GENETIC VARIATION IN FROST TOLERANCE, EARLY HEIGHT GROWTH, AND INCIDENCE OF FORKING AMONG AND WITHIN PROVENANCES OF EUCALYPTUS FASTIGATA

M. D. WILCOX

Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

(Received for publication 7 April 1982; revision 21 July 1982)

ABSTRACT

One hundred and twenty-six seedlots (115 open-pollinated families and 11 composites) of **Eucalyptus fastigata** Deane & Maid. representing eight native provenances from New South Wales and Victoria, one exotic population from South Africa, and 15 exotic populations from New Zealand were planted in tests in 1979 at Kinleith and Kaingaroa, New Zealand. The trees were assessed at Kinleith in 1980 for height growth and tolerance to winter frosts, and at Kinleith and Kaingaroa in 1981 for incidence of forking.

The seedlots varied greatly in frost tolerance, height growth, and incidence of forking. Components of variance for "provenances" were 3 to 4 times larger than components for "families-in-provenance". The hardiest provenances generally grew the slowest and showed the lowest incidence of forking. By far the hardiest native provenances were from Oberon and Barrington Tops, New South Wales, confirming the outstanding frost-tolerance of these provenances recorded in artificial frosting tests. Families from New Zealand and from Robertson, New South Wales, were notably more frost-tender and more forked than those from other Australian localities, and from South Africa. New Zealand families from Oakura and Hunterville showed excellent vigour but generally poor frost-tolerance and a high frequency of forking. The provenance in which the families possessed the best combination of good frost-tolerance, fast growth, and freedom from forking was from Bondi State Forest (south of Bombala, New South Wales) towards the southern end of the species' natural range.

The phenotypic correlations among family means within provenances were -0.41 between frost score and 1-year height (i.e., the tallest families generally showed the least frost damage), and 0.49 between 3-month and 1-year heights. Frost score at Kinleith was not well correlated at the family level (though highly correlated at the provenance level) with incidence of forking at either Kinleith itself or Kaingaroa.

INTRODUCTION

Eucalyptus fastigata is one of the ash group of eucalypts at present favoured in the North Island of New Zealand for growing as pulpwood and sawn timber. A genetic improvement programme was initiated in 1977 to breed strains with better stem and branching characteristics, and with adequate frost hardiness and vigour (Wilcox 1980).

Provenance variation in the frost tolerance of *E. fastigata* has been studied in some detail using artificial frosts (Wilcox, Rook & Holden 1980), and there have also been some studies reported of provenance variation in tolerance to natural frosts (Boden 1958; Roeder 1980; Sherry & Pryor 1967).

A better impression of genetic variability within a species can be gained by examining variation among families from a range of provenances rather than looking at variation among composite provenance seedlots. In this paper genetic variation among and within several provenances of *E. fastigata* is measured and compared for three important silvicultural traits — early height growth, incidence of forking, and frost tolerance. The methods used are generally similar to those adopted for comparable studies on *E. regnans* F. Muell. (Wilcox, Faulds, Vincent & Poole 1980).

MATERIALS AND METHODS

Provenances and Families

The genetic improvement programme for *E. fastigata* in New Zealand is based on 126 seedlots as listed in Table 1. Of these, 115 are open-pollinated families from individual mother trees and 11 are composite seedlots made up by bulking seed from several mother trees. Australian native stands are represented by 69 seedlots from eight provenances (Fig. 1), the parent trees of most of which can be regarded as random samples from the localities studied.

The other 57 seedlots are from exotic stands in South Africa (six lots) and New Zealand (51 lots). Nearly all the New Zealand families are from carefully selected plus-trees showing good stem form and branching characteristics, and vigorous growth (Table 1). The New Zealand populations sampled (Fig. 2) ranged from small woodlots or plots of only 20 or so trees to extensive plantations of several hectares (e.g., Oakura and Hunterville).

Most of the New Zealand seedlots were collected in 1977–78, and the Australian lots were collected over the period 1966–77.

Raising of Plants

Seed was soaked in cold water for 24 hours, stratified for 8 weeks, and sown in August 1979. Germinants were pricked out at the cotyledon stage into 55 × 55-mm peat pots. The plants were started off in a glasshouse, and later transferred outside to grow on to plantable size. The seedlings were planted out in November 1979 when they had three fully formed pairs of opposite leaves and the first few alternate leaves, and mean heights of individual lots ranged from 6 to 19 cm. The mean height of the five tallest trees per seedlot was recorded on 30 October 1979, 2 weeks before planting.

