

TABLE 2. Break-even land prices for firewood production

Firewood price \$/cord	Low intensity		High intensity*
	No N 2*	Mod N 6*	High N 10*
70	0	0	152
80	0	0	912
90	82	233	1,673
100	311	689	2,433
110	539	1,146	3,194
120	767	1,602	3,955

* Cords per acre per year.

costs, the break-even point would be \$29 per ton.

Break-even land prices for biomass production

The low-intensity management strategy is not appropriate for biomass production, unless growth rates of 6 tons per acre per year can be obtained or the price of fuelwood increases from the current level.

For the high-intensity, moderate-nitrogen strategy, the break-even land price is only \$338 per acre at a price of \$30 per dry ton and a growth of 12 tons per acre per year (table 3). If yield could be increased to 14 tons per acre and \$30 per ton were received for wood on the stump, the operation could support a land purchase price of \$795 per acre.

For the high-intensity, high-nitrogen regime, the break-even land price is \$327

TABLE 3. Break-even land prices at various biomass prices

Biomass price \$/dry ton	Low intensity		High intensity
	No N 4*	Mod N 12*	High N 20*
15	0	0	0
20	0	0	327
25	0	0	1,088
30	0	338	1,848

* Production of dry tons per acre per year.

per acre at \$20 per ton and jumps to \$1,088 per acre at \$25 per ton.

Conclusion

The potential for growing eucalyptus for firewood or biomass appears to be economically promising. As with any agricultural enterprise, there are several alternatives for production practices. More intensive management increases yield per acre, which spreads costs over a larger number of cords or tons and thus decreases the cost per unit produced.

In the three alternative management regimes analyzed—high-intensity, moderate nitrogen; high-intensity, high nitrogen; and low intensity—expected yields were 6, 10, and 2 cords per acre per year for firewood production and 12, 20, and 4 dry tons per acre per year for biomass. The break-even prices for firewood at the farm

gate were estimated to be \$85, \$68, and \$115 per cord. Break-even biomass prices were \$26, \$18, and \$40 per dry ton on the stump.

This analysis shows that low-intensity production would not be profitable, unless production could be increased to 6 dry tons (3 cords) per acre per year without increasing costs or the price received increased from current levels.

The high use of nitrogen seems to be justified. The greater revenue from the projected increase in yield far outweighs the added fertilizer cost between the moderate and the high rate of nitrogen application.

At \$100 per cord and \$35 for harvest for firewood production, the increased revenue per acre per year is estimated to be \$260. The increase in cost is \$17 per year for a net increase in profit of \$243.

Biomass production is not profitable for low-intensity or the moderate nitrogen regimes at a price of \$20 per ton. At present, more than \$20 per dry ton is a high price to expect for wood on the stump. It seems that the high-intensity, high-nitrogen alternative is the most suitable for biomass production.

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Selection and clonal propagation of eucalyptus

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Most eucalyptus plantations are started with seedlings that are highly variable in growth rate and form. Although breeding programs are under way to improve the quality of eucalyptus seed, the improvements are not expected to come soon.

Development of clones (genetically identical plants) from selected superior seedlings offers a possible means of rapidly increasing productivity and uniformity of eucalyptus plantations. Although eucalyptus has a reputation of being difficult to propagate vegetatively, research in France, New Zealand, Brazil, and India has demonstrated that clonal propagation of some species is feasible. Clonal planta-

