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Mixed Plantations of *Eucalyptus* and Leguminous Trees Enhance Biomass Production

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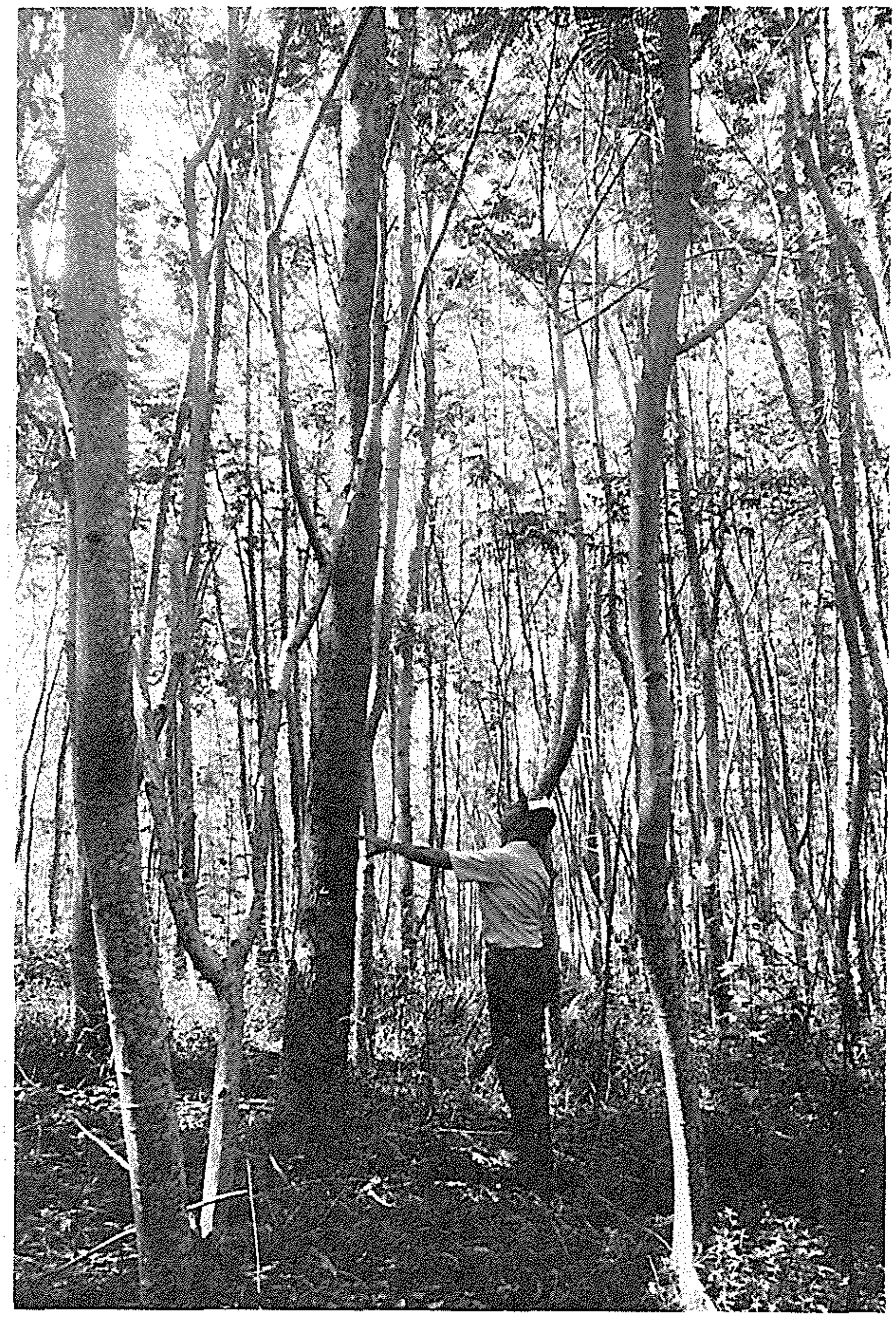

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IN BRIEF

DeBell, Dean S.; Whitesell, Craig D.; Schubert, Thomas H. **Mixed plantations of *Eucalyptus* and leguminous trees enhance biomass production.** Res. Paper PSW-175. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, 1985. 6 p.