Several families from the Hunterville provenance in particular had significant numbers of abnormal seedlings (e.g., crinkly leaves and yellow cotyledons). Such plants are presumably a consequence of self-fertilisation and were discarded.

TABLE 1—Origins of **E. fastigata** seedlots in New Zealand breeding programme

Origin	Lat. (S)	Long. (E)	Alt. (m)	Number of seedlots* Families	Composites
New South Wales					
Barrington Tops	31° 50′	151° 20′	1370	7	1
Yetholme	33° 27′	149° 49′	1210	1	
Oberon	33° 54′	149° 48′	1220	10	1
Robertson	34° 35′	150° 36′	720	13	
Rossi	35° 29′	149° 30′	970–1070	16	
Badja	36° 13′	149° 29′	1070	0	3
Bombala	37° 08′	149° 12′	910	13	1
Victoria					
Bendoc	37° 10′	148° 55′	1070	1	2
South Africa					
Draycott, Natal	29° 00′	29° 45′	1500	6	
New Zealand					
Tairua	37° 09′	175° 50′	20	1	
Cambridge	37° 53′	175° 29′	40	5	
Ngahinapouri	37° 53′	175° 15′	40		1
Rotoehu	37° 56′	176° 35′	90	1	
Tikitere	38° 04′	176° 22′	350	4	
Rotorua	38° 09′	176° 15′	305	7	
Waimana	38° 08′	177° 05′	30	1	
Kaingaroa	38° 31′	176° 35′	460	4	1
Lake Mangamahoe	39° 07′	174° 07′	150	1	
Oakura	39° 08′	173° 59′	125	11	1
Hunterville	39° 55′	175° 33′	300	9	
Broughton Bay	41° 13′	173° 56′	20	1	
Lake Ahaura	42° 33′	171° 44′	300	1	
Heathcote	43° 35′	172° 42′	150	1	
Charteris Bay	43° 40′	172° 43′	60	1	

* Families are seedlots from single trees; composites are commercial seedlots from various numbers of trees.

Test Sites and Establishment

The details of the two test sites are as follows:

Kinleith: Experiment No. R 1976; latitude 38° 17′S; longitude 176° 00′E; altitude 490 m; slope 3–14°; previous crop = *Pinus radiata* D. Don plantation; preparation = area logged 1978, topsoil heaped into ridges 3 m apart by tractor with V-blade; soil = loam overlying volcanic ash; air drainage = poor in places; location = Rauna Road, Cpt 691, N.Z. Forest Products Limited, Kinleith.

Kaingaroa: Experiment No. R 1975; latitude 38° 27′S; longitude 176° 42′E; altitude 270 m; slope 2–11°; previous crop = *Pinus ponderosa* C. Lawson plantation (1927); preparation = area logged 1978, burnt February 1979; soil = shallow layer

