Reprinted from the SOUTHERN JOURNAL
OF APPLIED FORESTRY
Vol. 1, No. 1, February 1978

Spacing *Eucalyptus grandis* in Southern Florida

A Question of Merchantable versus Total Volume

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ABSTRACT. The volume in merchantable trees (4 inches d.b.h. and larger) was about the same at spacings of 4 × 8, 8 × 8, 12 × 8, and 16 × 8 feet for Eucalyptus grandis *trees at plantation age 7.4 years in Glades County, Florida. Total volume in all stems, however, was 1.7 times greater at the closest spacing than at the two widest spacings. Thus, in a conventional pulpwood system, merchantable yields equal to those from closer spacings could be obtained from the wider spacings at lower cost for establishment and harvest. However, if merchantability limits could be circumvented by field chipping small trees, volume yields 16 to 68 percent greater could be achieved by planting at close spacings. Neither wood quality nor tree height was appreciably affected by stand density over the range of spacings tested. If the harvesting system is unknown at planting time, a spacing of about 6 × 12 feet is probably best.*

Eucalyptus grandis Hill ex Maiden is being planted operationally in southwestern Florida because

- it has repeatedly demonstrated commercial growth potential in local screening trials;
- locally grown wood has produced quality facial tissue in a mill-scale pulping test;
- genetically improved planting stock is available in quantity from second- and third-generation seed orchards;
- the anticipated rotation is eight to 10 years;
- stump sprouts should provide two or more coppice rotations before it is necessary to replant seedlings.

With coppice reproduction, the initial spacing constitutes a commitment over several rotations affecting total volume production, merchantable volume production, and average stem size at harvest. This study analyzed how spacing affected volume yield, tree size, bark thickness, wood and bark density, and proportion of merchantable stems.

PLANTING AND MEASUREMENTS

In August 1964 we planted an unimproved Australian seedlot on beds spaced 8 feet apart. Varying the planting interval along beds gave the following rectangular spacing treatments:

Spacing (ft.)	*Ft²/tree*	*Trees/acre*
4 × 8	32	1361
8 × 8	64	681
12 × 8	96	454
16 × 8	128	340

Buffer rows as wide as the assigned spacing surrounded each data plot of 0.097 acre, which was planted with 132, 66, 44, or 33 trees depending on spacing treatment. The layout was a randomized complete block design with four replications on one site—a native palmetto prairie of the Smyrna soil series, a sandy, siliceous, hyperthermic family of Aeric Haplaquods. Three months before planting we had cross-disked the site, broadcast 1,800 pounds per acre of ground rock phosphate, then bedded.

At plantation age four years we counted survival and measured height and diameter at 33 randomly selected planting spots in each plot. At 7.4 years, just before harvest, we measured all trees in the data plots and calculated whole-tree volumes using the formula: $V = D^2 (.001818\ H + .01636)$ where V = volume in cubic feet, D = diameter (outside bark) in inches at 4.5 feet above ground, and 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. Analysis of variance tested for treatment differences in growth traits.

Density and moisture content of wood and bark were determined from inch-thick disks sawn between the first and second pulpwood bolts (73 inches above ground). Wood samples were taken from 36 trees randomly selected from the entire study area.

FREEZE HAZARD

At age five months the saplings were frozen back to near ground level by a minimum recorded temperature of 23°F. five feet above the ground. The trees recovered well through basal sprouting, but suppressed sprouts and multiple trunks persisted on some stools throughout the study. Suppressed sprouts, resembling a basal whorl of branches, persisted on about 9 percent of the trees regardless of spacing. In contrast, multiple trunks were related to stocking. At 4 × 8 spacing only 0.9 percent of the trees had multiple trunks, a significantly lower frequency than 6.8 percent at 8 × 8, 5.8 percent at 12 × 8, and 9.8 percent at 16 × 8. Multiple trunks were doubles except for one tree with three stems.

Despite the freeze, survival averaged 92 per-

Table 1. Volume production at 7.4 years for all stems, and for stems 4 inches d.b.h. and larger.