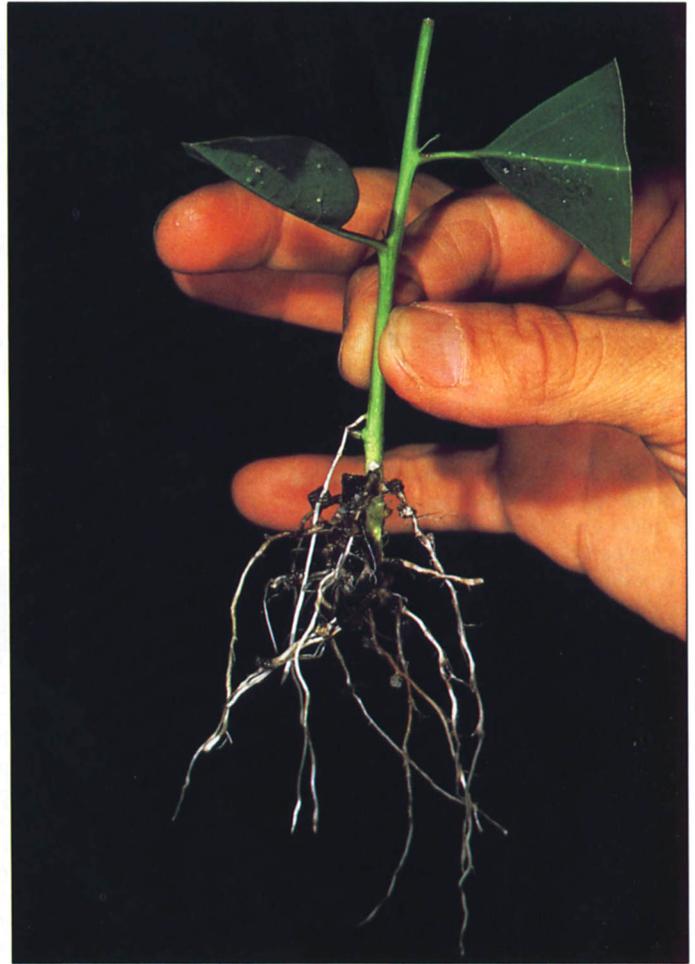
tions of *Eucalyptus grandis* (rose gum) and *E. camaldulensis* (river red gum) have been established in India, Brazil, regions of Africa, and California. A report on clonal propagation of species well adapted to several areas of California appeared in *California Agriculture*, May-June 1983 (pp. 20-22). This article adds information on selection criteria, methods of propagation, and problems encountered.

Clonal propagation for biomass has two basic objectives: (1) to capture desirable genetic traits, such as fast growth, straight trunk, minimum lateral branch development, thin bark, and tolerance of low temperature and other stress; and (2) to pro-

duce large numbers of uniform trees at a cost competitive with seedlings.

Selection of seedlings

We selected seedlings mainly from short-rotation intensively cultured plantations. We also planted seedlings in beds at a 2- by 2-foot spacing and, after 4 to 6 months, selected the most vigorous for further study. For salinity and cold hardiness screening, we grew seedlings in 1-gallon containers, subjected them to salt or cold stress, and then evaluated vigor and form of the surviving individuals. In other cases, screening for stress tolerances began after selection for form and vigor.



A balanced root system consisting of three or more radially distributed roots (above right) is necessary to avoid wind-throw. Entire blocks of the G-3 clone suffered wind-throw (below) because of a poor root system developed during the propagation period (above left).



In conventional forestry, selection of seedlings is normally done 20 or more years after planting, and trees are harvested 40 to 80 years after planting. During this period, some trees may initially grow rapidly ("sprinters") and then slow down to be overtaken by other trees ("stayers"). Although the stayers may be better adapted to nonirrigated, nonfertilized conditions, the sprinters have value in SRIC plantations.

The correlation between biomass and diameter at breast height is approximately the same as, and in most cases better than, that between biomass and height. DBH, which is more easily and accurately determined than tree height, was therefore used to estimate relative vigor of seedlings. We found that *E. grandis* seedlings that were among the top eight most vigorous in the first 12 months from outplanting retained that ranking through harvest at 3 years.

Upright growth habit, minimum lateral branch development, and a straight trunk are important selection criteria. Many *E. camaldulensis* seedlings have good form

for a year, but develop crooked, heavily branched trunks in later years. The best *E. camaldulensis* clone examined, C-2, has a ratio of trunk:branch biomass of 4:1 to 5:1 at 3 years from planting; 75% to 80% of the biomass harvested is thus recoverable for processing after de-limbing.

Tolerance of freezing temperatures likely to be encountered in northern California (where many SRIC plantations are being established) is important. In January 1984, several clones were exposed to a low temperature of 18°F and suffered no apparent damage. However, a 2-hour frost with a minimum temperature of 26°F in November 1985 caused terminal bud damage on several *E. grandis* and *E. camaldulensis* clones. This frost occurred after mild fall temperatures prevented hardening of the trees before exposure to subfreezing temperatures. Accurate measurements of cold tolerance require evaluation in a freeze chamber with control of both the hardening and thawing cycles.