Retrieval Terms: Eucalyptus, Eucalyptus saligna, Eucalyptus grandis, Acacia melanoxylon, Albizia falcataria, legumes, species trials, plantations, Hawaii

Because of their quick growth and high yields, two *Eucalyptus* species are especially favored for wood, fiber, and fuel production in Hawaii. But the growth of *E. saligna* Sm. and *E. grandis* Hill ex Maid. is limited on many sites by low levels of available soil nitrogen. Supplemental nitrogen needed for sustained production of the species can be provided by application of synthetic nitrogen fertilizer or through use of N_2-fixing plants—such as legumes—or both.

To test the effects of planting leguminous trees, two species—(*Acacia melanoxylon* R. Br. or *Albizia falcataria* (L.) Fosberg)—were added in 1:1 mixtures with *Eucalyptus* in managed biomass plantations along the Hamakua coast, island of Hawaii.

The experimental design consisted of three treatments: (1) pure *Eucalyptus,* (2) *Eucalyptus* mixed with *Acacia,* and (3) *Eucalyptus* mixed with *Albizia.* The trees were planted at 2-m by 2-m spacing in August 1979, and treatments were replicated three times on plots of 0.4 ha each. Height and diameter were measured at 6-month intervals. Foliar samples of *Eucalyptus* were collected at 14 months after planting and analyzed for N, P, K, S, Ca, and Mg. Soil samples were obtained at 65 months and analyzed for pH, N, P, K, Ca, and Mg.

At 25 months, *Eucalyptus* trees grown in mixture with legumes were larger than *Eucalyptus* trees grown in pure plantings. At 65 months, *Eucalyptus* grown in pure stands were 10.3 m tall and 8.5 cm in diameter. *Eucalyptus* grown with *Acacia* were 25 percent taller and 28 percent larger in diameter; and *Eucalyptus* grown with *Albizia* were 63 percent taller and 55 percent larger in diameter than *Eucalyptus* grown in pure plantings. Despite increased mortality of *Eucalyptus* trees in the mixed species treatments, differences in biomass yields per ha were even greater than differences in average tree size. Crop yields averaged 38 tonnes per ha in pure *Eucalyptus,* 52 in *Eucalyptus* with *Acacia,* and 95 in *Eucalyptus* with *Albizia.*

Foliar concentrations of N and some of the other macronutrients were increased in *Eucalyptus* in the mixed plantations—especially those including *Albizia.* Soil nutrients, with the exception of K in the surface soil, did not vary significantly among treatments.

This study demonstrates the potential for using leguminous trees in mixture with *Eucalyptus* for increased production in biomass plantations in Hawaii.

INTRODUCTION

Two *Eucalyptus* species are particularly favored for wood, fiber, and fuel production in Hawaii and other tropical and subtropical areas because they grow rapidly and produce high yields on short rotations (Walters 1980, Whitesell 1975). Production of *E. saligna* and *E. grandis,* however, is limited on many sites by low levels of available soil nitrogen. Responses to N fertilizer have been substantial (Miyasaka 1984), and supplemental N will undoubtedly be needed for sustained production from repeated croppings.

The availability and cost of N fertilizer depend heavily on the supply and price of fossil fuel. Fertilization is, therefore, a costly practice in Hawaii, and is not feasible in many developing countries. Nitrogen can also be added through symbiotic fixation, and the general presence of N_2-fixing plants is one of the most striking characteristics of many natural tropical rainforests (Cole and Johnson 1980).

We, therefore, conducted a test to evaluate effects of including N_2-fixing trees in managed *Eucalyptus* plantations. The trees tested were *Acacia melanoxylon* R. Br. and *Albizia falcataria* (L.) Fosberg; both are legumes and are known to grow well on the site selected for the study.

This paper reports results of tests after 65 months in which leguminous tree species were planted in mixture with *Eucalyptus* in managed biomass plantations on the island of Hawaii.

