DRY MATTER ACCUMULATION, NUTRIENT AND ENERGY CONTENT OF THE ABOVE GROUND PORTION OF 4-YEAR-OLD STANDS OF *EUCALYPTUS NITENS* AND *E. FASTIGATA*

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Annual dry matter increment of **E. nitens** and **E. fastigata** in Rotoehu State Forest was 20 and 15 tonnes/ha respectively. This is of the same order as the maximum value of 17 tonnes/ha at age 17 years published for an age series of **Pinus radiata**. In the **Eucalyptus** species, compared with pine, the nutrient content per unit of energy harvestable varied from the same order of magnitude for phosphorus, to almost 4 times as high for nitrogen. Fast growing **Eucalyptus** species warrant further study as potential sources of energy from biomass in New Zealand.

INTRODUCTION

New Zealand's dependence on imported oil and the precarious nature of world oil supplies have increased the need to consider alternative sources of liquid fuels, such as fuel from biomass (Harris *et al.* 1979). In New Zealand the major contenders as a source of biomass are *Pinus radiata* and agricultural crops. One reason for advocating *Pinus radiata* is the lack of information on other woody plants. Other potential genera include *Eucalyptus* which has received attention as a source of short-fibred pulp (Lembke 1977).

Stands which might approximate a silvicultural regime aimed at biomass production using close spacing are uncommon. We present data for dry matter, nutrient, and energy contents of the above ground portion of two closed, fast growing, 4-year-old *Eucalyptus* stands. We compare the mean productivity and nutrient content per unit of energy stored by these stands with the maximum mean annual increment for *Pinus radiata* D. Don (Madgwick *et al.* 1977). The maximum value for *P. radiata* occurred in a 17-year-old stand. Since yield per hectare is an important criterion in an energy plantation program (Harris *et al.* 1979) this maximum value for *P. radiata* is a useful benchmark against which to compare other crops. Other published data for *Eucalyptus* include 4-year-old stands of *E. signata* Smith (Andrae & Krapfenbauer 1979) and fertilised *E. globulus* Labill. (Cromer *et al.* 1975) but the higher stocking rate and faster growth of our stands make comparisons of doubtful value. It is not clear if the *E.*

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globulus stand had a fully closed canopy. Data for older stands include *E. obliqua* L'Hérit. (Attiwill 1972, 1979), *E. saligna* (Westman & Rogers 1977), and *E. populnea* F. Muell. (Harrington 1979), and mixed species (Stewart *et al.* 1979). These older stands all differ greatly in age and structure from our plots so that no useful comparisons can be made.

MATERIAL AND METHODS

The sample stands are in Rotoehu State Forest in the central North Island about 40 km north-east of Rotorua and about 12 km south-west of the forest meteorological station. The stands were originally part of a weedicide experiment (Yortt & Rowe 1977) but subsequent development had masked any initial growth differences. The soil is derived from Kaharoa ash overlying Rotokawa ash. Average meteorological data are based on at least 30-year records. Annual precipitation was 1680 mm with monthly averages ranging from 99 mm in January to 183 mm in May. Monthly temperatures ranged from 7.7°C in July to 17.8°C in February and an average of 55 ground frosts were recorded annually (New Zealand Meteorological Office 1973).

Two study plots of approximately 80 m^2 and containing 53 and 60 trees respectively, were tallied for diameter breast height. Seven trees in each plot, covering the diameter range present, were felled at ground level in April 1979.

The crown of each tree was divided, by 2-meter layers, into dead branches, live branches, and foliage-bearing twigs. The *E. nitens* trees had both juvenile and mature foliage which were also kept separate. Each component was weighed fresh and a large random sample was taken to the laboratory where it was oven-dried at 60°C and weighed to obtain dry-matter content.

Each stem was measured for total height, cut into 2-m sections, weighed fresh, and discs were removed at each cut to determine the ratios of water, stemwood, and stembark.

Samples were ground to pass 2 mm and 1 mm mesh sieves for woody and foliage components respectively. Subsamples were digested using sulphuric acid and hydrogen peroxide in the presence of lithium sulphate and selenium (Parkinson & Allen 1975). Nitrogen was determined by the indophenol-blue method and phosphorus by the vanadomolybdate method. Potassium, calcium, and magnesium were determined by atomic absorption (Nicholson, unpubl.). Energy values were measured with an adiabatic bomb calorimeter (Lieth 1968).

Height of uncut trees was estimated using the Petterson height curve:

$$\text{Height} = 1.40 + \text{Exp}\,(a + b/(\text{diameter breast height}))$$

where a and b are constants calculated using a linearised regression based on the sample tree data (Schmidt 1967).

Weights of each component of the stands were calculated from regressions of the form:

$$\log_e(\text{weight}) = c + d \log_e(\text{diameter breast height})$$

where c and d are constants. Bias in logarithmic estimates was accounted for (Madgwick & Satoo 1975).

