CUTTINGS PROPAGATION OF HYBRID *EUCALYPTUS GRANDIS* × *E. NITENS*

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ABSTRACT

Eucalyptus grandis × *E. nitens* F_1 hybrids were successfully propagated using rooted cuttings derived from coppice of 2-year-old seedlings. The hybrid behaved more like the *E. grandis* Maiden parent in its ability to coppice and produce rooted cuttings. Starving stock plants of nutrients and applying two-stage topping, which are necessary for obtaining coppice with *E. nitens* (Deane et Maiden) Maiden, gave poorer results for the hybrid. The ideal window in time for coppicing has not been identified and the experimental period for coppicing should be extended from June through to February. Clonal influence was the only critical factor in the rooting of the hybrid cuttings. Rooting percentages ranged from 0 to 100% depending on clone. Sixteen out of the 135 clones (12%) had 70% rooting or better. This figure should increase with further optimisation of the factors important to coppicing and rooting.

Keywords: *Eucalyptus grandis* × *E. nitens*; rooted cuttings; clonal propagation; coppice; hybrid; clonal forestry.

INTRODUCTION

The *Eucalyptus grandis* × *E. nitens* hybrid is currently being trialed in New Zealand (Shelbourne *et al.* 1999). It is hoped that a desirable combination of parental characteristics will provide a superior eucalypt for pulp and wood production in New Zealand conditions, particularly warmer coastal areas, and that the hybrid can be vegetatively multiplied for clonal forestry.

The maternal parent of this hybrid is *E. grandis*. This is the most important eucalypt species in the subtropics because of its fast growth and desirable pulp and timber properties (Denison & Quaile 1987). It can be vegetatively propagated with relative ease and this attribute appears to largely be passed on to the F_1 hybrids with *E. urophylla* S.T.Blake, *E. camaldulensis* Dehnh., and *E. tereticornis* Sm. (Denison & Kietzka 1993a,b). Coppice develops after mature trees are felled, and cuttings derived from these shoots have juvenile characteristics (Hartney 1980). Unfortunately, *E. grandis* is poorly adapted to New Zealand climates, mostly because of its poor frost tolerance.

The paternal parent of the hybrid is *E. nitens*. This species has a proven performance throughout most of New Zealand, with the exception of warmer coastal areas (Miller *et al.*

1992). Although it is difficult to propagate vegetatively (Hartney 1980; Zobel 1993; Maile & Nieuwehuis 1996), there has been limited success at the nursery of the New Zealand Forest Research Institute, particularly with juvenile cuttings and cuttings derived from young coppice of plants less than 2 years old (T. Faulds, pers. comm.).

In South Africa, the climatic range of *E. grandis* has been considerably extended by hybridisation. In the eastern Transvaal highveld, some clones of the hybrid *E. grandis* × *E. nitens* have not only good cold and frost tolerance, but also outperform their *E. nitens* parents (Wex & Denison 1997). Recently, at the request of the New Zealand Forest Research Institute, 15 hybrid crosses between *E. grandis* and two provenances of *E. nitens*, from central Victoria and southern New South Wales, were made in South Africa by Combined Science and Industrial Research, Environtek, Nelspruit (Brian Pierce, pers. comm.). Extra seedlings of the hybrids and of open-pollinated progenies of both parents, which were surplus to genetic field trials planted in New Zealand in 1994, were made available for a pilot trial involving experimental coppicing and cuttings propagation.

Methods for vegetative propagation of *E. grandis* × *E. nitens* must be developed if this hybrid is to be grown in New Zealand. The seed is expensive to produce and the hybrid progeny is highly variable. Early results from the field trials indicate that many hybrid trees are poorly grown, and a small proportion are very healthy well-grown trees that exceed the growth of the best *E. nitens* trees, from both provenances (Shelbourne *et al.* 1999). Clonal propagation will, therefore, be the most effective method of capturing favourable hybrid genotypes. It is envisaged that the greatest genetic gains would be achieved with a clonal forestry programme associated with well-managed breeding programmes for both parent species.

