EARLY RESULTS FROM TRIALS OF INTERSPECIFIC HYBRIDS OF *EUCALYPTUS GRANDIS* WITH *E. NITENS* IN NEW ZEALAND

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ABSTRACT

Eucalyptus nitens (Deane et Maiden) Maiden, a high-altitude species from the mountains of central Victoria and eastern New South Wales, is the eucalypt most commonly planted for pulpwood in New Zealand. Parents of these two provenances of *E. nitens* were crossed with *E. grandis* Maiden of coastal New South Wales origin to create first-generation hybrids that should be adapted to warmer, low-altitude sites in New Zealand and which might be able to be propagated by cuttings.

Single-pair crosses were made between eight New Zealand-selected parents from both central Victorian and southern New South Wales provenances of *E. nitens*, as pollen parents, with eight selected *E. grandis* female parents growing in a South African seed orchard. Eight seedlings of each hybrid family and of open-pollinated families from each of the *E. nitens* and *E. grandis* parents were planted in a single-tree-plot design at each of four sites in New Zealand. One trial in Southland was destroyed by frost, and hybrids performed poorly at a frosty central North Island site. At two, warm, coastal Bay of Plenty sites the hybrids at age 2 years and 8 months had average height and diameter that was about the same as their *E. nitens* open-pollinated siblings. There were a large proportion of poorly grown, genetically defective individuals in the hybrid families and a smaller proportion of extremely vigorous trees which exceeded the growth of the best-grown individuals of *E. nitens*.

These successful hybrid genotypes could form the basis of clonal forestry deployment of the hybrids, provided vegetative propagation methods can be developed. Some success has already been achieved in propagation trials and further crosses have been made and await planting.

Keywords: hybrid; provenance; diameter; height; *Eucalyptus grandis*; *Eucalyptus nitens*.

INTRODUCTION

Eucalyptus nitens is now the most widely-planted eucalypt species for pulpwood production in New Zealand (NZ). It is a native of the coastal mountain ranges of eastern Victoria and southern New South Wales (NSW), with isolated occurrences in the mountains of northern New South Wales (Tibbits & Reid 1987; Cook & Ladiges 1991; Miller *et al.* 1992). It is found between latitudes 30°23′ and 38°00′S, typically between 1000 and 1300 m altitude, on undulating plateaux and hills on either side of the Great Dividing Range in Victoria, but up to 1600 m in northern New South Wales. It is adapted to cold winters, with snow throughout the natural range and frequent and severe frosts, and to climates with annual rainfalls of 750–1750 mm.

In provenance-progeny trials planted in New Zealand in 1979 (M.D. Wilcox unpubl. data; King & Wilcox 1988) the central Victorian provenances have grown somewhat better than those from southern and northern New South Wales, and distinctly better than the provenance from eastern Victoria from Errinundra and Bendoc, now referred to as *E. denticulata* I.O.Cook & P.Y.Ladiges (Cook & Ladiges 1991). However, in a provenance and species trial planted in 1991 at Kaikohe in Northland, at age 7 years the southern New South Wales provenances were showing much better crown health and survival than central Victorian provenances, and the same growth in diameter (Low & Shelbourne in press).

A number of fungi cause leaf spots and sometimes defoliation in *E. nitens,* including *Mycosphaerella* spp. and *Kirramyces eucalypti* (Cooke & Massee) J.Walker, B.Sutton & Pascoe (syn. *Septoria pulcherrima* and *Phaeophloeospora eucalypti*) and the latter has recently been causing serious defoliation, particularly of juvenile foliage of Victorian provenances, mainly in low-altitude coastal sites in the Bay of Plenty and Northland. There is increasing evidence that southern New South Wales provenances are less defoliated (M.Dick pers. comm.; T.M.Withers & M.Kimberley unpubl. data).

