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Saligna Eucalyptus Growth in a 15-Year-Old Spacing Study in Hawaii

Gerald A. Walters

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A spacing study was started in 1961 to test the effects of four different spacings on the growth and development of saligna eucalyptus *(Eucalyptus saligna* Smith) trees in Hawaii. Spacings tested were 8 by 8 feet (2.4 m), 10 by 10 feet (3.0 m), 12 by 12 feet (3.7 m), and 14 by 14 feet (4.3 m). Plot trees were measured at ages 1, 2, 5, 10, and 15 years. Measurements included d.b.h., total height, height to a 4- and 9-inch (10.2- and 22.9-cm) top (outside bark), and height to live crown. Board feet and cubic foot volumes were determined. After 15 years, trees 140 to 150 feet tall were common in all spacings. Average d.b.h. ranged from 8.6 inches (21.8 cm) in the 8- by 8-foot spacings to 12.5 inches (31.8 cm) in the 14- by 14-foot spacings. Large volumes of wood were produced, averaging more than 29,000 board feet per acre, or more than 7600 cubic feet per acre (532 m^3/ha).
Retrieval Terms: Eucalyptus saligna, Hawaii, plantation spacing, volume increment.

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Retrieval Terms: Eucalyptus saligna, Hawaii, plantation spacing, volume increment

In 1961, a spacing study was begun to test the effects of four different spacings on the growth and development of saligna eucalyptus *(Eucalyptus saligna* Smith) trees. The study site was on the north slope of Mount Haleakala on the island of Maui. Spacings tested were 8 by 8 feet (2.4 m), 10 by 10 feet (3.0 m), 12 by 12 feet (3.7 m), and 14 by 14 feet (4.3 m). Because at the start of this study the only anticipated use of saligna was for sawtimber, these spacings are wider than those used for pulp and fuelwood production.

A randomized block design provided four replications of each of the four spacings tested. A 25-tree measurement plot was established in each spacing in each replicate. Plot trees were measured at ages 1, 2, 5, 10, and 15 years. Measurements included d.b.h., total height, height to a 4- and 9-inch (10.2- and 22.9-cm) top (outside bark), and height to live crown. Board-foot and cubic-foot volumes were determined.

Saligna trees in all trial spacings grew rapidly. Average height of all trees varied by spacing and ranged from 87 to 112 feet (26 to 34 m). Trees attained from 70 to 90 percent of their total height, depending on spacing, by the fifth year after planting. Sawtimber trees (those at least 11 inches [27.9 cm] d.b.h.) averaged about 129 feet (39 m) after 15 years, with no significant differences between spacings. Trees 140 to 150 feet (43 to 46 m) tall were common at all spacings.

Diameter growth in all spacings was rapid, and was most rapid during the first few years. Diameter growth curves indicated that competition became a factor before 5 years. By 15 years, diameter ranged from 8.6 inches (21.8 cm) for trees in the 8-foot spacings to 12.5 inches (31.8 cm) for trees in the 14-foot spacings. Average d.b.h. differences between spacings were statistically significant at the 5 percent level.

Rate of basal area increase was greater for all spacings between 2 and 5 years after planting. After 15 years, basal area ranged from 154 square feet per acre (35 m^2/ha) for the 14-foot plots to 295 square feet per acre (56 m^2/ha) for the 8-foot plots.

Saligna trees in all spacings produced large volumes of wood in just 15 years—about 29,000 board feet per acre. Because the 14-foot spacing requires fewer seedlings to plant and maintain, and because fewer trees need to be harvested than for the narrower spacings, it is probably the best of the spacings tested in terms of economics to use for sawtimber yield. An average of 7600 cubic feet per acre (532 m^3/ha) of pulpwood was produced in 15 years. For pulpwood, the narrower spacings resulted in a larger volume per unit area than the wider spacings. This study, however, did not indicate which spacing is best for pulpwood. Perhaps a spacing narrower than 8 by 8 feet would result in a greater volume per unit area.