STUDY AREA

The test was established near Onomea on an area typical of much marginal and abandoned sugarcane land along the Hamakua coast (19°30′ N, 155°15′ W). Elevation of the planting site is about 420 m, and annual rainfall is 5080 mm, distributed fairly evenly throughout the year. Slopes are gentle, ranging from 0 to 10 percent. The soil series is Akaka silty clay loam (thixotropic isomesic typic Hydrandept) and is acidic (pH 4.8-5.0). Nitrogen concentration is similar to that of most soils of the Hamakua coast, averaging about 0.6 percent in the 0- to 20-cm surface layer and 0.4 percent at the 40- to 80-cm depth. Sugarcane was produced on the land for more than 50 years, but was abandoned in 1978 because of low yields. Immediately before the study was started, the area was occupied by residual sugarcane that was heavily infested with California grass (*Brachiaria mutica* [Forsk.] Stapf.). The site was prepared for planting by using a Rome cut-away harrow, which flattened and cut up the sugarcane and grass to form a mulch. Developing vegetation was sprayed with glyphosate[1] prior to planting in 1979.

METHODS

The experimental design was a complete block with three treatments replicated in three blocks. Treatments were: (1) pure *Eucalyptus,* (2) *Eucalyptus* mixed with *Acacia melanoxylon,* and (3) *Eucalpytus* mixed with *Albizia falcataria.* The *Eucalyptus* seedlings consisted of *E. saligna* and *E. grandis;* one block contained *E. saligna* only, one block contained *E. grandis* only, and the third block contained a mixture of *E. grandis* and *E. saligna.* Differences associated with "block" in all analyses of tree size were not significant, however; thus, *E. saligna, E. grandis,* and the mixture thereof are treated and referred to as *Eucalpytus* in the rest of this paper.

In the *Eucalyptus*-legume mixture plots, *Eucalyptus* and either *Acacia* or *Albizia* were planted in alternate rows, thus providing a 50:50 mix. Three-month-old container seedlings were planted at 2 m by 2 m spacing (2500 trees per ha) in August 1979. Individual seedlings were fertilized with 115 g of N-P-K (14-14-14) at planting and 6 months later; each application was equal to about 40 kg N, P, and K per ha. In addition, *Eucalyptus* trees in pure plantings received 115 g of urea fertilizer (46 percent N) at 15 months—an application equal to about 130 kg N per ha. Thus, the test is to some degree a comparison of alternative methods of adding to N supply (synthetic fertilizer vs. N_2-fixing plants); unfortunately, subsequent performance of this plantation and other plantations in the area have indicated that this level of N fertilization is much below the optimum.

Plots were about 0.4 ha each, and growth measurements were collected on 50 interior trees of each genus *(Eucalyptus, Acacia,* and *Albizia)* present in each plot at approximately

[1]This publication does not contain recommendations for pesticide uses reported, nor does it imply that they have been registered by the appropriate government agencies.

6-month intervals. Heights were measured to the nearest 0.1 m with a telescoping pole and diameters were recorded to the nearest 0.1 cm by diameter tape. Stocking (trees per ha) was estimated at 65 months by tallying all live stems in five rows of 10 planting spots for trees of each genus in the center of each plot.

Foliage samples were collected from the upper crown of 10 to 15 interior *Eucalyptus* trees in each plot at 14 months. Dried foliage was analyzed for nutrient elements at the University of Hawaii as follows: total N by standard Kjeldahl procedure; P, total S, Ca, Mg, and K by X-ray fluorescence.

Soil samples were collected at 65 months from the 0- to 20-cm and 60- to 80-cm layers at 4 randomly selected points in the interior of each plot and composited by layer. Samples were air dried at room temperature in the C. Brewer Analytical Laboratory. Live roots and gravel were removed and discarded. Soil aggregates were crushed with a rolling pin, and the soil was passed through a 2-mm sieve. The 2-mm soil was weighed, and subsamples were taken for subsequent analyses. One subsample of soil from each plot was dried to constant weight at 100° C to determine moisture content. Soil pH was determined on soil-water pastes by glass electrode. Total N was estimated by the semimicro-Kjeldahl method (Bremner 1965). Minerals determined and analytical methods used were as follows: extractable P (extracted with Truog solution (Truog 1930) by the molybdenum blue technique (Chapman and Pratt 1961); exchangeable K, Ca, and Mg (extracted with neutral 1N NH_4OAC) by standard atomic absorption spectrophotometric methods.

Tree measurement (height and diameter) data were averaged for each plot and genus, and differences among treatments at each measurement date were evaluated by standard analyses of variance. When treatments were significantly different, the means were separated by Duncan's Multiple Range Test. Similar statistical procedures were applied to data from foliar and soil analyses. Patterns of stand development were compared by plotting average height against age for *Eucalyptus* in the three treatments and for each species in the *Eucalyptus*-legume mixtures.