Clonal forestry with *E. grandis* × *E. nitens* could be achieved via two distinct systems:

(1) Propagation of selected mature ortets from progeny trials, via cuttings derived from stump coppice. Subsequent establishment of clonal stool-beds would be necessary for the commercial production of superior clones.

(2) Concurrent establishment of clonal stool-beds and clonal field trials with cuttings produced via a juvenile propagation system. This system would have to allow for progressive culling of clones with poor performance and amplification of clones with superior performance, based on the field trial assessments. Again, commercial production of superior clones would be the ultimate goal.

The first system would be the most efficient in terms of returns over initial input (E.A.Duncan, Mondi Forests, pers. comm.; C.J.A.Shelbourne, New Zealand Forest Research Institute, pers. comm.). There would be five distinct selection criteria for clonal forestry:

(1) Selection of trees from controlled crosses in progeny tests for desired traits, including
   - wood / pulping properties
   - growth and form
   - disease resistance

(2) Selection for coppicing properties, including
   - survival after felling, with production of good coppice shoots
   - production of sufficient suitable cuttings from coppice

(3) Selection for rooting in viable numbers

(4) Selection based on clonal performance in clonal tests, as in (1)

(5) Selection for serial propagation, including

- establishment of stool plants capable of good coppice production
- production of quality rooted cuttings from stool plants.

In Brazil and South Africa, successful clonal forestry programmes with *E. grandis* and its hybrids have found that only 2 to 5% of the original genotypes pass all of these selection criteria (Denison & Quaile 1987; Zobel 1993). Denison & Quaile from Mondi Forests (South Africa) reported a 70–80% rejection of genotypes solely for failure to meet rooting requirements.

This paper reports on a pilot trial investigating cuttings propagation of the hybrid *E. grandis* × *E. nitens* seedlings. Our objectives were to investigate the conditions required for the hybrids to survive the initial topping and produce good coppice, and subsequently, the effects of the different coppicing treatments on the rooting of the cuttings and the effect of a rooting hormone.

MATERIALS AND METHODS

Raising Stock Plants

Approximately 240 vigorous hybrid *E. grandis* × *E. nitens* seedlings, from 12 different families, were potted in 9-litre buckets in March 1995 at the New Zealand Forest Research Institute nursery. The potting medium was 3 parts coarse peat : 1 part pumice, with the addition of Magamp fertiliser (N:P:K ratio 7:17:5) at 2 kg/m^3. Approximately 120 vigorous seedlings representing each of the parent species were also potted up for comparison, with seven *E. grandis* families and eight *E. nitens* families represented. Of the *E. nitens* families, four were from the central Victorian provenance and four were from the New South Wales provenance.

Conditions in March were typically mild with an average temperature of 16°C, a min./max. range of 3° to 24°C, and ample rainfall. In late autumn, the seedlings were shifted to a polythene house to avoid potential frost damage to the pure *E. grandis* and its hybrids.

Grading of Hybrids

The hybrid seedlings were subjectively graded on a one to five scale, because of an obvious variability in their expression of parental characteristics. Representatives of each grade were photographed (Fig. 1) and a record of the assigned grade was maintained throughout the coppicing and rooting experiments. The seedlings from each hybrid grade within each family were randomly assigned to each treatment combination.

The morphological characteristics taken into consideration during grading were: the presence or absence of a petiole, the shape of the leaf base, degree of squareness and fluting of the stem, leaf shape and size, overall colour, and arrangement of leaves and branches. Grade 1 was indistinguishable from the *E. nitens* parent, grade 2 was closer to *E. nitens* than *E. grandis*, grade 3 was intermediate, grade 4 was closer to the *E. grandis* parent, and grade 5 was indistinguishable from the *E. grandis* parent.