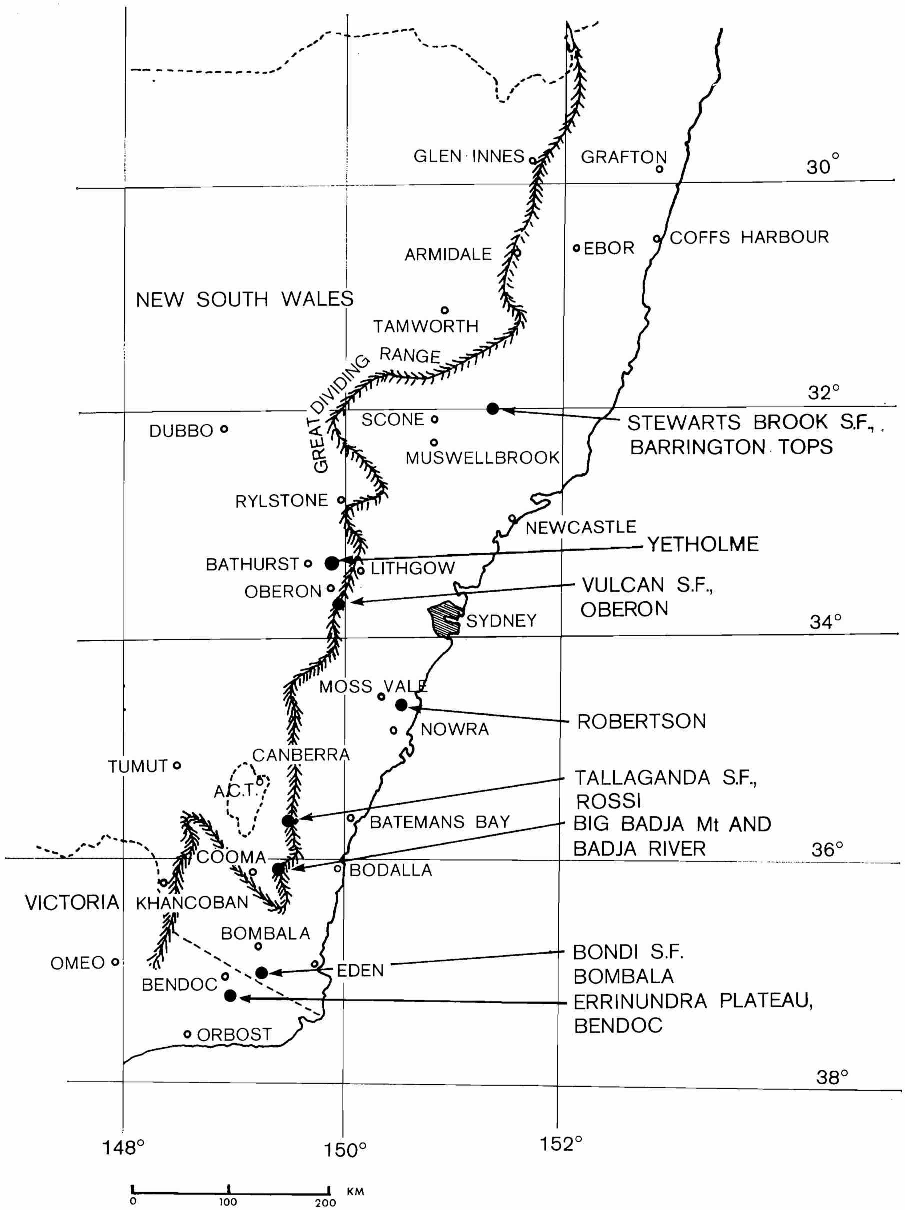

FIG. 1—Origins of eight native provenances (●) of **Eucalyptus fastigata** studied in New Zealand.

of dark topsoil overlying coarse, yellow, rhyolite ash; air drainage = poor in places; location = Caves Road, Cpt 1207, Kaingaroa Forest, near Murupara.

Trees were planted at 3 × 3 m spacing at Kinleith and 3 × 2.5 m at Kaingaroa, and 25 g of the slow-release fertiliser MagAmp$^{(R)}$ (registered trade mark of W. R. Grace