Species used for cloning

Ease of rooting varies greatly among eucalyptus species and even within members of a species. Since mature growth of all species, generally beyond a year from outplanting, is very difficult to root, juvenile material is used almost exclusively. If a mature tree is selected for cloning, the first step is to cut the tree to its base (generally to 1 foot) and wait for the stump to sprout. Once a mother plant is thus produced for cloning, the sprouts are continually cut back to prevent growth of mature shoots.

Eucalyptus camaldulensis is now probably the most widely planted species of eucalyptus in California. Because its natural distribution in Australia is very wide, across many climatic regions, there is great variability in growth rate and form in seedling plantations. It is also one of the most easily rooted species with rooting percentages often exceeding 60%.

The C-2 clone (also released as *E. camaldulensis* 'Dale Chapman'), has been superior to all other selections examined in vigor and form. Original C-2 cuttings came from a seedling planted by Dale Chapman, from seedlings obtained from the USDA-Florida program on improvement of *E. camaldulensis* from seed sources in Spain. In a small plantation at Dixon with 2,719 trees per acre, estimates of average biomass accumulation range up to 27 tons per acre per year with more than 80% of biomass as wood in the bole (see accompanying article "Maximum biomass yields..."). We are testing other clones of this species, selected from the most vigorous, best-formed seedlings (source, Lake Albacutya) in a 7-year-old plantation established in the Napa Valley, which may

have growth rates equal to that of the C-2 clone. C-2 develops forks in the stem during development that are probably the result of damage observed at the terminal bud following high winds, particularly during the hot summer months. Since these forks are easily broken in strong winds, with a consequent loss of harvestable biomass, it would be advantageous to select clones without this characteristic.

Twelve vigorous seedlings of *E. grandis* were selected from SRIC plantations at the UC South Coast Field Station for clonal propagation and evaluation. Clones G-1 and G-3 were selected from a seed lot of unimproved seedlings (origin unknown); G-4 through G-11 were from seedlings obtained from the State of Florida nursery (seed source, USDA-Florida program).

Eucalyptus grandis clones have a dominant central leader with trunks generally straighter than the best *E. camaldulensis* selections and little or no forking. Lateral branches of *E. grandis* grow rapidly with many more leaves per branch and a denser leaf canopy than those of *E. camaldulensis*. A 4-year-old *E. grandis* seedling found in a relatively cold location at the Sierra Foothill Range Field Station has also been cloned. These clones, designated G-13, are now being tested for comparative cold tolerance in freeze chambers and in the field.

In 1984, seed from *E. gunnii* (cider gum) trees in southern France that had survived exposure to 10°F were provided by the Association Foret-Cellulose (France) and sown in Davis. After a year, all but the most vigorous and straight-trunked seedlings were eliminated. The selected seedlings were pruned near the base, and cuttings taken from the sprouts that developed. Only two clones produced sufficient cuttings for further testing. At a 1,900-foot elevation in the Sierra foothills, these clones survived the first winter without damage (at one time they were substantially covered with snow). The clones are as vigorous as any species tested.

Production of clonal materials

Procedures. To develop clones, we use three to four node cuttings, approximately 1/16 to 1/8 inch (3 mm) diameter. Thinner and thicker cuttings will root, but the number of roots initiated per cutting or the percentage of rooted cuttings is too low for large-scale production (table 1). Cuttings are dipped for 5 to 10 seconds in a 4000 to 8000 mg/L aqueous solution of the potassium salt of indole butyric acid (IBA) and stuck in a vermiculite-perlite rooting medium. The rooting response for C-2 is optimal at about 3000 to 5000 ppm IBA (table 2).

Flats of cuttings, approximately 100 per flat with 2 square inches per cutting, are placed on a mist bench with a 2.5-second mist every 2.5 minutes from early morning

TABLE 1. Rooting of C-2 clone in relation to cutting thickness

Stem diameter	Roots		
	Percent	Number	Total length
mm			cm
1.5	100	2.5	12.5
2	100	5.6	11.1
2.5	95	6.7	5.6
3.5	95	6.9	5.3
4.5	45	5.1	0.9
5	35	5.9	2.9
6.5	0	0.0	0.0

NOTE: Rooting period Dec-Feb 1984; cuttings treated with 8000ppm indole butyric acid (IBA).