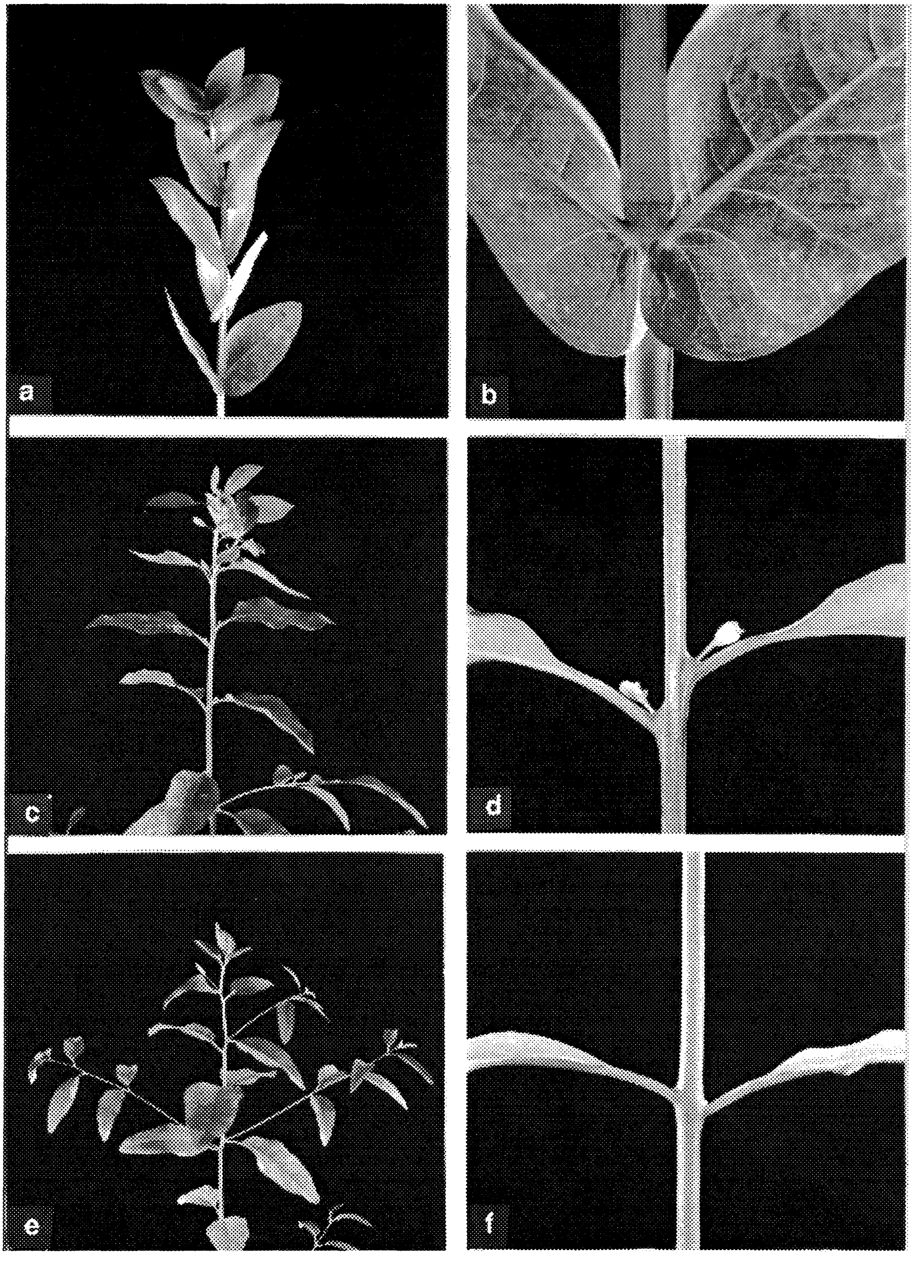

FIG. 1a–Pure *Eucalyptus nitens* stock plant (male parent of hybrid)
1b–Stem and leaf detail of pure *E. nitens*
1c–*Eucalyptus grandis* × *E.nitens* stock plant with a hybrid grading intermediate between the parent species (Grade 3)
1d–Stem and leaf detail of Grade 3 hybrid
1e–Pure *Eucalyptus grandis* stock plant (female parent of hybrid)
1f–Stem and leaf detail of pure *E. grandis*