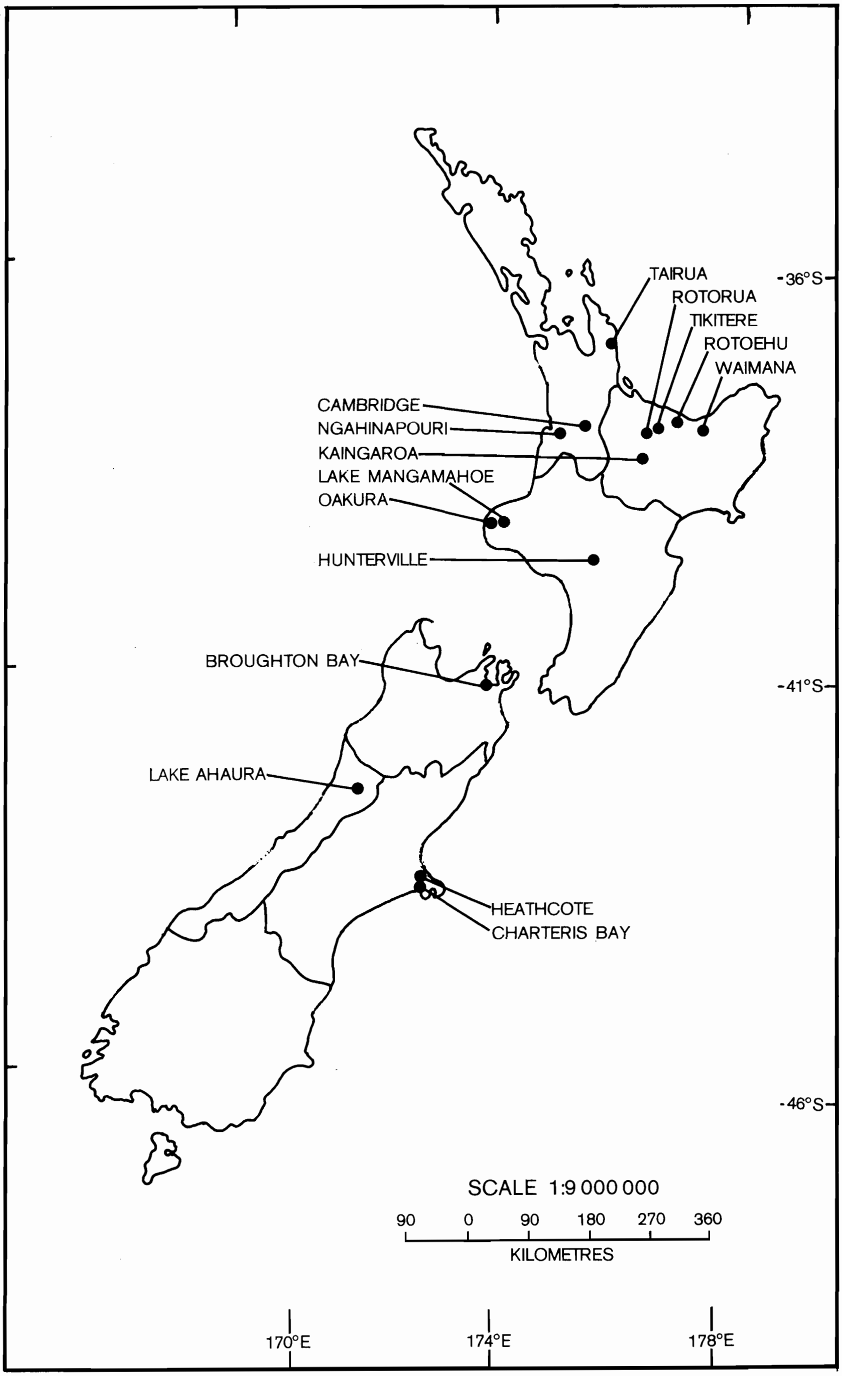

FIG. 2—Localities of **E. fastigata** stands in New Zealand represented by seedlots in the breeding programme.

& Co., United States) was incorporated in the planting hole. Hand weeding was carried out in January 1980. The Kinleith test was treated from the air with urea (250 kg/ha) in August 1980. The Kaingaroa test was treated with "Rustica" (NPK + MgO, 15 : 7 : 5 : 4) at a rate of 78 g per tree applied in a circle round the tree, in April 1980, and with urea at a rate of 60 g per tree applied in a slit, in October 1980.

Experimental Design

The Kinleith site was divided into 108 sub-blocks of 18 × 21 m. Sub-blocks were grouped in threes to make up 36 block replicates each of 0.113 ha.

The Kaingaroa site was divided into 126 sub-blocks, 15 × 21 m. Sub-blocks were grouped in threes to make up 42 block replicates of 0.094 ha.

The 126 seedlots were divided into three sets of 42 in a way which gave more or less equal representation of provenances in each set. Sets were assigned randomly to one of the three sub-blocks in each block replicate at each site. One tree of each seedlot was planted in each block.

Assessment of Frost Damage and Height Growth at Kinleith

Frost damage and tree heights were assessed on 13–14 October 1980 by a team of four people. Frost injury was significant in only 24 of the 36 blocks, so only these blocks were assessed.

The frost damage occurred during June and July when some heavy ground frosts with grass minimum temperatures estimated at –8°C were recorded in nearby Tokoroa. The main form of frost damage was desiccation of the foliage and shoot tips. A few trees also showed bark splitting in the lower part of the stem. Foliage and shoot damage were assessed on a 0–5 scale as follows:

0 = no foliage damage

1 = some leaves slightly damaged

2 = 10–30% of foliage killed

3 = *c.* 50% of foliage killed

4 = *c.* 90% of foliage killed

5 = tree killed by frost.

Care was taken to exclude trees that appeared to have died from causes other than frost. No assessment was made of bark splitting.

Trees with frost scores of 0, 1, or 2 were further classified as not sufficiently damaged to prevent normal recovery and growth, and allocated a "percentage severely frosted" score of 0. Trees with frost scores of 3, 4, or 5 were classified as permanently damaged or destroyed, and allocated a "percentage severely frosted" score of 100.