Eucalyptus grandis, a species found from northern New South Wales to northern Queensland, is adapted to a climate with more rain in the summer in New South Wales, and to a truly monsoonal climate with a winter dry season in Queensland. It has been planted extensively as an exotic, especially in Brazil and South Africa (Darrow 1983; van Wyk 1990), but it has not been seen as a good prospect or tested widely in New Zealand. Two provenances (from South Africa, and Coffs Harbour, New South Wales) were included in *E. saligna* Smith provenance trials planted in 1976 at Waitangi in Northland and at Ruatoria (Poverty Bay) (C.B.Low unpubl. data). By age 7 years at Waitangi the *E. grandis* provenances ranked on average fourth out of 17 provenances of *E. saligna* for diameter (at breast height, dbh), and top for bole straightness. However, at Ruatoria at the same age, *E. grandis* was growing more slowly than the slowest-grown *E. saligna*. In the species trial at Kaikohe, referred to above (Low & Shelbourne 1999), *E. grandis* ranked a close second to *E. nitens* in diameter growth at age 7 years.

Hybridisation of *E. nitens* with *E. grandis* was seen as a way of creating a new taxon that would be better adapted to warmer and more humid conditions and that would retain, in part, the good kraft pulping properties of *E. grandis* (Kibblewhite *et al.* 1991). A further benefit was that hybrids with *E. grandis* should be able to be propagated by cuttings to allow clonal forestry, a deployment system that has been used with great success in short-rotation pulpwood plantations of *E. grandis* and its hybrids in South Africa, Brazil, and the Congo Brazzaville (Denison & Quaile 1987; Campinhos & Ikemori 1983; Vigneron 1991).

As no *E. grandis* selections had been made in New Zealand and there were no accessible trees for controlled pollination, an arrangement was made with CSIR Environtek, Nelspruit, South Africa, to make some hybrid crosses using their *E. grandis* seed orchard parents as seed parents, and using pollens of New Zealand-selected *E. nitens*. The crossing programme was completed in 1994, and early results from the field trials, established in New Zealand later that year, are reported here.

Eucalyptus grandis and its hybrids with *E. urophylla* S.T.Blake, *E. camaldulensis* Dehnh., *E. tereticornis* Sm., and *E. nitens* have been deployed through clonal forestry in South Africa, particularly by Mondi Forests (Denison & Kietzka 1993a, b). *Eucalyptus grandis* roots easily from cuttings taken from coppice, which allows propagation of selected trees into stool beds where cuttings can be multiplied for clonal testing and eventual bulking up of selected clones. The hybrids with other species have retained much of the propagability of *E. grandis*. The hybrid between *E. grandis* and *E. nitens* from the northern New South Wales population has been successfully cloned and used for planting colder higher-altitude sites, intermediate between the highest-altitude sites where *E.nitens* is used, and the lower elevations where *E. grandis* is preferred (Wex & Denison 1997).

A preliminary New Zealand study of rooting coppice cuttings from 2-year-old seedlings of *E. grandis* × *E. nitens* hybrids (surplus stock from the trials reported here) has shown large differences between clones in rootability (Aimers-Halliday *et al.* 1999). Rooting of cuttings varied among clones from zero to 100%, with an average of 35%. Sixteen of the 135 clones tested showed 70% rooting or better and 36 of the clones showed 40% or better rooting. This was the first research in New Zealand on propagation of these hybrids and there appear to be reasonable prospects of being able to develop a commercial propagation technique that would work for sufficient clones to make a clonal forestry programme viable.

MATING DESIGN AND FIELD TRIAL DESIGN

A single-pair-cross mating design was used in making the interspecific crosses between *E. grandis* female parents and *E. nitens* male parents, with the aim of generating the maximum number of parental combinations from a small number of parents and crosses. Eight *E. grandis* parents in the seed orchard at Tzaneen in the northern Transvaal, selected from the South African land race (after van Wyk 1990), were successfully mated with eight New Zealand-selected pollen parents of the central Victorian provenances and another eight New Zealand-selected pollen parents of the southern New South Wales provenances of *E. nitens*. Open-pollinated (OP) seed was also collected from all *E. grandis* and *E. nitens* parents. There were, therefore, 41 seedlots: eight *E. grandis* × *E. nitens* (Vic); eight *E. grandis* × *E. nitens* (NSW); nine *E. grandis* (OP); eight *E. nitens* (Vic, OP); eight *E. nitens* (NSW, OP).

Seed was sown in August 1994 in root trainers and the stock planted in field trials in November 1994. One cross was later found to be *E. grandis*, either because of errors in lifting or in the original pollinations, and was excluded from analysis. Because of shortage of stock in some hybrid progenies, these were not culled as heavily as desirable before planting.