Saligna eucalyptus (*Eucalyptus saligna* Smith) is one of the most commonly planted tree species in Hawaii. It thrives on a variety of sites and produces a large volume of wood in short periods (Carlson and Bryan 1959, LeBarron 1962). Trees more than 150 feet tall and 3 feet in diameter are not unusual in Hawaii. Some trees may grow more than 100 feet tall in only 5 years (Walters and Schubert 1969). In a 30-year-old stand, 94,000 board feet (Int. 1/4-inch rule) per acre were tallied (Pickford and LeBarron 1960).

Saligna wood is used locally for general construction lumber, flooring, pallets, and fuel. It is potentially useful for poles and pilings, furniture, and particle board. Some saligna wood chips are exported from Hawaii to Japan for the manufacture of paper.

Presently in Hawaii, seedlings are planted at 10- by 10-foot (3.0-m) spacing, but in the past, tree spacings ranged from 5 by 5 (1.5 m) to 20 by 20 feet (6.1 m). The optimum spacing—one that results in the greatest yield in size, form, and quality of trees required—is not known.

The Forest Service, U.S. Department of Agriculture, and the Hawaii Division of Forestry began a study in 1961 to test the effects of four different spacings on the growth and development of saligna eucalyptus trees. At that time, the anticipated use of saligna was solely for sawtimber. Because small trees were not commercially marketable, the study's only objective was to determine which spacing would result in the largest volume of sawtimber in the least time. The market for both sawtimber and pulpwood is expanding. The spacings tested provide information for sawtimber and for sawtimber and pulpwood production. But they do not provide adequate information on just pulpwood production because all spacings tested were too wide for maximum volume production.

STUDY SITE

The study area lies on the north slope of Mount Haleakala, a 10,000-foot (3050-m) high dormant volcano that forms the eastern portion of the island of Maui. Slopes vary from 10 to 70 percent. Elevation is 500 feet (150 m). Annual rainfall of about 150 inches (3800 mm) is evenly distributed throughout the year. The soil is classified as Kailua silty clay of the thixotropic, isothermic family, Typic Hydrandepts group. It is deep, well drained, depleted of bases, and low in available phosphorus with a strongly acid A horizon and a moderately acid B horizon.

METHODS

Seed was collected from trees growing on the islands of Maui and Hawaii. Seedlings were grown in flats at the Hawaii Division of Forestry nursery at Kahului, Maui. The flats were taken to the site, where only thrifty seedlings of uniform size were planted.

A randomized-block design provided four replications of the four spacings being tested: 8 by 8 (2.4 m) 10 by 10 (3.0 m), 12 by 12 (3.7 m), and 14 by 14 (4.3 m) feet. A measure plot with 25 trees was established in each spacing in each block. Plot trees were measured at ages 1, 2, 5, 10, and 15 years. Measurements included diameter-at-breast-height (d.b.h.), total height, height to a 4-inch (10.2-cm) and 9-inch (22.9-cm) top (outside bark), and height to live crown. Board foot volumes were determined using the International ¼-inch formula. Whole tree volumes were determined using the formula

$$V = D^2 (0.001818\,H + 0.01636)$$

in which

V = volume in cubic feet

D = diameter (outside bark) in inches at 4.5 feet (1.4 m) above ground (d.b.h.)

H = total height in feet

This equation interprets each tree as a cylinder from ground level to breast height and a cone from breast height to tip (Meskimen and Franklin 1978).

The cubic foot volume of the stem above the 9-inch top diameter was determined using Smalian's formula

$$V = L\frac{(b+t)}{2}$$

in which

V = volume in cubic feet

b = area in square feet at large end of log

t = area in square feet at small end of log

L = length of log in feet

Analyses of variance techniques were used to test treatment differences.

Stem Height

Saligna eucalyptus trees in all trial spacings grew taller in 15 years than most United States mainland broad-leaved and coniferous species grow in 80 years. Saligna, like other eucalyptus species, is a "sprinter" —height growth is rapid for about the first 5 years, then slows. Periodic measurements of the trees in this study show this sprinter trend *(fig. 1)*. Trees attained 70 to 90 percent of their present height, depending on spacing, by the fifth year after planting. Annual height growth of trees in all spacings averaged 14 feet (4.3 m) for the first 5 years, 4 feet (1.2 m) for the second 5 years, and about 1 foot (0.3 m) for the third 5 years.