Total tree height (including dead tops) was recorded for each tree.

Assessment of Forking at Kinleith and Kaingaroa

In February-March 1981, a form pruning was carried out in both tests. Workers were instructed to remove heavy competing laterals and to single any forks. Trees were scored 100 if they were pruned and 0 if they were not. In addition, a tally was made of pruned trees that had obviously been severely malformed by frost damage.

Statistical Analysis

Variance components were estimated from analyses of variance to gauge the relative importance of "provenances" and "families-in-provenance" on genetic variation among the families. Relationships between different traits were studied using correlation coefficients.

RESULTS

Variation Among Seedlots

Seedlot means

Mean frost scores, percentage severely frosted trees, 1-year heights, and percentage forked trees (form-pruned) for each seedlot were recorded but are too bulky to be individually listed here. Seedlots ranged from 0.25 to 3.12 for frost score and from 0 to 62% for percentage of trees severely frosted at Kinleith, from 52 to 101 cm for 1-year height, and from 6 to 69% for incidence of forking. Heights of individual seedlots at 3 months ranged from 6 to 19 cm.

Nineteen of the seedlots were above average in all traits. These were from five provenances – Bombala (seven lots), Rossi (six lots), Bendoc (three lots), Badja (two lots), and South Africa (one lot). No New Zealand seedlots were above average in all traits.

Variance components and repeatabilities at Kinleith

Estimates of variance components and repeatabilities from a model which retained the subdivision of the 126 seedlots into three sets of 42 are shown in Table 2. The seedlots (within sets) differed significantly in both frost resistance and height growth, with high repeatabilities (i.e., high average correlations in performance between trees within the same seedlot), considering the small number of seedlings per seedlot. Thus, the single-tree plot experiment design used was clearly efficient. Within the site there were important block-to-block environmental differences which affected frost resistance but not height growth.

Variation Among Provenances

Provenance means

It was evident from the individual seedlot means that there were some striking similarities in frost score, height growth, and percentage forking, among seedlots from the same provenance. Means of the 10 major provenances (105 families) in the tests are shown in Table 3, with provenances listed in order of frost resistance at Kinleith. The hardiest provenances (Oberon, Natal, Barrington Tops) were the slowest growing, and the two most frost-tender provenances (Oakura and Hunterville) were among the fastest growing. The provenance from Bombala showed perhaps the best combination of frost resistance, freedom from forking, and vigour. All the New Zealand provenances, and the one from Robertson (New South Wales) were comparatively frost-tender and heavily forked.

TABLE 2—Estimates of variance components for frost score, percentage severely frosted trees, and 1-year height of 126 **E. fastigata** seedlots at Kinleith

	Frost score (0–5)	Severely frosted trees (%)	1-year height (cm)
Sets (σ^2_s)	-0.01 ± 0.04† (0%)‡	-5.05 ± 1.35 (0%)	0.43 ± 2.44 (0%)
Seedlots : sets ($\sigma^2_{f:s}$)	0.29 ± 0.04 (17%)	131.66 ± 22.43 (9%)	60.28 ± 9.28 (15%)
Blocks (σ^2_b)	0.34 ± 0.11 (19%)	177.59 ± 58.10 (12%)	9.63 ± 6.69 (2%)
Blocks × sets (= sub-block error) (σ^2_{bs})	0.08 ± 0.02 (5%)	54.78 ± 16.49 (4%)	29.43 ± 7.54 (7%)
Blocks × seedlots : sets (= single-tree plot error) (σ^2_e)	1.04 ± 0.03 (59%)	1070.39 ± 28.68 (75%)	307.83 ± 8.25 (76%)
Total (σ^2_T)	1.75	1434.42	407.60
F-test $H_0: \sigma^2_{f:s} = 0$	7.58**	3.91**	5.63**
Repeatability of seedlot means (within sets) ($h^2_{\bar{F}:S}$)	0.87	0.74	0.82

† ± standard error

‡ Percentage contribution of component to total variance

** = significant at 0.01% level

Mean heights of provenances in the nursery, 3 months after sowing, ranged from 8 cm (Oberon and Robertson) to 16 cm (Hunterville). Generally, the tallest provenances in the nursery were also the tallest after 1 year in the field. A notable exception was the Natal provenance which grew relatively slowly in the field after a fast beginning in the nursery.