The field trial used a randomised complete block design with eight or nine replications of single-tree plots of each of the 41 families, at each of four sites. Trials were established as follows (*see* Fig. 1):

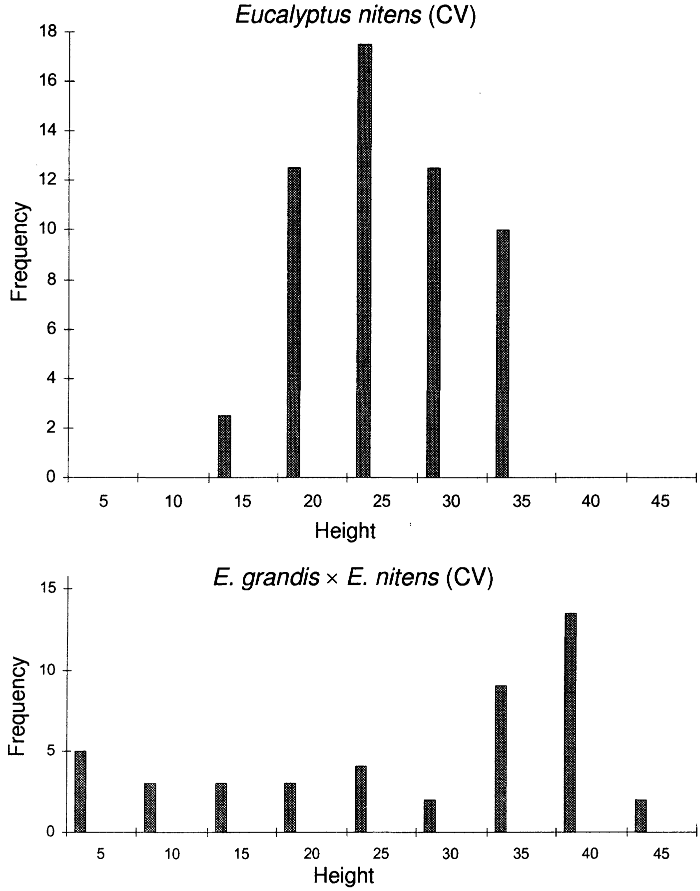

FIG. 1–Frequency distribution of height (age 10 months), Te Teko

- Tairua (Coromandel Peninsula); lat. 37°02′; altitude sea level; north-north-east aspect; ex-pasture; ripped.
- Te Teko (Rangitaiki Plains); lat. 38°02′; altitude <50 m; flat; ripped and rotary-hoed; ex-*Pinus radiata* D. Don seed orchard.
- Kinleith (Tokoroa); lat. 38°25′; altitude 250 m; flat, v-bladed; ex-*P. radiata* cutover.
- Awarua (Southland); lat. 45°05′; altitude 220 m; north-east aspect; 15°–20° slope; ex-pasture.

TRAITS ASSESSED

The first assessment was made at age 10 months from planting (September 1995) and the following traits were assessed:

- height — in decimetres (dm)
- stem shape — 1–5 scale (1 = square, like *E. nitens*, to 5 = rounded like *E. grandis*)
- petiole — 1–5 scale (1 = no petiole, like *E. nitens*, to 5 = well-developed petiole like *E. grandis*)

- foliage health 1–3 scale (1 = unhealthy to 3 = healthy)
- malformation 1–5 scale (1 = multileadered to 5 = dominant; single leader)
- survival percentage

The second assessment was made at age 2 years 8 months from planting (July 1997), and the following traits were assessed:

- dbh diameter at breast height in millimetres (mm)
- height in decimetres (dm)
- malformation 1–5 scale (1 = multileadered to 5 = single leader)
- foliage health 1–3 scale (1 = unhealthy to 3 = healthy)
- survival percentage of trees planted that exceed 60 mm dbh

Individuals with dbh <60 mm were not assessed.

The Awarua trial in Southland was not assessed in 1997 as it had been decimated by frost in 1996; this was an extraordinary advection frost, with freezing temperatures over many days that killed plantations in many parts of Southland. The Kinleith trial was not assessed at age 10 months, after weedicide spray damage, but the survivors were assessed at age 2 years 8 months.