Coppicing Experiment

Fifty percent of the hybrids (120 seedlings) and parents were starved of nutrients, and 50% were well fertilised. The fertiliser treatment was 1.77 g Yates "Thrive", in 1 *l* water, applied to each container approximately on a monthly basis from October until cutting collection. At topping, Nitrophoska Blue granules (N:P:K ratio 12:5:14) were sprinkled in each container at 10 g/plant.

When the danger of frost was over, the seedlings were returned outside, to full light, to encourage coppicing after topping. Care was taken to allocate seedlings randomly from each family, hybrid grade, and fertiliser treatment, to each of three topping treatments. The first topping treatment was on 29 September 1995, with two subsequent treatments at 3-weekly intervals, i.e., on 20 October and 10 November (early-, mid-, and late-spring toppings). At each topping, 50% of the seedlings were cut back abruptly to 5–10 cm above the root collar and 50% were cut back in two stages to avoid shock. The first stage of the gradual topping treatment involved removal of about half the green foliage. The second stage involved cutting back to 5–10 cm above the root collar at the earliest sign of coppicing, approximately 4 weeks later.

The four treatment combinations for each of the three periods of topping were: well-fertilised/cut back abruptly, well-fertilised/cut back gradually, starved/cut back abruptly, starved/cut back gradually. Coppice shoots were collected when they reached the semi-lignified stage, about 6 weeks after emergence. Twenty seedlings were allocated to each of the 12 treatment combinations.

The time elapsed between topping and collection of coppice shoots, and the number of shoots produced, were recorded for each treatment combination. The data were analysed to determine the effects of the different treatments on coppice production, using the SAS GLM procedure (SAS Institute 1989) for the analysis of variance (ANOVA). The treatment design was a three-factor factorial with 12 treatment combinations (3 topping periods × 2 fertiliser treatments × 2 topping methods × 6 families).

The ANOVA was based on the following model:

$$Y_{ijkn} = \mu + F_i + D_j + T_k + M_n + (DT)_{jk} + (DM)_{jn} + (TM)_{kn} + (DTM)_{jkn} + e_{ijkn}$$

where $i = 1 \ldots 6, j = 1 \ldots 3, k = 1 \ldots 2, n = 1 \ldots 2$

μ = overall mean

Y_{ijkn} = value of family i, topping date j, fertiliser treatment k, and topping method n

F_i = effect of family i

D_j = effect of topping date j

T_k = effect of fertiliser treatment k

M_n = effect of topping method n

$(DT)_{jk}$ = interaction effect of topping date j and fertiliser treatment k

$(DM)_{jn}$ = interaction effect of topping date j and topping method n

$(TM)_{kn}$ = interaction effect of fertiliser treatment k and topping method n

$(DTM)_{jkn}$ = interaction effect of topping date j, fertiliser treatment k, and topping method n

e_{ijkn} = random error related to Y_{ijkn}

Because of an imbalance in numbers assigned to each hybrid grade (*see below*) only the data associated with Grade 2 from the six largest hybrid families were analysed with SAS, to allow for almost balanced data analyses. This involved 67% of the dataset for the hybrids. Where necessary, the data were transformed to stabilise the variances and satisfy the ANOVA assumptions.