When all trees in the measure plots were included, stem height curves varied by spacing *(fig. 1)*. No significant differences in stem height were found at 2, 5, or 10 years, but were found at 15 years *(table 1)*. Trees in the 12- and 14-foot spacings averaged about 111 feet (33.8 m), significantly taller (5 percent level) than trees in the 10-foot spacing that averaged 96 feet (29.3 m). Trees in the 10-foot spacing, on the average, were significantly taller than trees in the 8-foot spacing. Trees in the 8-foot spacing plots averaged 87 feet (26.5 m) tall—5 feet (1.5 m) shorter than 5 years before. The slower rate of height growth for trees in the 10-foot spacings and the decrease in average stem height for trees in the 8-foot spacings was apparently the result of increased competition. Some of the less vigorous trees became suppressed; some even died back. Sawtimber trees—those at least 11 inches (27.9 cm) d.b.h. in all spacings—averaged 116 feet (35.4 m) at 10 years, and 129 feet (39.3 m) at 15 years after planting. Differences between average height by spacing for sawtimber trees at either measurement time were not significant.

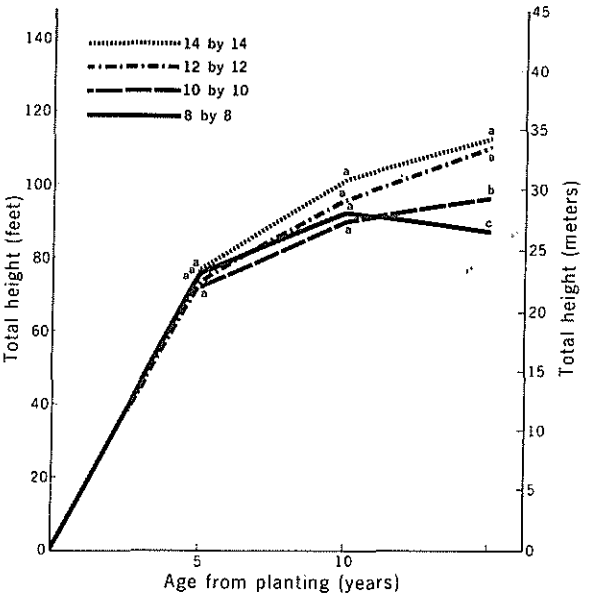

Figure 1—Cumulative height growth of saligna eucalyptus (all trees), by spacing. Means for trees of the same age with the same letter do not differ significantly at the 5 percent level.

The largest tree measured at 15 years was 161 feet (49.1 m) tall and 24.4 inches (61.2 cm) in diameter in the 14-foot spacing. Trees 140 to 150 feet (43 to 46 m) tall were common at all spacings.

Stem Diameter

Diameter growth of trees in all spacings was rapid. Diameter growth curves were similar to the height

Table 1—*Stand density, basal area, diameter, and height of saligna eucalyptus trees 15 years after planting, by spacing*

Spacing *(Feet [m])*	Stand density		Basal area	Diameter-at-breast-height (d.b.h.)		Height	
	All trees	Sawtimber[1]		All trees	Sawtimber[1]	All trees	Sawtimber[1]
	Trees/acre (Trees/ha)		*Ft²/acre (m²/ha)*	*Inches (cm)*			*Feet (m)*
8 by 8 (2.4)	524 (1294)	162 (400)	[2]245 a (56)	[2]8.6a (21.8)	13.1 d (33.3)	87 a (26)	126 d (38)
10 by 10 (3.0)	362 (894)	154 (380)	221 ab (50)	9.6 a (24.4)	13.4 d (34.0)	96 b (29)	125 d (38)
12 by 12 (3.7)	242 (598)	136 (336)	189 bc (43)	11.1 b (28.2)	14.4 e (36.6)	110 c (34)	133 d (40)
14 by 14 (4.3)	164 (405)	100 (247)	154 c (35)	12.5 c (31.75)	15.1 f (38.4)	112 c (34)	131 d (40)

[1] Sawtimber trees are those 11.0 inches (27.9 cm) d.b.h. and larger.