Biomass at 65 months was estimated for *Eucalyptus* trees of mean basal area in each treatment with the equation: $\log_e$ Dry Weight = -3.8604 + 0.9644 $\log_e$ (Diameter^2 x Height). This equation was developed from trees of comparable age and size (n = 93, R^2 = 0.99, RMSE = 0.11).[2] The equation was also used to estimate dry weight of *Acacia* and *Albizia*, based on the following assumptions and modifications: (1) height-diameter relationships were approximately the same as for *Eucalyptus* in this trial; (2) wood density, moisture content, and branching patterns of *Acacia* were also similar to *Eucalyptus;* and (3) wood density of *Albizia* was about one-half that of *Eucalyptus*. We therefore used the equation without modification for *Acacia*. For *Albizia*, we multiplied the dry weight estimated with the equation by 0.50 and consider this to be a conservative estimate because multiple stems occurred on most trees. Mean tree weights were then multiplied by number of surviving trees per ha to provide estimates of dry biomass per ha.

Table 1—*Average sizes and survival of trees at 65 months in pure* Eucalyptus *and mixed* Eucalyptus-*legume plantings, Hawaii*[1]

Treatment and species	Mean dbh	Mean height	Stems per hectare	Sample size
	cm	*m*		
Pure:				
Eucalyptus	8.5 a	10.3 a	2200	3
Mixed:				
Eucalyptus	10.9 ab	12.8 ab	1012	3
Acacia	8.4	9.1	1012	3
Total			2024	
Mixed:				
Eucalyptus	13.2 b	16.8 b	838	3
Albizia	13.6	16.5	1225	3
Total			2063	
Root mean square error[2]	1.3	2.1		

[1]Means followed by the same letter do not differ significantly at the 5 percent level of probability.
[2]For comparing height and diameter values for *Eucalyptus*.

RESULTS AND DISCUSSION

Substantial differences existed among treatments at 65 months in size and number of remaining *Eucalyptus, Acacia* and *Albizia* trees *(table 1)*. Heights averaged 13.3 m for *Eucalyptus*, 9.1 m for *Acacia*, and 16.5 m for *Albizia;* diameters were 10.9 cm, 8.4 cm, and 13.6 cm, respectively. Height and diameter of *Eucalyptus* trees in the mixed plantings were greater than in the pure plantings even though the latter received additional N fertilizer. *Eucalyptus* grown with *Acacia* were 25 percent taller and 28 percent larger in diameter than those grown in pure plantings. *Eucalyptus* trees grown with *Albizia* were significantly larger (63 percent taller and 55 percent larger in diameter) than *Eucalyptus* in pure plantings.

Such differences in average size of *Eucalyptus* trees in the mixed species treatments were associated with increased competition-related mortality. About 2200 trees per ha remained in the pure *Eucalyptus* planting *(table 1);* thus survival was 88 percent. The mixture of *Eucalyptus* and *Acacia* had somewhat lower overall survival (81 percent) and the two species had equal survival. Average survival in the *Eucalyptus-Albizia* treatments was similar (83 percent) to that of the *Eucalyptus-Acacia* mixture, but the two species differed markedly. Only two-thirds of the *Eucalyptus* trees remained after 65 months whereas 98 percent of the *Albizia* survived.

Differences among treatments in size of *Eucalyptus* trees developed during the second growing season *(fig. 1)*. Heights and diameters did not vary significantly among treatments at 12 months, but the difference between *Eucalyptus* grown in

[2]This value for root mean square error is in terms of the natural logarithm of biomass.

pure plantings and those grown with *Albizia* became significant at 25 months and remained so throughout the study. At 30 months, *Eucalyptus* grown with *Acacia* averaged about 2 m taller than *Eucalyptus* grown in pure plantings, and this difference in height remained nearly constant to 65 months. Increase in the height difference for *Eucalyptus* grown with *Albizia* was gradual, however; from 30 to 65 months, the difference between *Eucalyptus* mixed with *Albizia* and those in pure plantings increased from 4 m to more than 6 m.