At Te Teko, 20 of the better-grown trees of the five groups listed below were sampled with a single bark-to-bark 5-mm increment core, and basic density was measured:

- *E. grandis* × *E. nitens* — Victoria (hybrid Vic)
- *E. grandis* × *E nitens* — New South Wales (hybrid NSW)
- *E. grandis* — (*grandis*)
- *E. nitens* — Victoria (*nitens* Vic)
- *E. nitens* — New South Wales (*nitens* NSW)

Progeny data from each site were combined by groups (as shown above) and subjected to analysis of variance using the SAS GLM procedure with weighted means. Duncan's multiple range test was applied to group means at each site. There was evidence of large group × site interaction, but an overall-sites analysis was not undertaken.

RESULTS

Assessment at Age 10 Months

Results of this assessment are given in Table 1. The scoring of stem shape and petiole showed that hybrid seedlings were always intermediate in these characters between *E. grandis* and *E. nitens.*

Presence of absence of petiole distinguished between *E. nitens* and *E. grandis,* and the hybrids nearly always showed some sign of a petiole. Any tendency towards a square stem indicated hybrid or *E. nitens* identity. Using these traits together, it is possible to be reasonably certain of hybrid *v.* pure species identity of seedlings at this age. All seedlings of all hybrid progenies appeared to be hybrids, except one cross which was pure *E. grandis* and was discarded from subsequent analyses.

Average height growth of *nitens* Vic was greater at all sites than *nitens* NSW. At Te Teko, hybrid Vic grew the best of all groups, with little difference amongst *grandis*, hybrid NSW,

TABLE 1–Group means age 10 months

	Tairua		Te Teko		Awarua	
	Mean	Duncan	Mean	Duncan	Mean	Duncan
Petiole score (1–5)						
Hybrid Vic	4.2	B	3.9	B	3.3	B
Hybrid NSW	3.9	B	4.2	B	3.1	B
Grandis	4.9	A	5.0	A	4.8	A
Nitens Vic	1.0	C	1.0	C	1.1	C
Nitens NSW	1.0	C	1.0	C	1.1	C
Stem shape score (1–5)						
Hybrid Vic	1.3	C	1.7	C	3.4	B
Hybrid NSW	2.0	B	1.5	B	3.3	B
Grandis	4.7	A	4.9	A	4.7	A
Nitens Vic	1.0	C	1.0	D	1.4	C
Nitens NSW	1.0	C	1.0	D	1.4	C
Height (dm)*						
Hybrid Vic	15.8	A (28.4)	30.9	A (42.6)	4.2	BC
Hybrid NSW	13.5	B (21.8)	25.8	A (38.4)	4.1	BC
Grandis	15.3	A (25.2)	26.3	A (36.2)	3.2	C
Nitens Vic	17.0	A (25.2)	26.2	A (35.0)	6.3	A
Nitens NSW	12.5	B (19.4)	19.8	B (28.8)	5.2	B
Foliage health (1–3)						
Hybrid Vic	2.7	B	1.7	B	2.5	B
Hybrid NSW	2.7	B	1.7	B	2.4	B
Grandis	2.6	B	2.3	A	1.5	C
Nitens Vic	3.0	A	2.6	A	2.9	A
Nitens NSW	2.9	A	2.6	A	2.9	A
Malformation (1–5)						
Hybrid Vic	3.9	B	3.9	B	3.1	AB
Hybrid NSW	3.6	B	4.4	B	3.4	AB
Grandis	4.4	A	4.2	B	3.3	B
Nitens Vic	4.4	A	4.8	A	3.8	A
Nitens NSW	4.2	A	4.1	B	3.6	A
Survival (%)						
Hybrid Vic	72.3		70.3		81.4	
Hybrid NSW	66.7		65.6		83.9	
Grandis	65.4		98.4		36.1	
Nitens Vic	82.5		84.4		98.2	
Nitens NSW	84.7		92.2		93.8	

*Tallest five trees per group in parentheses

and *nitens* Vic, and with *nitens* NSW clearly smaller. At Tairua where height growth was much slower, *nitens* Vic was tallest, and also at Awarua. When the average heights of the five tallest trees per site of each group were compared (Table 1, figures in parentheses), hybrid Vic was outgrowing all other groups at Te Teko and Tairua.