[2] Values followed by the same letters are not significantly different at the 5 percent level.

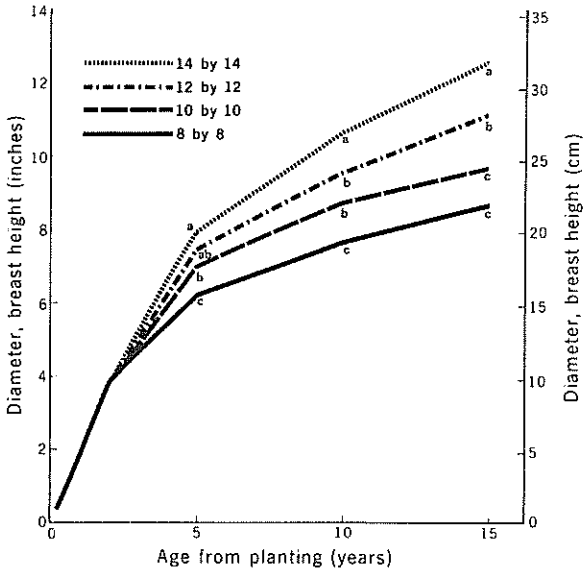

Figure 2—Cumulative diameter growth of saligna eucalyptus (all trees), by spacing. Means for trees of the same age with the same letter do not differ significantly at the 5 percent level.

growth curves; that is, they were rapid for about the first 5 years, then slower *(fig. 2)*. Trees in each spacing averaged 3.8 inches (9.6 cm) in diameter after 2 years. The divergence of the curves after 2 years indicates that competition became a factor before 5 years. The periodic annual diameter increment was less between 2 and 5 years than it was between 0 and 2 years for all spacings. Between 5 and 10 years, the periodic annual increment was only about one-third of what it was between 2 and 5 years for all spacings *(table 2)*. Rate of growth continued to decline between 10 and 15 years.

By 15 years, diameter ranged from 8.6 inches for trees in the 8-foot spacing *(fig. 3)* to 12.5 inches for trees in the 14-foot spacing. Diameter varied significantly (5 percent level) with spacing *(table 1)*. Average diameter of trees in the 14-foot plots was significantly greater than that of trees in the 12-foot plots. Diameters of trees in the 8- and 10-foot spacings were significantly less than those in the 12-foot plots, but any difference between the 8- and 10-foot spacings was not significant. Significant differences between d.b.h. and spacing were also found when only sawtimber trees were considered. The percentage of sawtimber-size trees increased as spacing increased, from 31 percent for the 8-foot spacings to 61 percent for the 14-foot spacings. The 8-foot spacings, however, contained the largest number of sawtimber-size trees *(table 1)*.

Table 2—*The periodic annual diameter increment of saligna eucalyptus trees by spacing*

Spacing	Measurement periods (years after planting)			
	0 to 2	2 to 5	5 to 10	10 to 15
Feet (M)	*Inches (Cm)*			
8 by 8 (2.4)	1.9 (4.8)	1.0 (2.5)	0.3 (0.8)	0.2 (0.5)
10 by 10 (3.0)	1.9 (4.8)	1.3 (3.3)	.3 (0.8)	.2 (0.5)
12 by 12 (3.7)	1.9 (4.8)	1.4 (3.6)	.4 (1.0)	.3 (0.8)
14 by 14 (4.3)	1.9 (4.8)	1.6 (4.1)	.5 (1.3)	.4 (1.0)

Basal Area

For each measurement, basal area increment was greatest for the 8- by 8-foot plots. The rate of basal area increase was greatest for all spacings between 2 and 5 years after the trees were planted *(fig. 4)*. The rate of increase ranged from 17 square feet per acre per year (4 m^2/ha/yr) for the 14-foot spacing to 33 square feet per acre per year (8 m^2/ha/yr) for the 8-foot spacing. The rate of basal area accumulation for each spacing between 5 and 15 years was about 10 square feet per acre per year (2 m^2/ha/yr). After 15 years, basal area ranged from 154 square feet per acre (35 m^2/ha) for the 14-foot plots to 245 square feet per acre (56 m^2/ha) for the 8-foot plots *(table 1)*.