Average heights of *Acacia* and *Eucalyptus* were similar for 25 months after which *Eucalyptus* overtopped *Acacia* and more or less continued its early growth rate of nearly 3 m per year *(fig. 2)*. Growth rate of Acacia diminished from 25 to 65 months. Heights of *Albizia* and *Eucalyptus* also were about

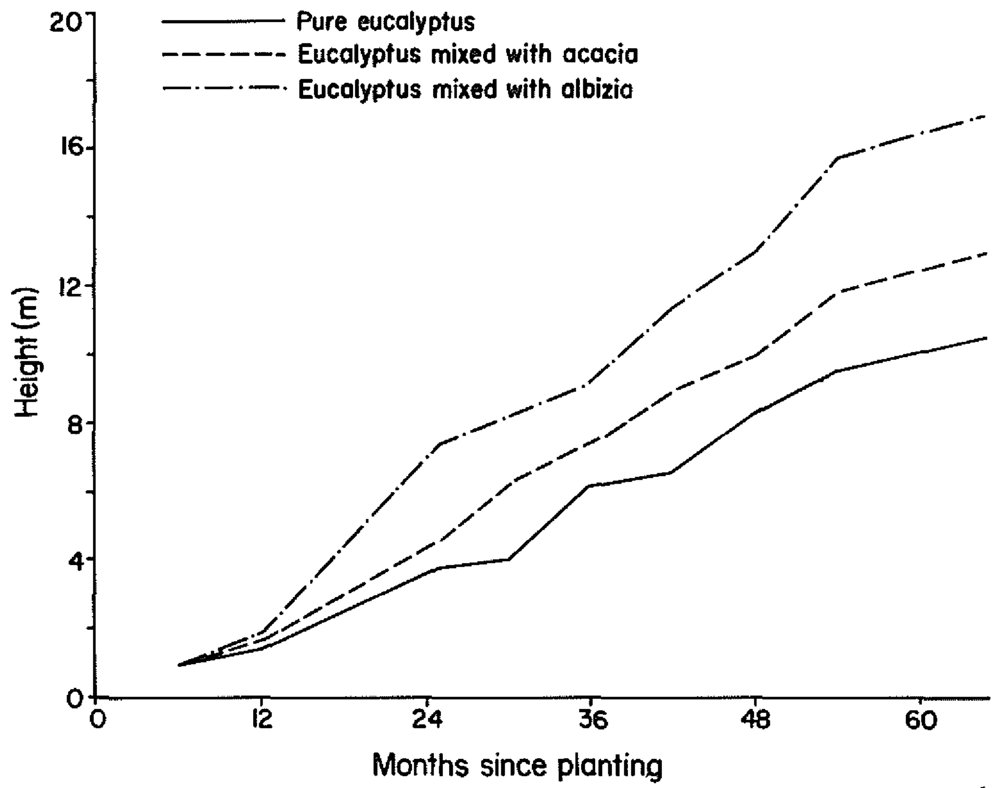

Figure 1—Average height of *Eucalyptus* trees grown in pure and mixed stands.