Foliage health scores of the hybrids were significantly inferior to those of the respective *E. nitens* provenances at Te Teko, though less so at Tairua. This was probably caused by a relatively large proportion of sub-vital individuals in the hybrid progenies. Survivals at age

10 months at Te Teko were lower for both hybrid groups than for *E. grandis* or *E. nitens*. At Tairua, and especially at Awarua, *E. grandis* also survived poorly.

Assessment at Age 2 Years and 8 Months

Trials at the three North Island sites showed considerable rank changes from site to site amongst the five groups of progenies for diameter and height growth (Table 2). At Kinleith, a colder frosty site that was subject to serious weedicide spray damage about 6 months after planting, so few *E. grandis* survived and grew properly that this species was excluded from analysis. Both hybrids grew considerably more slowly here than the parent *E. nitens* groups, and growth rates were generally much lower than at Te Teko and Tairua.

TABLE 2–Group means age 2 years and 8 months

	Tairua		Kinleith		Te Teko	
	Mean	Duncan	Mean	Duncan	Mean	Duncan
Diameter (dbh) (mm)						
Hybrid Vic	129	AB	82	B	143	A
Hybrid NSW	122	BC	81	B	138	A
Grandis	109	C			114	B
Nitens Vic	140	A	107	A	139	A
Nitens NSW	121	BC	101	A	122	B
Height (dm)						
Hybrid Vic	79.5	B	52.7	C	108.9	B
Hybrid NSW	69.1	C	44.9	D	94.0	C
Grandis	58.2	D			84.1	D
Nitens Vic	95.3	A	82.2	A	114.9	A
Nitens NSW	83.1	B	72.4	B	103.9	B
Malformation (1–5)						
Hybrid Vic	4.19	A	4.35	A	4.68	A
Hybrid NSW	4.00	A	3.58	B	3.86	B
Grandis	3.19	B			3.89	B
Nitens Vic	4.38	A	4.76	A	4.75	A
Nitens NSW	4.36	A	4.57	A	4.62	A
Health (1–3)						
Hybrid Vic	2.37	B	2.60	A	2.68	A
Hybrid NSW	2.89	A	2.25	B	2.82	A
Grandis	2.86	A			2.70	A
Nitens Vic	2.72	B	2.90	A	2.37	B
Nitens NSW	2.86	A	2.75	A	2.65	A
Basic wood density (kg/m^3)						
Hybrid Vic					385.6	
Hybrid NSW					380.4	
Nitens Vic					385.3	
Nitens NSW					383.0	
Survival (%)						
Hybrid Vic	41.7		33.5		47.4	
Hybrid NSW	31.5		21.9		50.8	
Grandis	25.6		1.4		79.2	
Nitens Vic	79.4		100.0		92.9	
Nitens NSW	81.9		90.6		85.9	

At Tairua the hybrids were, on average, slower-grown in height and diameter than their respective *E. nitens* groups, with *grandis* much slower than both hybrid and *nitens* groups. The frequency distributions of individual-tree values for diameter and height (Fig. 2) show a wider range of values for the hybrid groups than the pure species, with a higher proportion of trees in the lower tail of the distribution, especially for height, and some skewing of the peak towards the upper tail. A similar situation existed at Te Teko (Fig. 3), but there the mean diameter of each hybrid group exceeded that of the respective *E. nitens* groups, though mean heights of the hybrids were still less than for *E. nitens*. The frequency distributions for diameter and height of the hybrids are skewed even more towards the high tail than at Tairua. Growth at Tairua was generally less than at Te Teko for all groups.

In the field, at both Tairua and Te Teko, it was evident that there was a small proportion of extremely vigorous, healthy, well-grown individuals in both hybrid groups that equalled or exceeded the growth of the best individuals of *E. nitens* of both Victoria and New South Wales origin. *Nitens* NSW and its hybrids with *E. grandis* were growing appreciably more slowly (at this age) than *nitens* Vic and its hybrids.