Stem Quality

After 15 years, sawtimber-size trees in all spacings averaged about 100 feet (30 m) to a 4-inch (10-cm) top. Height to live crown averaged about 75 feet (23 m). Differences among spacings were not significant. Only 2 or 3 percent of the trees in each spacing had severe crooks, sweeps, or other deformities that made them unmerchantable for sawtimber.

Table 3—*Sawtimber volume and cubic foot volume after 15 years, by product and spacing*

Spacing	Product (volume)		
	Sawtimber[1] and pulpwood[2]		Pulpwood only
Feet (M)	*M bd ft/acre*	*Ft^3/acre (m^3/ha)*	*Ft^3/acre (m^3/ha)*
8 by 8 (2.4)	[3]27.3 a	3060 (214)	[3]9759 a (683)
10 by 10 (3.0)	28.3 a	2275 (159)	8930 a (625)
12 by 12 (3.7)	31.3 a	1345 (94)	8672 a (607)
14 by 14 (4.3)	29.9 a	530 (37)	7096 a (496)

[1] Board foot volume—International 1/4 Rule, trees 11.0 inches (27.9 cm) d.b.h. and larger measured to 9-inch (22.9-cm) top diameter, outside bark.

[2] This pulpwood volume consists of trees with d.b.h. ranging from 4.0 to 10.9 inches (10.2 to 27.7 cm) and tops of sawtimber, i.e., the stem above the 9-inch top diameter.

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

Figure 3 — Saligna eucalyptus in an 8- by 8-foot spacing plot 15 years after planting. Trees in the 8-foot plots averaged 8.6 inches (21.8 cm) d.b.h. and 87 feet (26.5 m) tall, and yielded more than 9759 cubic feet per acre (683 m^3/ha).

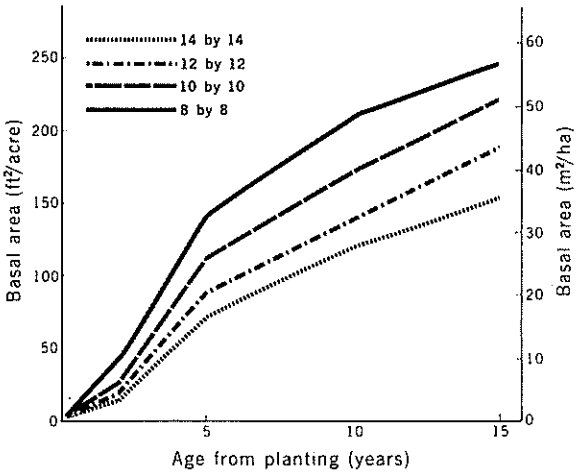

Figure 4 — Cumulative basal area growth of saligna eucalyptus, by spacing.

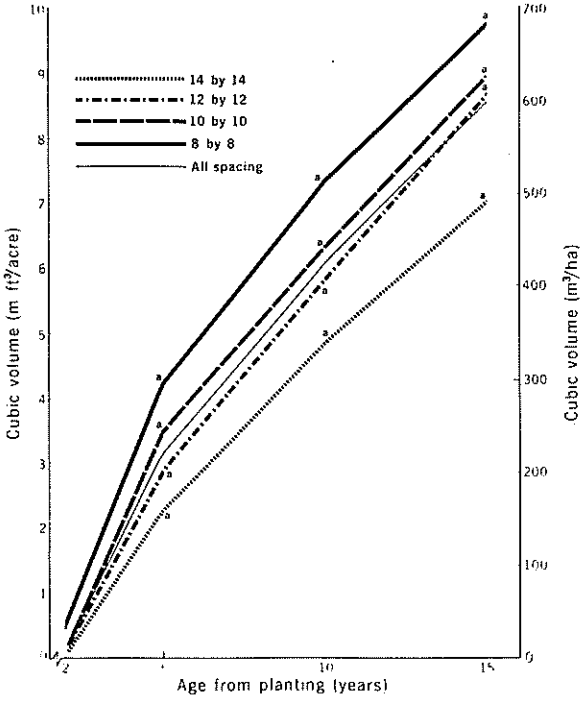

Figure 5 — Mean annual volume increment of saligna eucalyptus, by spacing.