TABLE 2. Rooting of C-2 cuttings at various indole butyric acid (IBA) concentrations

IBA	Rooted	Roots/cutting
ppm	%	number
0	70	3 ± 0.5
3000	100	9.4 ± 1.1
5000	100	11.1 ± 1.1
8000	90	13.1 ± 1.0

NOTE: Cuttings taken from mother block grown as hedgerows in the field at Davis; 3 node cuttings, 3 mm in diameter, were used. Basal ends of cuttings dipped in IBA solutions for approximately 10 seconds.

to early evening with 75°F bottom heat (provided by heating cables buried in a 3-inch sand base). Cuttings root after 2 to 3 weeks, depending on the clone and time of year, and are then transplanted to 4-inch peat pots filled with a well-drained peat/sand potting mix. Cuttings are hardened for a week in a mist bench (half the misting frequency of the rooting bench) and then transferred to a shaded greenhouse bench or lathhouse (50% shade).

During the 2- to 3-week rooting period, some shoot tips and immature leaves die, but new shoots begin to grow during the hardening period (usually one shoot per cutting is retained). In good cultural conditions, this shoot will grow 8 to 12 inches in six weeks and the cutting will be ready to plant.

The same procedures have been adopted for all selected seedlings for all species, although we have found large differences among species and clones in ease of rooting (tables 3 and 4). These differences are, in part, inherent. For example, G-14 did not root, whereas all other sprouts from *E. grandis* seedlings rooted to some extent. Among the relatively easy-to-root clones of *E. grandis*, however, some of the variance is related to the care and culture of the mother blocks. The best rooting was obtained with cuttings from recently rooted cuttings or from relatively young mother plants that were cut back frequently. Mother plants in containers in the can yard yielded few easy-to-root cuttings, regardless of species and seedling selection.

Quality of root system. Many trees in our first clonal plantation were blown over by strong winds during their first two years after planting. Wind-throw of trees in clonal (and seedling) plantations is re-



Eucalyptus camaldulensis, probably the most widely planted species in California, is easily rooted. The C-2 clone of this species, shown here at 10 months, has superior vigor and form and may grow as tall as 50 feet in four years.

in the April to October interval. When rooting was attempted in the winter, however, large numbers of plants with one and two roots per cutting were produced. Cuttings of other more difficult-to-root species produce fewer roots per cutting, often with an asymmetrical distribution. In these cases, since large numbers of cuttings must be discarded, larger numbers of cuttings must be stuck initially. In many clones relatively few of the rooted cuttings had adequate root systems for plantation establishment (tables 2 and 3).

Timing of propagation. We obtained high rooting percentages in the Davis area primarily during April through October, when mother plants were growing rapidly. High rooting percentages and high-quality root systems were occasionally obtained from cuttings of field-grown plants in December, but results depended on weather conditions during the late fall and early winter.

Year-round production is possible when cuttings are from mother plants held in greenhouses, but even in this case, best cuttage production occurs in the spring to fall, when growth rates are high. Light energy is the primary limiting factor in the winter. Since the optimum period for beginning plantations is in the early spring, cuttings are best made in October (fully 3 to 4 months ahead of planting).

Size of mother blocks. We estimate that a 2-year-old mother block of C-2, maintained 1.5 feet high by 1.5 feet wide, will produce 30 to 40 cuttings per linear foot per month during April to October. If a 50% rooting success were achieved, 600 to 800 linear feet of outdoor mother block hedge would have to be maintained for each clone to produce enough rooted cuttings to plant 10 acres of an SRIC plantation with 1,200 trees per acre. If the rooting percentage were 25%, twice the number of cuttings would have to be stuck and twice the size of mother block maintained.

Future work

Storage of cuttings. Rooted cuttings grow rapidly after potting and acclimation, making it difficult to hold them in a greenhouse or shade area before planting. We are testing methods to hold rooted cuttings of *E. camaldulensis* for 6 to 12 weeks. If successful, that will permit more efficient use of propagation facilities, greater annual production of cuttings, and smaller mother blocks.

Cold tolerance. Although *E. grandis* and *E. camaldulensis* can be rooted from

lated invariably to poor root system development during the propagation period. Damage at planting or cultural conditions during the first 12 months after planting may contribute to problems. However, the wind-throw of entire blocks of G-3, a relatively difficult-to-root clone of *E. grandis*, adjacent to blocks of G-1 and C-2 that did not blow over, suggests that the problem in this planting was primarily related to the quality of the root system.