At all sites the hybrids showed slightly more malformation (lower scores) than the respective *E. nitens* groups, and *E. grandis* showed more malformation than either. For crown health at Tairua, hybrid Vic was somewhat poorer than the other groups while at Te Teko, *nitens* Vic was clearly inferior, probably because *K. eucalypti* was causing more spotting and leaf-fall on the juvenile foliage with this provenance than with the New South Wales provenance.

Average wood densities at Te Teko of the two hybrid groups and the two *E. nitens* provenances (based on 20 selected trees of above-average diameter of each group) were all very similar, at between 380 and 386 kg/m^3. Wood density was not sampled in *E. grandis* because of its poor growth. There was considerable variation amongst individual trees of all groups at Te Teko, ranging from 333 kg/m^3 to 454 kg/m^3. The only information available indicates that wood density of the inner 120 mm diameter of 12 trees of *E. grandis* in the species/provenance trial at Waitangi averaged 420 kg/m^3 (M.McConchie unpubl. data).

"Survival" at age 2 years 8 months, as indicated by the percentage of trees exceeding a diameter of 60 mm, was the trait that showed the greatest difference between hybrid and pure species groups. At Tairua this "survival" was 42% and 32% for hybrid Vic and hybrid NSW *v.* 79% and 82% for *nitens* Vic and *nitens* New South Wales. At Te Teko the survival was 47% and 51% *v.* 94% and 86% for hybrid and *E. nitens* groups respectively; at Kinleith the survival was 34% and 22% *v.* 100% and 91% for hybrids and *E. nitens*.

DISCUSSION AND CONCLUSIONS

The results of these two early assessments and impressions of the trials in the field over the last 2$^1/_2$ years have shown some changes in the status of the different groups since establishment, and more changes can be expected in the future. The *E. nitens* seedlots from both Victoria and New South Wales provenances were evidently growing well at age 2 years and 8 months. The appearance of the best-grown hybrid individuals, by inference those that have combined the *E. grandis* and *E. nitens* genomes effectively, was generally healthy. The foliage, which is uniquely different from either parent species, at this stage showed no evident signs of fungal disease or attack by *Paropsis charybdis* Stål beetles. Growth of these