Variation Among and Within Provenances

A variance component analysis of 105 families grouped into 10 provenances (Table 4) showed that the variance among the families was largely a reflection of genetic variation between provenances. The "families-in-provenance" components were 3–4 times smaller than the "provenances" components. However, the estimates of the pooled "family means-in-provenance" phenotypic variance ($\sigma^2_{\bar{F}:P}$) belie the fact that variances within individual provenances were heterogeneous, i.e., there were differences among-provenances in the magnitude of family-to-family phenotypic variability (Table 5).

TABLE 3—Mean frost-hardiness, heights, and percentage of forked trees of 10 ***E. fastigata*** provenances at Kinleith and Kaingaroa

Provenance	Number of families	Kinleith					Kaingaroa	
		Frost score 1980 (0–5)	Percentage severely frosted trees (1980)	Height (cm) 3-month	Height (cm) 1-year	Percentage forked trees (1981)	Percentage forked trees (1981)	Percentage frosted trees (1981)
Oberon, NSW	10	0.42	1.6	8	67	24	21	3
Natal, South Africa	6	0.68	4.7	14	71	20	32	5
Barrington Tops, NSW	7	0.69	6.1	11	62	20	28	3
Bombala, NSW	13	0.92	9.7	13	82	20	26	5
Rossi†, NSW	16	0.94	11.3	9	78	27	30	5
Cambridge, NZ	5	1.27	15.2	11	75	39	41	6
Bay of Plenty‡, NZ	17	1.53	23.4	11	75	38	43	11
Robertson, NSW	11	1.54	25.5	8	73	39	47	14
Oakura, NZ	11	1.70	26.1	14	83	39	49	15
Hunterville, NZ	9	1.93	31.2	16	83	35	44	15
Mean	10	1.19	16.2	11	76	30.5	36.4	8.5
LSD (0.05)§		0.30	8.0	2	6	6.7	8.2	4.5
F-test, provs.		20.94**	12.57**	11.01**	11.21**	12.06**	12.06**	9.62**

† Rossi provenance comprises 16 seedlots from Tallaganda State Forest

‡ Bay of Plenty provenance comprises 17 seedlots from Kaingaroa, Rotorua, Tikitere, Waimana, and Rotoehu

§ Mean group LSD, assuming average of 10.34 families per provenance

** = significant at 0.01% level

TABLE 4—Contributions of "provenances" and "families-in-provenance" to the families variance component for frost score, percentage severely frosted trees, and 1-year heights in 105 **E. fastigata** families from 10 provenances at Kinleith

Component	Frost score (0–5)	Percentage severely frosted trees (%)	1-year height (cm)
Families (ignoring provenance) (σ^2_f)	0.28	120.13	64.75
Provenances (σ^2_p)	0.22 (79%)	92.99 (77%)	39.67 (61%)
Families-in-provenance ($\sigma^2_{f:p}$)	0.06 (21%)	27.14 (23%)	25.08 (39%)
Residual (within family) (σ^2_w)	1.46	1302.76	346.89
Phenotypic variance among family means within provenances ($\sigma^2_{\bar{F}:P} = \sigma^2_{f:p} + \frac{\sigma^2_w}{23.586}$)	0.12	82.37	39.79
Repeatability of family means within provenances ($h^2_{\bar{F}:P} = \sigma^2_{f:p} / \sigma^2_{f:p} + \frac{\sigma^2_w}{23.586}$)	0.50	0.33	0.63

The heterogeneity of within-provenance variance for frost score arose largely from two of the New Zealand populations, Oakura and Hunterville, which were markedly more variable than the others. The Oakura population in particular showed a very high variance and coefficient of variation in relation to its mean frost score. The native provenances were all about equally variable in frost score.

Heterogeneity of within-provenance variances was less marked for height growth, the most variable provenances again being New Zealand exotics – Hunterville and Bay of Plenty for 1-year height, and Cambridge and Bay of Plenty for 3-month height.

Correlations

Correlations between height and frost tolerance at Kinleith

Estimates of correlations are given in Table 6. There was scarcely any association between the height of an individual tree and its frost score ($\hat{r}_p = -0.11$), but the field blocks with the tallest trees tended to show the least frost damage ($\hat{r}_e = -0.39$), or, in other words, trees in frost hollows grew slowest and suffered the most frost damage.