The most prevalent cause of instability in clonal trees is unbalanced distribution

of roots, a problem that can be avoided by better evaluation of rooted cuttings. Cuttings with only one or two major lateral roots or with roots distributed predominantly on one side will develop unstable tree root systems and should be culled. In addition, rooted cuttings must be handled and potted carefully to avoid damage. Roots should be pruned rather than coiled or bent during potting to fit the container.

Three or more radially distributed roots were formed on nearly 75% of three- to four-leaf cuttings of *E. camaldulensis* taken

TABLE 3. Variability in rooting of rose gum (*E. grandis*) clones

Clone	Good*		Rooted		No. trials	Total cuttings
	%		%			
G-1	0	- 9	0.4	- 27	30	1030
G-3	0	- 2	1	- 13	21	802
G-4	0	- 19	11	- 32	25	542
G-5	0	- 6	0	- 9.3	15	376
G-6	1.4	- 6	10	- 28	27	638
G-7	0.4	- 8	17	- 31	25	489
G-8	15	- 20	34	- 50	38	808
G-9	0	- 3	7	- 31	17	436
G-10	2	- 3	6	- 13	8	157
G-11	0	- 4	3	- 15	20	415
G-12	13	- 43	28	- 68	52	2073
G-13	0.5	- 11	14	- 56	51	1761
G-14	0		0		1	8
G-15	0	- 21	0	- 67	3	29

NOTE: Cuttings taken from mother plants under shade cloth or in a lathhouse, from sprouts from tree stumps in the field, from greenhouse-grown plants, and from recently rooted cuttings.

* Good rooting means that roots are radially distributed around the cutting.

TABLE 4. Variability in rooting of seedling selections of several *Eucalyptus* clones

Species, clone	Rooted		Good	
	%		%	
<i>E. cladocalyx</i>				
CC1	31		15	
CC2	0		0	
<i>E. tereticornis</i>				
TC1	72		41	
TC2	68		15	
TC3	78		6	
TC4	93		55	
TC5	94		60	
TC6	87		32	
TC7	96		13	
TC8	55		10	
<i>E. grandis</i>				
GT-1	72		27	
GT-2	87		7	
<i>E. camaldulensis</i>				
CT-1	50		27	
CT-2	70		30	
<i>E. trautii</i>				
TT1	93		67	

NOTES: CT, GT, and TT are from Leonard Tanner; CC and TC, from Paul Moore. Data are for one trial with 11 to 30 cuttings per seedling.

cuttings, these species are not necessarily the best adapted for biomass production in the many cooler sites available in California. Tissue-culture procedures have been tested for propagation of cold-tolerant, difficult-to-root species, such as *E. viminalis* (manna gum), *E. dalrympleana* (mountain gum), and *E. nitens*.

Shoot proliferation and root initiation have been achieved in *E. viminalis*, but the roots for the most part are not connected to the proliferating shoots. Propagation from stump sprouts of superior 20-year-old trees in Mendocino County (monitored by Pete Passof, Farm Advisor) has a high priority; tissues from these trees have been placed in sterile culture for further study.

Shoot tips from vigorous 2- to 3-year-old trees of *E. nitens* from the Concord Naval Weapons Station (USDA program, Dr. F. T. Ledig) have proliferated in the laboratory. Blocks of *E. globulus* (blue gum), *E. camaldulensis*, *E. dalrympleana*, and *E. viminalis* have been established (see "Low-elevation foothill fuelwood plantation," this issue). The *E. globulus* blocks contain excellent candidates for biomass plantations, and an attempt to propagate the best seedlings will begin in 1990.

In many perennial crops, clonal propagation is done by grafting of scion wood to seedling or clonal rootstocks. Although this technique has had limited success with eucalyptus, studies will begin with the more difficult-to-root species.

Salt tolerance. Selection of relatively vigorous seedlings of *E. camaldulensis* seedlings planted in large numbers on saline sites has begun under sponsorship of the California Department of Food and Agriculture. Vigorous seedlings that passed a 200 meq/L irrigation screen (irrigation with 50, 100, and finally 200 meq/L saline solutions of mixed sodium, calcium, chloride and sulfate salts) have been propagated vegetatively and are now ready for field testing.

Seed orchards. A statewide effort to improve the *E. camaldulensis* seed available in California has begun with the establishment of seed orchards (under the auspices of the USDA Forest Service, the Eucalyptus Improvement Association, the Genetic Resources Conservation Program, the California Department of Food and Agriculture and the California Department of Forestry). From this project additional, probably better adapted, clones can be selected.

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