Rooting of Cuttings

In January 1996, the collection and setting of cuttings began. All the details of the coppicing treatments (date undertaken, type of stock plant, nutrition, method of cutting back) were maintained for all the cuttings collected. After harvest, the semi-lignified coppice shoots were dipped in Benlate solution (1.0 g/*l*) for about 10–15 seconds. The shoots were then cut into one- or two-node cuttings and the leaves clipped back approximately 50% to avoid overlap and reduce water loss. The cuttings were immediately placed in water. Up to 24 cuttings from each stock plant were set and the total number of available cuttings was recorded.

The cuttings from each stock plant (where more than six cuttings were available) were divided as evenly as possible by length, diameter, number of nodes, and general cutting condition into two groups—hormone and control. The hormone-treated cuttings were dipped in Yate's Clonex (3% IBA in a gel base). The control cuttings were set without any rooting treatment. All the cuttings were set into BCC Hiko V150 containers in a 3 peat : 2 pumice potting medium. They were placed in a shade house on a heated bed (18–20°C) under 50% shade and given intermittent mist (frequency of 10 seconds every 15 minutes during daylight hours).

Three times a week, until mid-May, each tray of cuttings was lifted and visual evidence of root emergence noted for each clone. When roots were visible, the cuttings were transferred to a shade house (with no heated bed) for hardening off. Root production was visually assessed for each treatment combination 6 to 7 months after setting. Analysis of variance was done using the SAS GLM procedure (SAS Institute 1989) to determine if there were any significant interactions between the different coppicing treatments and subsequent rooting of cuttings. The effect of the Yate's Clonex treatment was tested using a non-paired t-test, after homogeneity in variances was confirmed.

RESULTS AND DISCUSSION

Grading of Hybrids

Of the 195 hybrid stock plants, none were assigned to Grade 1 (indistinguishable from *E. nitens*), and 137 (70%) were assigned to Grade 2 (closer to *E. nitens* in appearance). Smaller numbers were assigned to Grade 3 (intermediate in appearance), Grade 4 (closer to *E. grandis*) and Grade 5 (indistinguishable from *E. grandis*) (12%, 8%, and 10% respectively). We are uncertain if this result was due to sampling error, or if it is typical for the hybrid population as a whole. There was some prior selection of the hybrid seedlings for the progeny field trials (R. McConnochie, pers. comm.).

F_1 hybrids are normally fairly uniform in appearance (Sedgley & Griffin 1989). The wide variation seen here may be due to incompatibility in the two parental genomes, with possible elimination of parts of either genome and/or abnormalities in gene expression. Germination of the hybrid seed was slow and erratic, compared with seed from the parents, and many aberrant germinants were observed. This indicates some degree of genetic incompatibility between *E. grandis* and *E. nitens*. Many of the initially healthy, but somewhat unusual hybrids planted in the field trials (reported by Shelbourne *et al.* 1999) died within the first year, leaving a fairly uniform hybrid population in the field (C.J.A. Shelbourne, pers. comm.).

Because of the imbalance in numbers assigned to each hybrid grade in this experiment, the effect of grade on coppicing and rooting of cuttings could not be tested statistically. For the coppicing and rooting experiments, only the data associated with Grade 2 from the six largest families were analysed with SAS, to allow for almost balanced data analyses. This involved 67% of the dataset for the hybrids.

Coppicing Experiment

The survival of the trees after topping, indicated by the development of coppice, was generally high. To allow for a comparison of hybrid grades and parent provenances, the coppice and cuttings treatments were disregarded and the data pooled (Table 1). Survival of the stock plants was particularly high for *E. grandis* and the hybrids assigned to Grade 5. However, there were uneven numbers of stock plants in each hybrid grade, making definitive conclusions difficult.

TABLE 1–Stock plant survival and mean number of cuttings obtained per stock plant for each hybrid grade and parent provenance.