TABLE 5—Family mean (within-provenance) phenotypic variances ($\sigma^2_{\bar{F}:P}$) and coefficients of variation (CV) for frost score, 1-year heights, and 3-month heights of 105 **E. fastigata** families at Kinleith

Provenance	Number of families	Frost score (0–5)		1-year height (cm)		3-month height (cm)	
		Variance	CV	Variance	CV	Variance	CV
Oberon	10	0.03	38.9%	20.54	6.8%	1.43	14.9%
Natal	6	0.08	40.9%	32.97	8.1%	4.80	15.6%
Barrington Tops	7	0.02	20.7%	10.90	5.3%	2.62	14.7%
Bombala	13	0.05	26.2%	39.27	7.6%	4.56	16.4%
Rossi	16	0.09	32.4%	38.78	8.0%	2.83	18.7%
Cambridge	5	0.03	12.9%	12.30	4.7%	14.30	34.4%
Bay of Plenty	17	0.08	18.8%	57.82	10.1%	13.87	33.9%
Robertson	11	0.11	21.8%	20.05	6.2%	5.22	28.6%
Oakura	11	0.36	35.3%	21.89	5.6%	6.22	17.8%
Hunterville	9	0.24	25.5%	110.44	12.7%	7.03	16.6%
Pooled Values		0.12	28.8%	39.79	8.3%	6.31	22.6%
χ^2 (Bartlett's test†)		30.13**		16.47**		20.27**	
LSD‡			18%		5%		14%

† Test for heterogeneity of within-provenance variances

‡ Least significant difference $= \sqrt{\frac{(CV)^2}{n}} \times 2$

where n is the average number of families per provenance (10.34), and CV is the pooled coefficient of variation.

As evident in Table 3, the tallest provenances tended to suffer the most frost damage ($\hat{r}_{PR} = 0.58$) but there were several notable departures from this general trend. Within provenances, however, the tallest families generally had the least frost damage ($\hat{r}_g = -0.60$; $\hat{r}_F = -0.41$), indicating that simultaneous selection for better frost-resistance and faster growth could be readily accomplished in suitable provenances.

Correlations between 3-month and 1-year heights at Kinleith

There were big differences in heights of individual seedlots at the time of planting (range 6–19 cm). The phenotypic correlations between the 3-month and 1-year heights were rather weak ($\hat{r}_F = 0.49$, family means within provenances, and $\hat{r}_{PR} = 0.57$, provenance means), showing that early differences between seedlots, especially within provenances, were not always persisting. Nevertheless, the three currently tallest provenances (Oakura, Hunterville, and Bombala) were very vigorous from the start.

TABLE 6—Correlations between frost resistance (frost score 0–5) and 1-year height in 126 **E. fastigata** seedlots at Kinleith

Correlation	n	Symbol	Estimate
Individual tree phenotypic correlation	2978	r_p	–0.11
Environmental correlation (block-to-block)	24	r_e	–0.39
Families-in-provenance mean phenotypic correlation	105	r_F	–0.41
Genetic (families-in-provenance) correlation	105	r_g	–0.60
Provenance mean phenotypic correlation	10	r_{PR}	0.58

Correlations involving incidence of forking

The correlations shown in Table 7 confirm that variation in the incidence of forking in both the tests was not random but highly associated with seedlot. The strongest correlations were among provenance means; a low incidence of forking was associated with good resistance to frost. At Kaingaroa, the most frost-tender seedlots were generally heavily forked, with visual evidence that forking was in many cases caused, or made worse by the frost damage. There were nevertheless several very frost-hardy seedlots that were also heavily forked.

TABLE 7—Correlations between incidence of forking, frost resistance, and height growth in 126 **E. fastigata** seedlots at Kinleith and Kaingaroa

Correlation	Individual seedlots (r_s)	Provenance means (r_{PR})	Families within provenance (r_F)
Percentage forking at Kinleith and Kaingaroa	0.58**	0.92**	0.12
Percentage forking and frost score at Kinleith	0.51**	0.85**	0.07
Percentage forking at Kaingaroa and frost score at Kinleith	0.62**	0.93**	0.14
Percentage forking and percentage frosted trees at Kaingaroa	0.73**	0.95**	0.51**
Frost score at Kinleith and percentage frosted trees at Kaingaroa	0.64**	0.95**	0.30**
Height and percentage forking at Kinleith	0.17n.s.	0.28n.s.	0.02n.s.