Stem Volume

Trees in all spacings produced large volumes of *sawtimber* in 15 years, ranging from 27,300 board feet per acre for the 8-foot spacing to 31,301 board feet per acre for the 12-foot spacing *(table 3)*. These volumes represent an annual growth rate of 1800 board feet per acre for the 8-foot spacing and 2100 board feet for the 12-foot spacing. The greatest volume produced on a *plot* basis was 41,180 board feet per acre in a 10-foot spacing. Because of variation in replication, differences in mean volume per acre by spacing were not statistically significant at the 5 percent level.

In addition to the sawtimber volume produced per acre, a substantial amount of *pulpwood* volume was produced. Pulpwood in a sawlog-pulpwood operation consists of the upper stems of sawtimber-size trees and of trees between 4 inches (10.2 cm) and 11 inches (27.9 cm) d.b.h. Pulpwood volume decreased as spacing increased, ranging from 3060 cubic feet per acre (214 m^3/ha) for the 8-foot spacings to 530 cubic feet per acre (37 m^3/ha) for the 14-foot spacings *(table 3)*.

The total volume of pulpwood produced ranged from 9759 cubic feet per acre (683 m^3/ha) for the 8-foot spacings to 7096 cubic feet per acre (496 m^3/ha) for the 14-foot spacings. Although mean total volume increased as spacing decreased for each of the measurements *(fig. 5)*, differences in volume per area by spacing were not statistically significant. As with board foot volumes, large variations among replications masked any significant differences between spacings.

Mean annual volume increment varied with spacing and was greatest for the trees in the 8-foot spacing and least for those in the 14-foot spacing *(fig. 6)*. The mean annual volume increment was greatest at 5 years for trees in the 8- and 10-foot spacings, and then declined. Trees in the 12- and 14-foot spacings reached maximum mean annual increment after about 10 years.

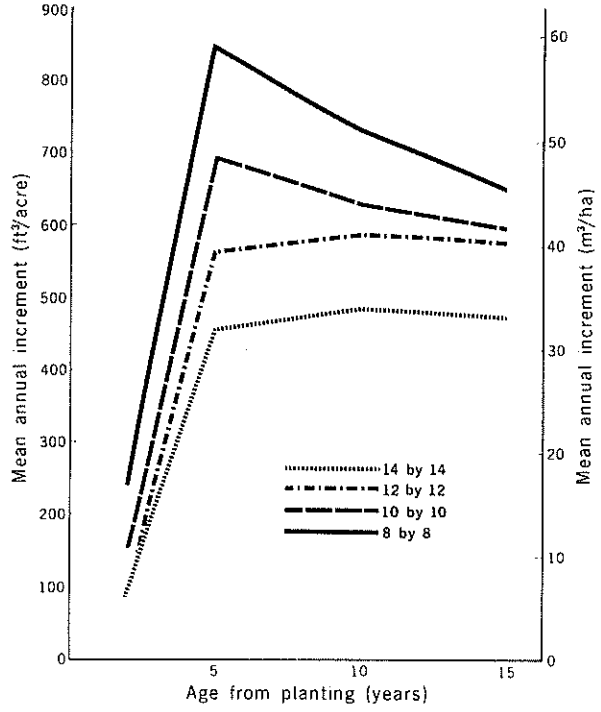

Figure 6—Mean annual volume increment of saligna eucalyptus, by spacing.

DISCUSSION

This study was begun in 1961 when the only use anticipated for saligna eucalyptus was sawtimber. The objective was to determine which of the spacings tested would result in the greatest yield of sawtimber in the shortest time. Saligna eucalyptus has not proven to be a very good sawtimber tree because of growth stresses that develop in the stem as the tree grows. When older trees are harvested, the effects of growth stress, including log end-splitting, spring in sawing, and the compression failures of brittleheart become serious problems. Wood density within the tree also becomes more variable as age increases. Skolmen (1974) found the effects of growth stress less in younger trees, about 12 years old. Lumber from the young trees is generally of lower grade, but because of its lower density and easier working characteristics, it has a greater potential for use in general construction than wood from older trees.