RESULTS AND DISCUSSION

Trees in the *E. nitens* plot had outgrown those in the *E. fastigata* plot in both height and basal area (Table 1). The nutrient concentrations in the various tissues for the two species were broadly comparable and tended to decrease in the expected order of foliage, stembark, branches, stemwood (Table 2).

We have not found published standards for foliage nutrient concentrations associated with satisfactory growth for the two species but the concentrations of nitrogen and phosphorus presented in Table 2 are of the same order as those found by Cromer *et al.* (1975) in fertilised 4-year-old *E. globulus*. Foliar phosphorus concentrations, in particular, and foliar nitrogen were low compared with a variety of *Eucalyptus* species grown in nutrient cultures (Kaul *et al.* 1968, 1970a, b). Energy values for foliage were lower, and for woody material greater, than comparable tissues from *Pinus radiata* (Madgwick *et al.* 1977).

TABLE 1—Stand data

	Stocking (stems/ha)		Basal area	Mean height
	Live	Dead	(m^2/ha)	(m)
E. nitens	6470	0	31.1	9.45
E. fastigata	7250	380	20.6	7.28

TABLE 2—Average nutrient concentrations in, and energy values of, plant tissues

Plant tissues	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Energy (kJ/g)
Eucalyptus nitens						
Leaves						
Juvenile	1.34	0.083	0.87	1.06	0.22	21.3
Mature	2.04	0.132	0.91	0.72	0.19	21.8
Branches						
Live	0.46	0.041	0.53	0.77	0.12	18.6
Dead	0.21	0.004	0.20	1.32	0.18	18.3
Stem						
Wood	0.19	0.012	0.23	0.07	0.03	18.6
Bark	0.53	0.045	0.67	1.60	0.25	17.1
Eucalyptus fastigata						
Leaves	1.85	0.109	0.91	0.74	0.25	22.3
Branches						
Live	0.40	0.026	0.43	0.55	0.10	18.8
Dead	0.25	0.007	0.12	1.01	0.13	18.6
Stem						
Wood	0.19	0.011	0.22	0.07	0.03	18.7
Bark	0.54	0.037	0.54	1.18	0.23	17.2

Total foliage mass for both *Eucalyptus* species was about 10 tonnes/ha (Table 3) which is comparable to other evergreen hardwoods (Zavitkovski *et al.* 1974) and also to closed *Pinus radiata* stands (Madgwick *et al.* 1977) but is higher than reported values for either planted *E. saligna* in Brasil (Andraes & Krapfenbauer 1979) or older, closed *Eucalyptus* stands in Australia (Attiwill 1972, 1979; Westman & Rogers 1977; Harrington 1979; Stewart *et al.* 1979). Both stands had closed canopies with a zone of dead branches extending at least 2 m above the ground. Above this zone foliage was distributed in the usual bell-shaped distribution (Fig. 1). In *E. nitens* juvenile foliage extended to branches attached up to 6 m from the ground. The mature foliage of this species had been partially eaten by *Paropsis* beetles but no estimate of this consumption was made.

TABLE 3—Oven-dry weight, nutrient, and energy content of stands

Plant tissues	Oven-dry wt. (tonnes/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Energy (10^9J/ha)
Eucalyptus nitens							
Leaves							
Juvenile	0.7	9	0.5	6	7	1	14
Mature	8.7	164	10.3	76	64	17	190
Branches							
Live	9.1	38	3.3	49	71	10	169
Dead	2.1	4	0.1	4	27	3	38
Stem							
Wood	52.1	85	6.1	120	34	15	968
Bark	7.6	35	3.2	52	118	16	129
Total	81.8	332	23.2	306	332	63	1508
Eucalyptus fastigata							
Leaves	10.6	190	11.4	96	83	26	237
Branches							
Live	11.2	41	2.5	47	71	12	212
Dead	1.9	4	0.1	1	21	2	35
Stem							
Wood	33.6	61	4.2	77	19	11	628
Bark	4.6	24	1.8	26	53	10	79
Total	61.8	319	19.9	246	245	61	1191

Branches weighed 11–13 tonnes/ha, with the majority being living material. The *E. fastigata* stand carried more branch material than *E. nitens* and this is particularly noticeable when the ratio of branch to stem material is computed (0.34 and 0.19, respectively). Total stem material in the *E. nitens* stand weighed about 60 tonnes/ha or about 50% more than in the slower grown *E. fastigata.*

Net above-ground dry matter production was 20 and 15 tonnes/ha/year for *E. nitens* and *E. fastigata* respectively (Table 4). Even when only woody material is considered *E. nitens* produced 18 tonnes/ha/year which places it third when compared