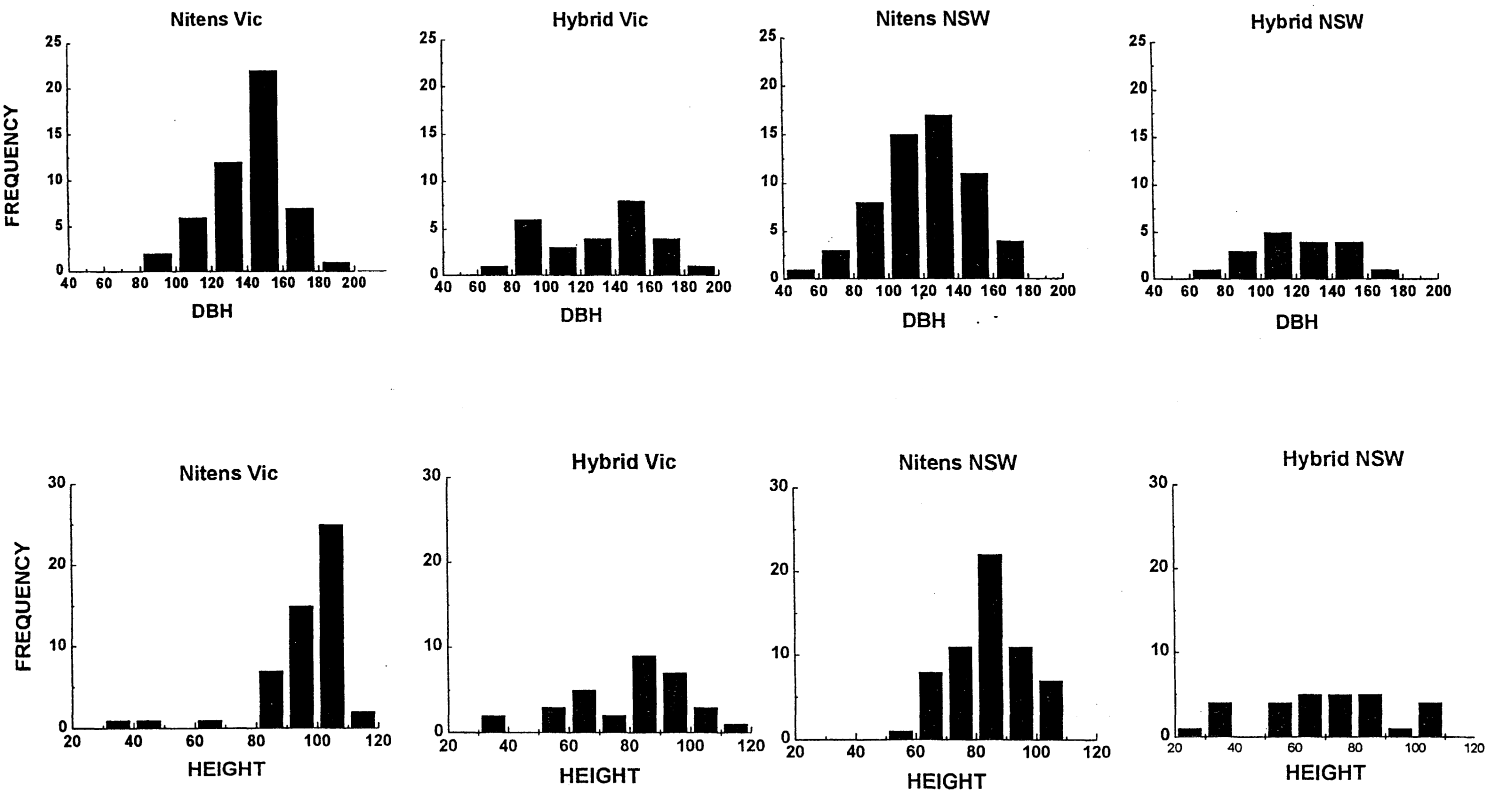

FIG. 2: Frequency distribution for diameter and height at Tairua

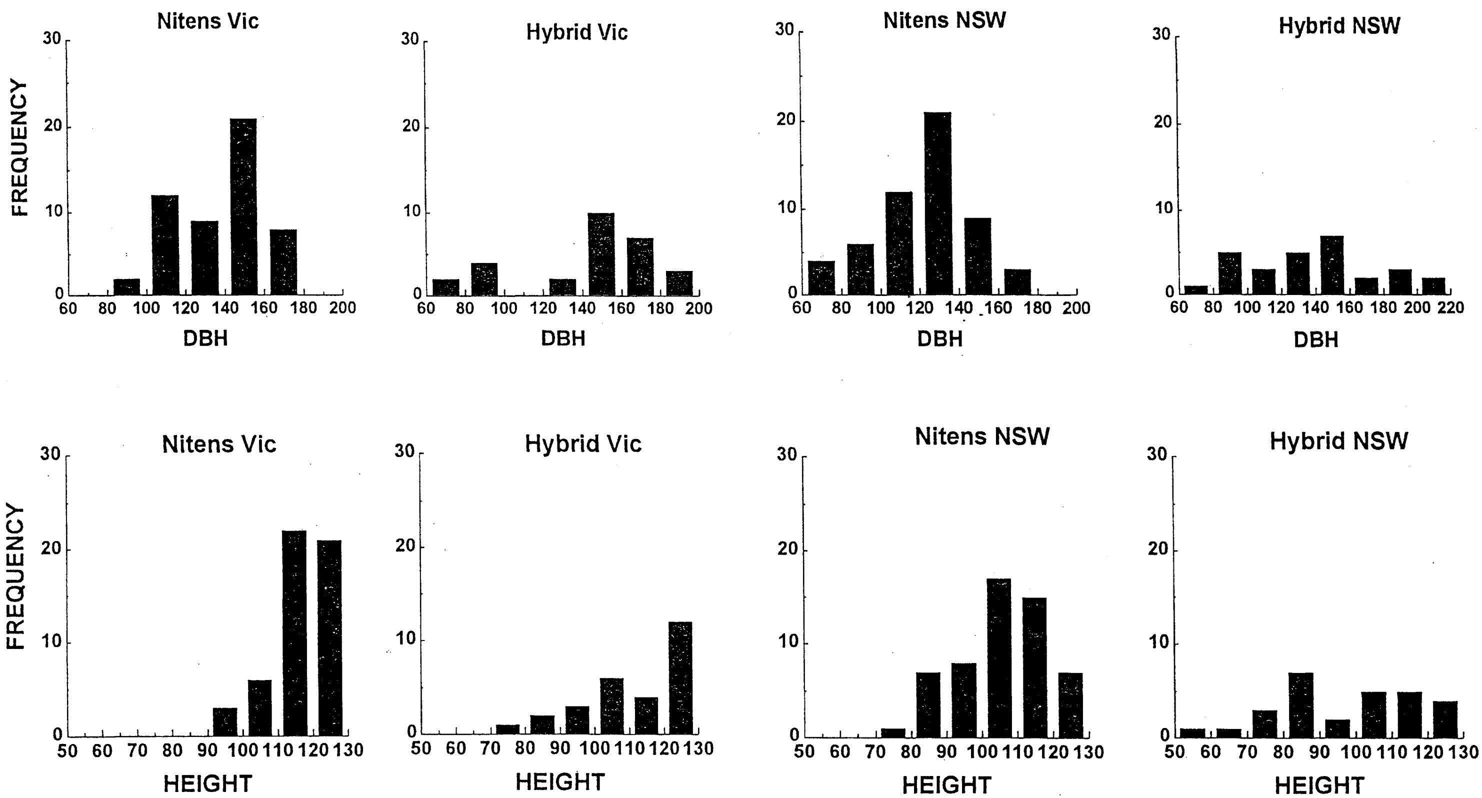

FIG. 3–Frequency distribution for diameter and height at Te Teko

individuals was as good as or better than the better-grown individuals of *E. nitens,* but only at the two low-altitude sites, Te Teko and Tairua. At Kinleith the effects of the colder climate were confounded with weedicide damage in the first year, which was evidently much worse on the hybrids and *E. grandis* than on *E. nitens.*

The "survival" at age 2 years 8 months (percentage of trees exceeding 60 mm dbh) was much lower for the hybrids than for *E. nitens* which is another indication of the phenomenon of a high frequency of sub-vital individuals in the hybrid crosses, showing in the frequency distribution of diameter and height at Te Teko (Fig. 2). This has important implications for planning further crossing and for any future developments. Family forestry or mass production of selected hybrid families through seed or vegetatively multiplied cuttings would be neither practicable nor desirable because of the low frequency of vigorous hybrid genotypes within first-generation hybrid families. For clonal forestry of the hybrids, it would be necessary to raise several hundred seedlings per family, to undertake heavy culling before planting, and to do intense selection at age 3 or 4 years of at least five times the number of clones needed, to allow for selection for propagability by cuttings or tissue culture.

