvested. Nutrient cost per energy value varied between nutrients. Phosphorus costs were approximately the same in all species except for *C. siamea*. The nitrogen cost of *L. leucocephala* was about twice that of *E. camaldulensis* and slightly higher than the other tree species. All element costs, except the calcium cost for stem-plus-branch, of *E. camaldulensis* were the same as those for *Eucalyptus nitens* and *Eucalyptus fastigata* (Table 6). Leaf foliage in the stand decreased the nitrogen cost by 14 to 29%, phosphorus cost by 10 to 34%, potassium cost by 10 to 23%, calcium cost by 3 to 15% and magnesium cost by 11 to 40%.

ACKNOWLEDGEMENTS

The authors thank Harry Wood for editing. We also thank the Department of Soil Science, Kasetsart University for the nutrient analyses and the Department of Animal Science, Kasetsart University for energy measurements.

REFERENCES

BRADSTOCK, R. 1981. Biomass in an age series of *Eucalyptus grandis* plantations. *Aust. For. Res.* 11(2): 11 – 127.

BUNYAVEJCHEWIN, S. 1984. The relationship between planting distance and growth, above-ground biomass and firewood production in *Leucaena leucocephala* De Wit at Sakaerat, Pak Thong Chai, Nakhon Ratchasima. *Thai J. For.* 2(4): 307 – 319. (in Thai with English abstract).

BUNYAVEJCHEWIN, S. and S. KIRATIPRAYOON. 1989. Primary production of plots of five young close-spaced fast-growing tree species, I. Biomass equations. *Nat. Hist. Bull. Siam Soc.* 37: 47 – 56.

CHAKRAPHOLWARARIT, C. 1985. *Yield-Density Effect of* Eucalyptus camaldulensis *Plantation.* M.S. Thesis. Kasetsart Univ., Bangkok (in Thai with English abstract).

MADGWICK, H.A.I., P. BEETS and S. GALLAGHER, 1981. Dry matter accumulation, nutrient and energy content of the above ground portion of 4-year-old stands of *Eucalyptus nitens* and *E. fastigata*. *New Zealand J. For. Sci.* 11(1): 53 – 59.

MADGWICK, H.A.I., G. OLIVER and P. HOLTEN-ANDERSON. 1982. Above-ground biomass, nutrients, and energy content of trees in a second-growth stand of *Agathis australis*. *New Zealand J. For Sci.* 12(1): 3 – 6.

PETMAK, P. 1983. *Primary Productivity, Nutrient Cycling and Organic Matter Turnover of Tree Plantations after Agricultural Intercropping Practices in Northeast Thailand.* Ph.D. dissertation. Univ. of the Philippines at Los Banos.