	All stems				Stems 4 inches d.b.h. and larger		
Spacing treatment	Stocking at 7.4 years		Basal area outside bark	Volume outside bark	Volume outside bark	Proportion of stems ≥ 4 in. d.b.h.	
Feet	*Stools/acre*	*Stems/acre*	*Ft²/acre*	*Ft³/acre*	*Ft³/acre*	*Stems/acre*	*Percent*
4 × 8	1147	1157	74.4[a][1]	1293[a]	771[a]	335[a]	29[a]
8 × 8	577	615	59.8[ab]	1032[ab]	890[a]	277[ab]	45[ab]
12 × 8	399	423	42.9[b]	759[b]	654[a]	219[b]	52[b]
16 × 8	286	317	42.7[b]	770[b]	747[a]	227[b]	72[c]

[1] *Means with different superscripts differ significantly with an experimentwise error rate of .05 (Tukey's w-procedure).*

cent at four years and 85 percent at 7.4 years and was unrelated to spacing. Therefore, stand densities remained proportional to those intended throughout the study.

STOCKING AND YIELD

The most important results concern total volume versus merchantable volume. The 4 × 8 spacing produced the greatest total stem volume —25 percent more than 8 × 8 and 68 percent more than the two wider spacings. But if we assume that merchantable stems must be at least 4 inches d.b.h., then spacing treatments did not differ significantly in the merchantable volume (Table 1).

The number of merchantable stems per acre increased with stocking, but the percentage of merchantable stems was highest at the widest spacing. For example, the 4 × 8 spacing yielded 335 merchantable stems per acre, but only 29 percent of the stems were merchantable. In contrast, the 16 × 8 spacing produced only 227 merchantable stems per acre, but 72 percent of the stems were merchantable (Table 1). Both total and merchantable were about the same at the 12 × 8 as at the 16 × 8 spacing.

Table 2. Heights and diameters of *Eucalyptus grandis* trees four and 7.4 years after planting at four spacings in Glades County, Florida.

	4 years		7.4 years			
			All stems		Stems 4 inches d.b.h. and larger	
Spacing	Height	D.b.h.	Height	D.b.h.	Height	D.b.h.
Feet	*Feet*	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*
4 × 8	24.9[a][1]	2.3[a]	38.4[a]	3.2[a]	46.1[a]	4.8[a]
8 × 8	24.7[a]	3.0[ab]	39.3[a]	4.0[b]	46.9[a]	5.6[b]
12 × 8	23.6[a]	3.0[ab]	38.1[a]	4.1[b]	44.8[a]	5.5[b]
16 × 8	26.4[a]	3.5[b]	41.3[a]	5.0[c]	44.2[a]	5.8[b]

[1] *Means with different superscripts differ significantly with an experimentwise error rate of .05 (Tukey's w-procedure).*

Height growth was independent of stand density at both four and 7.4 years of age. In contrast, diameter growth showed a strong relationship to spacing, which was obvious as early as the four-year measurements (Table 2).

The average diameter of all stems was significantly larger at 16 × 8 spacing than at the three closer spacings. But considering just merchantable stems (4 inches d.b.h. and larger), diameters averaged about as large at 8 × 8 as at 16 × 8. Apparently only the 4 × 8 spacing was close enough to limit the expression of diameter growth by inherently vigorous trees.

The four-year measurements were closely correlated with 7.4-year measurements for both height (r = 0.92) and diameter (r = 0.99). The

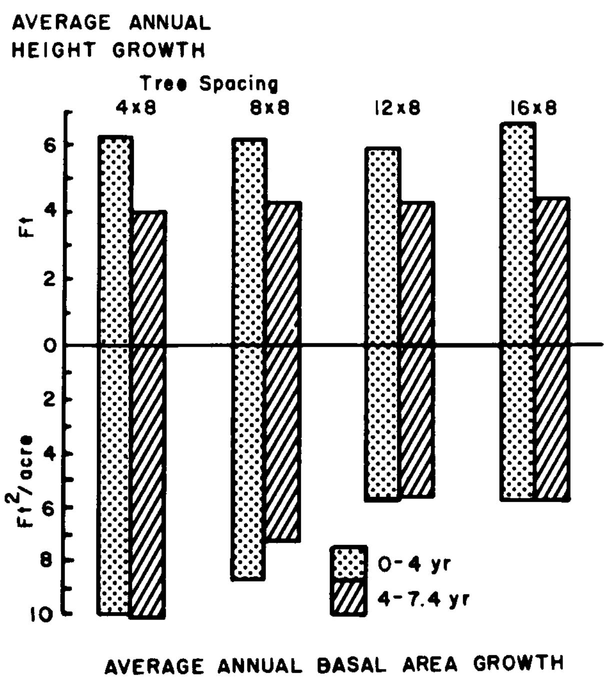

Figure 1. Periodic annual increment for height growth and basal area production.