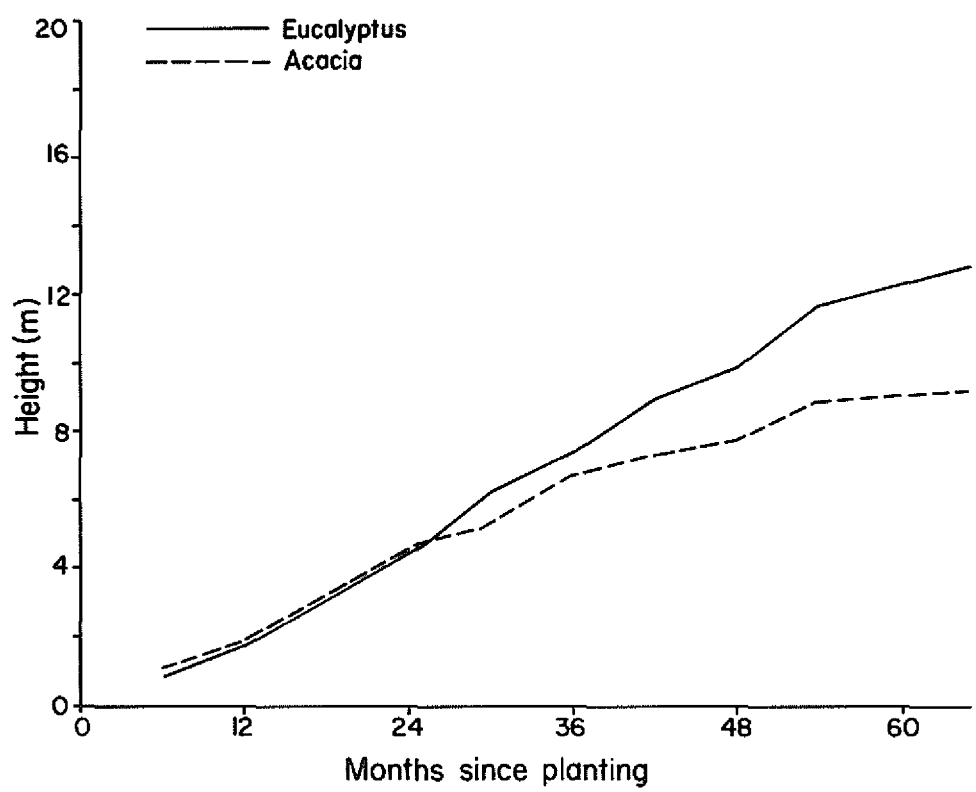

Figure 2—Average height of *Eucalyptus* and *Acacia* grown in mixture.

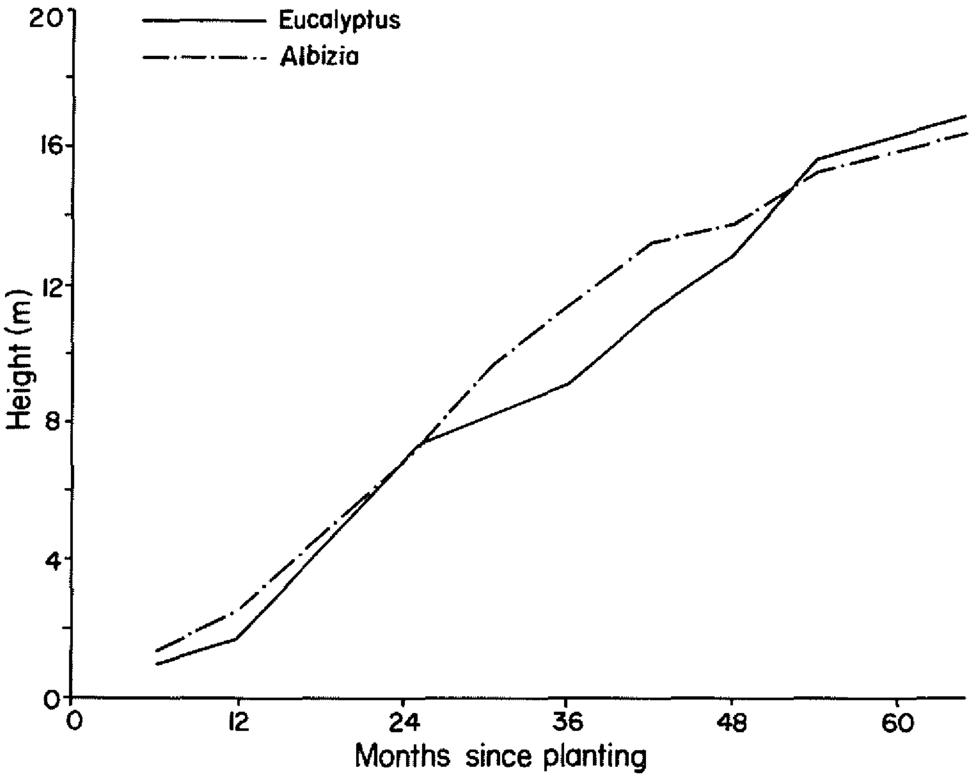

Figure 3—Average height of *Eucalyptus* and *Albizia* grown in mixture.

the same for the first 25 months, but *Albizia* overtopped *Eucalyptus* from 25 to nearly 54 months *(fig. 3)*. Despite its subordinate position in the mixed plantings for more than 2 years, *Eucalyptus* mixed with *Albizia* were taller than *Eucalyptus* in the other treatments throughout this period. This result is counter to our expectation concerning mixtures of nitrogen-fixing and other principal crop trees. We would expect growth of the latter to be depressed when they are overtopped by N_2-fixing trees and little apparent benefit until the principal crop trees attained a superior crown position. The *Eucalyptus* species in this experiment may be tolerant of the shade cast by the open, spreading canopy and feathery foliage of *Albizia;* possibly such light shade is even favorable. *Albizia falcataria* is used extensively in agroforestry in Java, and several agricultural and horticultural crops (annual and perennial) are grown beneath it (National Academy of Sciences 1979).