A pulpwood market also has developed since the study was begun. Available saligna eucalyptus trees are being chipped and sent to Japan for the manufacture of paper. Saligna chips may also be used as a fuel in Hawaii. One ton (oven dry) of saligna chips is about equivalent in Btu's to 2.7 barrels of Bunker c fuel oil (Yang and others 1977).

Sawtimber

Saligna trees in all spacings produced about the same board foot volume in 15 years (differences were not statistically significant)—about 29,000 board feet per acre. This volume yield was from only 100 sawtimber trees per acre at the 14-foot spacing, whereas it was from 162 trees per acre at the 8-foot spacing. More than 61 percent of the trees in the 14-foot spacing were of sawtimber-size as compared with only 31 percent in the 8-foot spacing. Because the 14-foot spacing requires fewer seedlings to plant and maintain, and because fewer trees need to be harvested than for the narrower spacings, it is probably the best of the spac-

ings we tested in terms of economics to use for a sawtimber operation. Because of the problems that result from growth stress in older eucalyptus, trees in the 14-foot spacing should be harvested at 15 years of age. For the 8-foot spacing, it may be best to delay harvesting until a higher percentage of the trees reach sawtimber-size. With the competition that exists in the narrow spacings, however, diameter growth would only be about 0.2 inch per year. This extension of the rotation would, of course, add to the overall costs that the increased yield may or may not cover. Trees smaller than sawtimber-size can be used for pulpwood. Because pulpwood is a product lower in value than sawtimber, it is desirable to use as many trees as possible for sawtimber.

Pulpwood

In a pulpwood operation, it is desirable to fully utilize the site as quickly as is practical and harvest the trees when mean annual cubic volume increment culminates. In this study, mean annual cubic volume increment culminated at about 5 years for trees in both the 8- and 10-foot spacings. By then, the 8-foot spacings contained an average of about 4200 cubic feet per acre (294 m^3/ha) and the 10-foot spacings contained an average of about 3500 cubic feet per acre (245 m^3/ha). Diameter (breast height) of trees in the 8-foot spacings averaged 6.2 (15.8 cm) and in the 10-foot spacings averaged 7.0 inches (17.8 cm). Trees in both spacings averaged about 74 feet tall. The cubic foot volume produced in 5 years in the 8-foot spacing was almost 4 times the volume produced in an 8-foot spacing in a Florida study in 7.4 years (Meskimen and Franklin 1978). The species in the Florida study was *Eucalyptus grandis*, one closely related to *E. saligna*. The annual volume growth rate of 840 cubic feet per acre (59 m^3/ha) for trees in the 8-foot spacing was 2 to 3 times more than the rates reported for eucalyptus growing in Latin America, South Africa, and Australia (Carter 1974). If one cubic foot equals about 28 pounds, then 840 cubic feet equal 23,520 pounds (10,669 kg) or about 11.7 tons (10.4 tonnes) (dry weight). In terms of Btu's, this dry weight is equivalent to about 32 barrels of oil produced per acre per year. For trees in the 12- and 14-foot spacings, mean annual volume increment culminated at about 10 years. At 10 years the cubic foot volume in the 14-foot spacing was 34 percent less than it was in the 8-foot spacing, whereas the cubic foot volume in the 12-foot spacing was 20 percent less. For a pulpwood operation, the narrower spacings result in a larger volume per unit area than the wider spacings. This study does not indicate however, what spacing is best for a pulpwood operation. Perhaps a spacing narrower than 8 by 8 feet should be attempted.

Combination Sawtimber/Pulpwood

In a combination sawlog/pulpwood operation, trees could be planted close, perhaps 6 by 6 feet (1.8 m), and then thinned at the age of 3 to 4 years, depending on the severity of the competition. Thinned material, including deformed or low vigor trees, or both, could be chipped. Thinning could be such that spacing of crop trees of about 12 by 12 feet (3.7 m) or 14 by 14 feet (4.3 m) would result. Crop trees should be harvested at 12 to 15 years. Utilization could be complete—sawlogs and pulpwood. This study does not provide information as to what initial spacing is best, when the thinning(s) should be made, or the volumes of sawlogs or pulpwood produced.

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