Further crosses of different *E. grandis* and *E. nitens* parents of both Victorian and New South Wales provenances have recently been made by CSIR at Nelspruit for testing in New Zealand, and much larger numbers of seed per family are available than before. Trial planting of these hybrid families will provide a basis for future selection and clonal testing, provided satisfactory propagation techniques can be developed (*see* Aimers-Halliday *et al.* 1999).

Before commercial propagation techniques are developed it would be desirable to propagate a sample of selected hybrid clones from both Victorian and New South Wales *E. nitens* parents that are growing in the 1994 planted trials to provide hybrid stock to investigate siting and yield. This would be a necessary preliminary step to developing any clonal forestry programme. Further studies of wood properties of the hybrids *v. E. nitens* at more advanced ages are required, as well as pulping studies to determine whether the hybrids have desirable pulping characteristics.

The possibilities of clonal forestry with unique new taxa that combine the characteristics of two desirable species by hybridisation are exciting and the potential economic gains may be high. However, costs may also be high, the technological hurdles may be challenging, and the time-frame long.

The breeder should not lose sight of the possibility that environmental and ecological sustainability and the forest industry's needs may be better served by introducing, testing, and selecting both between and within adapted populations of "new" species (or ones already introduced). After testing, such populations can be deployed immediately and improved genetically through simple recurrent selection. Such programme options should be exhausted before more costly and technologically sophisticated ones are initiated.

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