	Total number of stock plants	Survival of stock plants (%)	No. of cuttings per stock plant	Rooting percentage
Hybrid grade 2	137	91	15.3	19.8
3	23	87	14.1	28.4
4	15	88	21.8	63.7
5	20	100	12.3	41.6
Parent provenances				
E. grandis	107	99	12.5	53
E. nitens (Victoria)	54	86	6.8	0
E. nitens (NSW)	63	88	9.0	1

In Table 2, results of the different coppice treatments were considered for the hybrids only. There were no discernible trends in the survival percentages for the four different fertiliser and topping treatments (91% or 92% for each treatment). The proportion of stock plants coppicing from the mid-spring topping was 88%, slightly lower than for the early- and late-spring toppings (94% and 92%, respectively). The time period from the topping of stock plants to emergence of coppice shoots was analysed (Table 3). The date of topping was statistically significant, with the mid-spring (October) topping resulting in slower coppice development (a mean of 23 days to emergence) compared with the early- and late-spring toppings (16 and 18 days, respectively).

The effect of the method of topping on emergence time was highly significant. Abrupt topping resulted in faster coppicing (a mean of 15 days) than topping in two stages (23 days).

TABLE 2–Percentage of trees coppicing well and mean number of cuttings collected from each hybrid stock plant.

Topping date:	Cut back 29 September				Cut back 20 October				Cut back 10 November			
	Fertiliser		No Fertiliser		Fertiliser		No Fertiliser		Fertiliser		No Fertiliser	
Method of topping:	Abrupt	Gradual	Abrupt	Gradual	Abrupt	Gradual	Abrupt	Gradual	Abrupt	Gradual	Abrupt	Gradual
Percentage of trees coppicing	75	100	100	100	94	94	100	63	88	93	88	100
Mean No. of cuttings per tree	29	25	15	5	21	16	11	3	21	22	13	11

TABLE 3–Analysis of variance for number of days to coppice emergence. (The data were square-root transformed).

Source of variation	Degrees of freedom	Mean squares	F values	Pr > F	Level of significance
Family	5	1.024	1.46	0.2187	
Topping method	1	10.763	15.33	0.0003	***
Fertiliser	1	2.398	3.42	0.0701	
Topping method × Fertiliser	1	3.526	5.02	0.0292	*
Topping date	2	2.864	4.08	0.0225	*
Topping method × topping date	2	0.668	0.95	0.3928	
Fertiliser × topping date	2	1.069	1.52	0.2273	
Topping method × Fertiliser × Topping date	2	1.692	2.41	0.0995	
Error	53	0.702			
Corrected total	69				

* Significant at the 0.05 level

*** Significant at the 0.001 level

Fertiliser treatment tended to decrease the time for emergence of coppice, but this trend was marginally non-significant. There was a statistically significant interaction between the topping method and fertiliser treatments. When fertiliser was applied there was no difference between the two topping methods in emergence of coppice. On the other hand, coppice emergence after gradual topping was significantly delayed, compared with abrupt topping, when no fertiliser was applied.

More cuttings were obtained from the hybrids and *E. grandis* stock plants, than from the *E. nitens* stock plants (means per stock plant of 16, 13, and 8, respectively) (Table 1). This indicates that the hybrids behave more like *E. grandis* in their ease of coppicing. For the hybrids, the mean number of cuttings collected for each treatment combination is summarised in Table 2. The most important factor was the nutritional state. Stock plants that had fertiliser applied at the time of topping produced more cuttings than starved stock plants because the coppice shoots grew faster. This treatment difference was highly significant in the analysis of variance (Table 4).

Significantly higher numbers of cuttings were produced by the stock plants topped in early and late spring. The fertiliser-×-topping-date interaction was also highly significant (Table 4). The early-spring topping produced the highest number of cuttings when fertiliser was applied to the stock plants. Conversely, when stock plants were not fertilised, the late-spring topping resulted in the highest number of cuttings. However, for all treatment combinations, the mid-spring topping resulted in the lowest number of cuttings. This ties in with the slightly poorer survival of stock plants and the significantly longer period of time for coppice emergence for the mid-spring topping.