Table 3. Ratio of bark to wood at breast height in *E. grandis* at plantation age 7.4 years.

Trait	D.b.h. class (in.)							
	1	2	3	4	5	6	7	8
Av. single-bark thickness (in.)	.05	.11	.18	.22	.26	.30	.30	.35
Bark percent[1]	16.1	20.8	22.8	21.3	20.1	19.2	16.7	17.1

[1] *Bark percent* = $\frac{\text{av. basal area outside bark} - \text{av. basal area inside bark}}{\text{av. basal area outside bark}} \times 100$

strong correlations between four- and 7.4-year data indicate that early measurements can be used to predict yields at rotation age. We have seen similarly high correlations between early and later measurements in *E. robusta* Sm.

Trees at wider spacings had greater than average diameter with thicker bark. But the more important factor, ratio of bark to wood, did not vary significantly with spacing. The bark fraction of basal area averaged 19 percent for merchantable trees (≥4 inches d.b.h.) and 20 percent for all trees. Table 3 presents the relationship of bark to wood for diameter classes adequately represented in this study.

Density and moisture content of wood and bark were nearly uniform and unresponsive to spacing treatment. Wood density ranged from .41 to .45 g/cc, and bark density from .31 to .35. Moisture content varied between .52 and .55 g/cc for wood, and between .70 and .72 for bark.

As frequently observed with eucalypts, mean annual increment for height growth culminated sometime before age 4 years (Figure 1). The early culmination is interesting in this plantation considering that it had to start height growth anew after freezing to the ground at age five months.

In contrast, basal area increment (and presumably volume production) was generally as great from four to 7.4 years as it had been from 0 to four years (Figure 1). From 0 to four years, annual basal area growth at the two widest spacings trailed the 4 × 8 treatment by 45 percent, and the gap remained at 45 percent from four to 7.4 years. Failure to close the growth gap suggests that even toward the end of the study the site was not being fully utilized and culmination of volume production was probably not imminent.

The unimproved Australian seedlot planted in this study produced less than half the volume currently accumulating in commercial plantations of genetically improved strains selected under Florida conditions. Furthermore, the genetically improved plantations have about 45 percent more merchantable stems at comparable stocking. These data should not be used to predict volume production, but they do provide useful spacing guides.

DISCUSSION AND CONCLUSIONS

The most important results concern merchantable versus total volume. The closest spacing produced the most total volume; the two widest spacings, the least. But all spacings yielded approximately the same merchantable volume.

If merchantability limits could be circumvented by chipping small trees in the field, spacing 8 × 8 feet or closer would yield volumes 16 to 68 percent greater than conventional pulpwood systems. But costs would rise substantially for seedlings, bedding, and planting.

In conventional pulpwood operations, spacing beds 12 feet apart and seedlings 8 feet or wider would decrease establishment and harvesting costs without decreasing merchantable yields. However, planting at wide spacing could result in understocked coppice stands unless a very high percentage of stumps sprout after each harvest. For example, if the seedling mortality were the same as that in this study (about 15 percent) and if 20 percent of the stumps failed to coppice after the seedling harvest, then a stand planted at 12 × 8 spacing (454 trees per acre) would enter the first coppice rotation stocked with only 309 stools per acre—fewer than would have been planted at the widest spacing in this study. And the same stump mortality after the first coppice harvest would leave stocking in the second coppice rotation at 247 stools per acre—equivalent to 22 × 8 spacing.

Regardless of what acceptable harvest size might be, there was no evidence that wood quality would be adversely affected over the range of stockings tested.

Despite short harvest cycles, coppice rotations make eucalyptus spacing decisions long-term commitments. Pulp companies might reconsider the minimum stem size they can harvest and pulp efficiently. And researchers must define the average size stem that will be most efficient in potential energy crops. The key parameters for spacing eucalypts are minimum acceptable stem size, coppice failure rate, and productivity of genetically improved stock. Until more local experience is gained, we recommend planting seedlings 6 feet apart on beds spaced 12 feet apart (for vehicular access) for a total of 605 trees per acre.

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