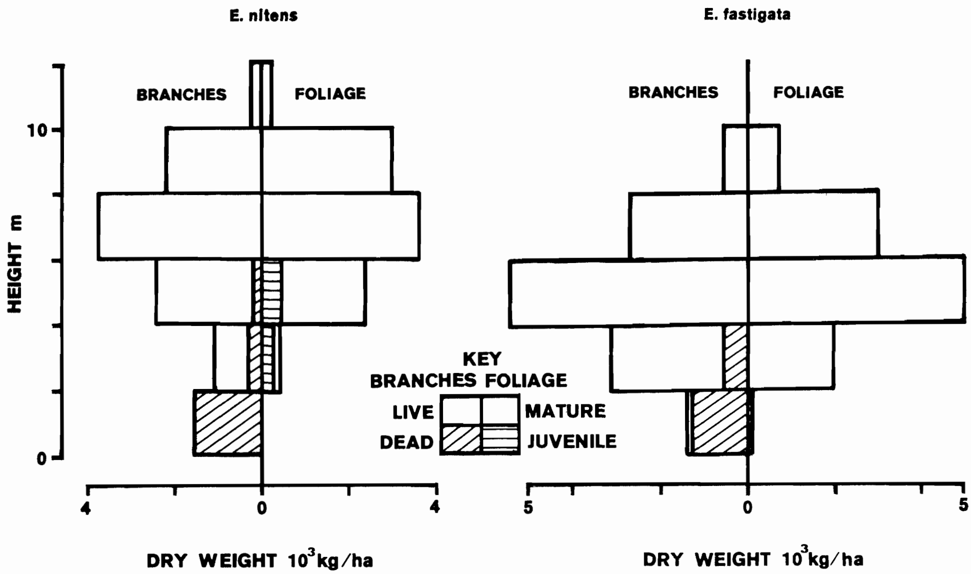

FIG. 1—Distribution of foliage and branches within canopies of **Eucalyptus** stands.

TABLE 4—Mean annual increment and nutrient cost of energy

	Pinus radiata		**E. nitens**		**E. fastigata**	
	Stem + branch	Total	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 (10^9J/ha/year)	292	305	326	377	238	298
Nutrient cost per 10^6J						
N (kg)	46	74	122	220	135	268
P (kg)	11	14	10	15	9	17
K (kg)	65	80	172	203	157	207
Ca (kg)	50	55	200	220	170	206
Mg (kg)	16	17	35	42	37	51

with 53 hardwood stands considered by Zavitkovski *et al.* (1974) and slightly higher than the maximum mean annual increment of 17 tonnes/ha/year for an age series of *Pinus radiata* stands in New Zealand (Madgwick *et al.* 1977). Net above-ground energy accumulation was 3.8×10^{11} J/ha/year for *E. nitens* which compares with 3.1×10^{11} J/ha/year for the same *P. radiata* stand. Since the *Eucalyptus* data represent only one point in time it is not clear whether either *Eucalyptus* stand had achieved maximum mean annual increment.

Total nutrient and energy content reflect differences in nutrient concentrations, total dry weights, and age of tissues. The total nitrogen, phosphorus, and magnesium contents in the stands of *E. nitens* and *E. fastigata* were of the same order of magnitude. The *E. nitens* stand contained considerably more potassium and calcium than *E. fastigata* (Table 3).

Compared with a 4-year-old plantation of *E. saligna* in Brasil (Andrae & Krapfenbauer 1979) both our *Eucalyptus* stands had larger weights of foliage, branches, and stems and contained greater quantities of the nutrients studied. Although *E. saligna* had been planted in our study area we did not sample it because of its obviously slower growth rate.

Any plan to use biomass as a renewable energy source must consider the ecological impact of harvesting. The nutrient "cost" of energy can be defined as the amount of nutrient removed in the crop per unit of energy harvested. Table 4 contains data on mean annual increment and the nutrient cost of energy from the two *Eucalyptus* stands and from a 17-year-old *Pinus radiata* stand which has the maximum measured rate of energy storage for that species. Values are presented for both the stem plus branch component and the total above ground stand. Mean annual increment of both dry weight and energy capture decreased in the order *E. nitens, P. radiata, E. fastigata.* Increments of stem and branches ranged from 80 to 96% of the total above ground material; it was lowest for *E. fastigata* and highest for *P. radiata.* Energy costs varied among nutrients as did the relative ranking of the 3 species. Thus phosphorus costs were approximately the same in all cases but nitrogen costs from harvesting 4-year-old *E. fastigata* would have been almost 4 times those from the older *P. radiata.* Leaving foliage in the forest would decrease nutrient costs by about 10% for calcium and almost 50% for nitrogen. Nutrient costs of energy from biomass are very sensitive to stand age in young stands where the relative proportions of foliage to wood and of young to old wood are changing quickly (Fraser & Madgwick, in press). Any comparison between *Eucalyptus* and *P. radiata* must be treated with caution until more is known about optimal silvicultural regimes for the different species and their relative yields of liquid fuel. However, our research suggests that fast growing *Eucalyptus* species warrant further study as potential sources of energy in New Zealand.

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