The overall poorer results for the mid-spring topping may possibly have been due to adverse environmental conditions at the time, or due to sampling error, or this may have been a true trend in coppice productivity over time. In other words, there may be a bimodal distribution with peaks of productivity in early spring and late spring. However, the two peaks of this possible bimodal distribution may be only partly represented in the time period of this experiment.

A decision was made to delay the topping treatments until after the danger of frost had passed, because of the susceptibility of *E. grandis* to frost and because of the limited number of stock plants. The window of time for the topping treatments was, therefore, very narrow and may not have covered the optimal time period of coppicing for the hybrids. Other researchers have found that many eucalypt species coppice better in winter or early spring, but *E. grandis* coppices better during the spring and summer (Blake 1983; Hartney 1980). Therefore, the coppicing treatments should be repeated, beginning in June and carrying through to February, assuming that the hybrids are not sensitive to frost.

Stock plants that were topped abruptly to 5 cm above the root collar (low cut) produced significantly more cuttings than trees that were topped in two stages (gradual cut). Another important effect was the family component, with significant differences in the numbers of cuttings produced per family (Table 4). However, only the six families with the largest numbers were included in the data analyses, to provide a more balanced dataset, as described in the "Materials and Methods" section.

The treatment combinations of topping-method × fertiliser-treatment, fertiliser × topping-date, and topping-method × topping-date were statistically significant for the number of

TABLE 4—Analysis of variance for number of cuttings produced per stock plant. (The data were square-root transformed).

Source of variation	Degrees of freedom	Mean squares	F values	Pr > F	Level of significance
Family	5	1.772	3.17	0.0141	*
Topping method	1	13.129	23.51	0.0001	***
Fertiliser	1	40.848	73.15	0.0001	***
Topping method × Fertiliser	1	2.362	4.23	0.0447	*
Topping date	2	4.618	8.27	0.0007	***
Topping method × Topping date	2	1.946	3.49	0.0378	*
Fertiliser × topping date	2	3.517	6.30	0.0035	**
Topping method × Fertiliser × Topping date	2	0.077	0.14	0.8715	
Error	53	0.558			
Corrected total	69				

* Significant at the 0.05 level
** Significant at the 0.01 level
*** Significant at the 0.001 level

cuttings produced (Table 4). These significant interactions can be explained largely by a greater difference in the number of cuttings obtained for the two topping methods, depending on the fertiliser treatment and topping date. The different topping and fertiliser treatment combinations were less important for the late-spring topping than for the early- and mid-spring periods of topping. The treatment combination producing the lowest number of cuttings (a mean of three cuttings per stock plant) was the no-fertiliser treatment with gradual topping starting in mid spring (Table 2). The best treatment combination was the fertilised stock plants abruptly topped in early spring (a mean of 29 cuttings per stock plant).

Rooting of Cuttings

There was almost total failure in the rooting of cuttings from both *E. nitens* provenances while *E. grandis* had an overall rooting of 53% (Table 1). Hybrids graded as morphologically closer to *E. grandis*, rooted better than those graded closer to *E. nitens*, which raises the possibility of an early screening of stock plants for ability to propagate in a clonal forestry programme. However, there were uneven numbers of stock plants in each hybrid grade, making definitive conclusions difficult.

The only critical factor in the rooting of the hybrids was the clonal influence. Rooting varied from 0 to 100% depending on the clone, but this could not be tested statistically owing to imbalance in the dataset. Sixteen out of the 135 clones (12%) had 70% rooting or better, which is generally seen as the minimum requirement for successful propagation in clonal forestry (Denison & Quaile 1987; Zobel 1993). Percentage of clones falling within each rooting percentile (percentage of cuttings rooting per clone) is shown in Table 5.