The enhanced height and diameter of *Eucalyptus* in mixed plantings were associated with greater gains in dry biomass yields *(table 2)*. Estimated dry weight of average *Eucalyptus* trees in pure plantings was about 17 kg; weights were 104 percent and 306 percent greater for *Eucalyptus* grown with *Acacia* and *Albizia,* respectively. Increased growth in the mixtures was accompanied by greater mortality, but yields per hectare were substantially higher than yields in pure *Eucalyptus* plantings. Despite the presence of less than one-half as many *Eucalyptus* trees in the mixtures, dry weight of *Eucalyptus* alone in the mixture with *Acacia* was nearly equal to that in pure plantings; weight of *Eucalyptus* in the mixture with *Albizia* was 55 percent greater than that in pure plantings. When estimated weights of the leguminous trees were included, total dry yield of the *Eucalyptus-Acacia* planting was 37 percent greater than yield in pure *Eucalyptus* planting, and yield of *Eucalyptus-Albizia* plantings was about 2.5 times that of the pure planting. Such yields represent mean annual production rates (tonnes per ha) of 6.9 for pure *Eucalyptus,* 9.5 for *Eucalyptus-Acacia,* and 17.6 for *Eucalyptus-Albizia* plantings.

Data on foliar concentrations of macronutrients *(table 3)* suggest that increased nitrogen is responsible, at least in part, for the subsequent enhanced growth of *Eucalyptus* in the mixed plantings. At 14 months, N concentration averaged 9

Table 2—*Sizes of mean trees and estimated yields of dry biomass at 65 months for pure* Eucalyptus *and mixed* Eucalyptus-*legume plantings, Hawaii*

Treatment and species	Tree of mean basal area		Dry weight per mean tree	Dry weight per hectare
	Dbh	Height		
	cm	*m*	*kg*	*tonnes*
Pure:				
Eucalpytus	9.5	11.6	17.1	37.6
Mixed:				
Eucalpytus	12.1	14.9	34.9	35.3
Acacia	9.3	11.3	16.0	16.2
Total				51.5
Mixed:				
Eucalpytus	15.3	19.0	69.4	58.2
Albizia	14.6	18.1	30.3	37.1
Total				95.3

percent and 32 percent higher in foliage of *Eucalyptus* mixed with *Acacia* and *Albizia,* respectively, than in foliage of pure *Eucalyptus* plantings. Even the highest foliar N concentrations attained in this study were quite low for *Eucalyptus.* Thus, it is quite probable that N remained a major factor limiting production in all treatments. Some of the other macronutrients also tended to be higher in the mixed plantings, especially those plantings including *Albizia.* Such increases in concentrations of non-nitrogenous macronutrients may be related to enhanced root growth (hence, increased exploitation of soil) or to increased rates of nutrient cycling (hence, greater availability) associated with additions of nitrogen-rich litter to the soil in the mixed plantings, or to both conditions.

Analyses of macronutrients and pH in soils collected at 65 months in the various treatments *(table 4)* do not shed light on factors responsible for superior growth performance of the mixed plantings or present clearcut evidence of treatment effects on the soils. Only extractable K in the 0- to 20-cm soil layer differed significantly among treatments. Some trends, however, are noteworthy. Concentrations of total N, extractable P, and extractable K were slightly lower in the mixed species treatments, and appeared to vary inversely with growth and yield of the treatments. Presumably the lower amounts of these nutrients reflect greater uptake by the vegetation in the mixed plantings. The higher concentrations of Ca and Mg and slightly higher pH in the surface soil layer of the *Eucalyptus-Albizia* plantings were surprising, and are at variance to recent findings as to soil changes beneath a major nitrogen-fixing tree (*Alnus rubra* Bong.) in the temperate zone (DeBell et al. 1983; DeBell and Radwan 1984). With alder and some agricultural legumes, nitrification rates increase as N accumulates in the soil leading to a decrease in pH; concomitantly, Ca and Mg are leached to lower levels of the soil profile. Nitrogen did not increase in soil beneath the treatments containing N_2-fixing legumes in the present study, and this may partially account for such contrasting results. Moreover, we know little about uptake and cycling of calcium and magnesium in *Acacia* and *Albizia* stands.

Table 3—*Concentrations of nutrients in* Eucalyptus *foliage collected at 14 months, Hawaii*[1]

Treatment	N	P	K	Ca	Mg	S	Sample size
	Percent						
Pure	.88a	.11a	.67a	.71a	.37a	.11a	3
Mixed:							
with *Acacia*	.96b	.12a	.87b	.73a	.37a	.12a	3
with *Albizia*	1.16c	.13b	.91b	.91b	.36a	.14b	3
Root mean square error[2]	.019	.003	.050	.071	.050	.003	

[1]Means followed by the same letter do not differ significantly at the 5 percent level of probability.

[2]For comparing nutrient values among treatments.

Table 4—*Concentrations of macronutrients and pH in soils beneath pure* Eucalyptus *and mixed* Eucalyptus-*legume plantings at 65 months*

Treatment	Soil depth	N	P	K	Ca	Mg	pH
	cm	*Percent*	*ppm*				
Pure *Eucalyptus*	0-20	0.62	16	29	32	33	5.2
	60-80	.45	10	16	55	33	5.4
Mixed:							
with *Acacia*	0-20	.57	13	26	27	21	5.2
	60-80	.42	8	16	21	9	5.4
with *Albizia*	0-20	.55	12	14	78	54	5.4
	60-80	.41	6	9	52	24	5.5
Root mean square error[1]	0-20	.07	6	7	11	31	0.4
	60-80	.09	6	7	10	24	0.3

[1]For comparing macronutrient concentrations and pH in soils among treatments at each soil depth.

CONCLUSIONS

Eucalyptus growth can be increased substantially by planting the species in mixture with leguminous trees. *Eucalyptus* trees in mixed plantings were larger than those in pure plantings even though the latter received an additional fertilizer amendment equivalent to about 130 kg N per ha. Total biomass production was also much greater in the mixed species plantations.

Albizia appears especially promising for inclusion in such mixtures. It led to the best *Eucalyptus* growth (per tree and per hectare) despite the fact that it overtopped *Eucalyptus* for a considerable length of time and *Eucalyptus* survival was lowest when mixed with *Albizia.* Based on other studies, however, we know that relative growth patterns of *Eucalyptus* and *Albizia* vary greatly with site conditions and therefore effects of *Albizia* on *Eucalyptus* growth and on total biomass production may differ on other sites.

Information on foliar nutrient concentrations obtained in this experiment confirms a close relationship between nitrogen status and growth of *Eucalyptus.* The possibility that admixtures of legumes may enhance availability and cycling of mineral macronutrients as well as nitrogen merits further study. We also need to confirm and understand the factors responsible for the differences or lack thereof in soil properties in the various treatments: Why did N concentrations not increase in the soil beneath the mixed plantings containing N_2-fixing trees? Why did Ca, Mg, and pH values tend to be higher beneath *Albizia*-containing treatments? Although the individual tree growth and total crop yield advantages of the mixed species plantings are obvious, additional information on nutrients is needed to appraise the long-term economic and ecological costs and benefits of using legumes in mixture or in rotation with *Eucalyptus.*

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Two *Eucalyptus* species—*E. saligna* Sm. and *E. grandis* Hill—are especially favored in Hawaii for wood, fiber, and fuel production because of their quick growth and high yields. Their growth is limited, however, on many sites by low levels of available nitrogen. Supplemental nitrogen can be provided by nitrogen-fixing plants, such as legumes. A test was conducted to determine whether planting two leguminous species—*Acacia melanoxylon* R. Br. and *Albizia falcataria* (L.) Fosberg—could increase biomass production. Results after 65 months suggest that *Eucalyptus* growth can be increased substantially by planting the species in mixture with leguminous trees. Total biomass production was much greater in the mixed species plantations than in the pure *Eucalyptus* plantation.

Retrieval Terms: Eucalyptus, Eucalyptus saligna, Eucalyptus grandis, Acacia melanoxylon, Albizia falcataria, legumes, species trials, plantations, Hawaii