TABLE 5–Percentage of clones falling within each rooting percentile (percentage of cuttings rooting per clone)

Cumulative percentage of clones within each rooting percentile	Percentage of clones within each rooting percentile	Rooting percentile (No. of cuttings rooted per clone)
4.4	4.4	100%
7.7	3.3	80–99
17.6	9.9	60–80
27.0	9.4	40–60
50.3	23.3	20–40
80.1	29.8	1–20
100	19.9	0%

There were no significant differences detected between any of the coppice treatments. The effect of the Yate's Clonex treatment was tested using a non-paired t-test. No significant difference was found in the rooting of the treated cuttings and the control (36.52% and 34.46%, respectively, $p = 0.70$). However, there may be other hormone treatments, quite different from the one tested here, that would have a significant effect on rooting. Further research on rooting treatments is needed.

The rooting of the cuttings within a clone was variable. There appeared to be no clear trends in the time it took roots to emerge or in the type of cutting that rooted best. For example, in any single clone, some rooted within 6 weeks while others had only just formed roots 6 months after setting. Well-developed root systems, with up to six roots emerging from the callus (Fig. 2), would sometimes be found in both small- and large-diameter cuttings (2 to 8 mm diameter). More often, only one to three roots were initiated on the cutting.

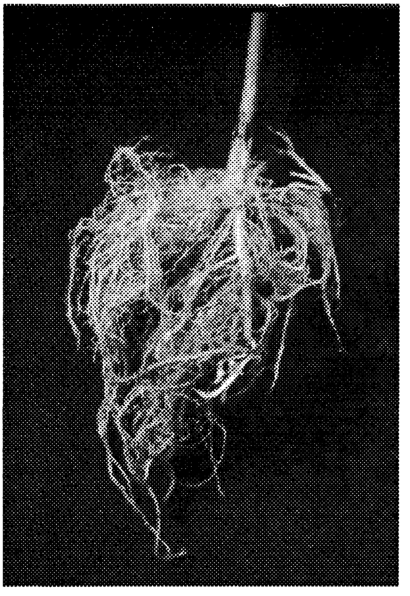

FIG. 2–Roots from a 1-year-old *Eucalyptus grandis* × *E. nitens* hybrid cutting. Note tap root and lateral root development.

CONCLUSIONS

This experiment was a pilot study on the potential for cuttings propagation from coppice of *E. grandis* × *E. nitens* seedlings. Unfortunately, only 240 hybrid seedlings were available. However, we were able to determine that the hybrid behaved more like the *E. grandis* parent in its ability to coppice and produce rooted cuttings. The starving of the stock plant and two-stage topping, which are necessary for obtaining coppice with *E. nitens,* gave poorer results for the hybrid. The ideal period for topping of hybrid stock plants, and subsequent coppicing, has not been identified and the experimental period should be extended from June through to February.

The clonal influence was the only critical factor in the rooting of hybrid cuttings. Rooting percentages ranged from 0 to 100% depending on clone. Sixteen out of the 135 clones had 70% rooting or better. This figure should increase significantly with further optimisation of the variables important to coppicing and rooting. More research is needed on the production of quality root systems, including treatments that promote rooting and improve clonal uniformity in rooting.

Initial clonal testing of the hybrids will be dependent on vegetative multiplication of superior genotypes. The additional step to clonal forestry would require selection of superior clones in clonal tests, rejuvenation of this material by coppicing or collection of cuttings, and then establishment of clonal stool-beds for large-scale clonal propagation. Therefore, future research must include techniques for cloning mature trees and the development of stool-bed coppicing methods.

Established clonal forestry programmes with *E. grandis* and its hybrids have found that only 2 to 5% of the original genotypes pass all of their selection criteria for clonal forestry (Denison & Quaile 1987; Zobel 1993). Denison & Quaile from Mondi Forests reported a 70 to 80% drop-out of genotypes solely for failure to meet rooting requirements. It is critical, therefore, that sufficient superior individuals are identified in our field trials to allow for this reduction in potential candidates. Extensive planting of a small number of clones is ill-advised (Zobel 1993).

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