** = significant at 0.01% level

n.s. = not significant

DISCUSSION

The relative difference in winter frost-tolerance shown by the *E. fastigata* provenances in this study did not always agree with results from artificial frost experiments (Wilcox, Rook & Holden 1980). Although the three hardiest provenances (Oberon, Barrington Tops, and Natal) were clearly identified in both field and artificial frosts, there were others such as Oakura and Bombala in which relative frost tolerance appeared to differ between field and artificial frosts. The Bombala provenance (from Bondi State Forest) showed poor tolerance to artificial frosts in autumn and spring (i.e., unseasonable frosts), and only average tolerance in winter (Wilcox, Rook & Holden 1980); yet in the field test at Kinleith the same seedlot was one of the hardiest. Conversely, the Oakura provenance showed good average frost-tolerance in the frost-room tests, but was one of the least tolerant in the field. These interactions are difficult to explain as identical seedlots were used in each case. Possibly the field frosts were not severe enough to differentiate precisely between the numerous seedlots of intermediate hardiness, thus giving apparent, but meaningless, changes in rank.

The single-tree plot randomised block designs used appear to have been very effective for screening seedlots for frost tolerance, growth, and forking. Despite the rather low average frost injury (1.23 frost score and 17.2% of trees severely frosted) in the Kinleith field test compared with the high average frost injury (3.36 frost score and 68.3% of trees severely frosted) in the artificial frosts at Palmerston North (Wilcox, Rook & Holden 1980), the field test efficiently screened the seedlots. The least significant difference between seedlots in the field test was 0.61 – exactly the same value as in the artificial frosts, but using 6 times fewer trees per seedlot.

New Zealand seedlots were generally less frost-hardy than native seedlots except those from Robertson, New South Wales. This suggests that the genetic base of New Zealand *E. fastigata* is narrow, unrepresentative of the species as a whole, and apparently biased towards low-altitude, frost-tender ecotypes. The provenance from Draycott in Natal, South Africa, behaved more like typical provenances from the Great Dividing Range in New South Wales.

There were important genetic differences in frost tolerance and height both between and within the provenances. However, family-to-family variation in frost tolerance differed significantly among provenances. Of the total variance among families for frost score, 79% was attributable to provenance differences in mean frost score and 21% to family differences within provenances. Of this 21%, two of the New Zealand provenances, Oakura and Hunterville, alone contributed 15%; the other eight provenances together contributed only 6%. The Oakura provenance was particularly variable, suggesting that this extensive plantation on the lower north-eastern slopes of the Kaitake Range near Mt Egmont in Taranaki is of reasonably broad genetic base and therefore potentially valuable for within-population selection.

Of the 126 individual seedlots, 18 ranked in the top 50 at Kinleith for both frost hardiness (frost score) and 1-year height, highlighting the absence of any overwhelmingly adverse correlation between frost hardiness and growth rate. Of these seedlots, 10 were of the Bombala provenance, five of the Rossi provenance, two of the Badja provenance, and one from the Oakura provenance. The best all-round commercial seedlot tested was No. 114 (HO 78/22) from Badja River, New South Wales, ranking forty-sixth for frost hardiness, twenty-fourth for height growth, and showing a low incidence of malformation at both Kinleith and Kaingaroa. The same seedlot has given excellent results in commercial plantations at Kaingaroa Forest.

The incidence of forking and heavy ramicorn branching, as determined by the need to form prune, showed surprisingly strong provenance variation, and there was good agreement between the results from the two sites. The New Zealand and Robertson provenances had an incidence of forking of 35–49%, and were generally far more malformed than most of the other New South Wales and the Victorian seedlots. Thus, the impression in New Zealand that *E. fastigata* is a eucalypt of poor form could have given the species as a whole an undeserved reputation. A move away from local seed sources to selected native provenances could bring immediate improvement in the branching quality, and renewed confidence in the species.

Notwithstanding their mediocre aggregate performance in artificial frosts, the Bombala families were clearly outstanding for combined winter frost-hardiness, freedom from malformation, and fast growth under the environmental conditions of the Kinleith and Kaingaroa field tests. The actual seed collection site of this provenance was in Bondi State Forest in New South Wales very close to the southern border with Victoria.

APPLICATION OF RESULTS

These results will be helpful in choosing sources for immediate commercial seed collections and for interim constitution of breeding populations and seed orchards for breeding superior strains of *E. fastigata*. With the exception of the Robertson provenance, which in these tests had the unfortunate combination of poor frost-resistance, severe forking, and slow early growth, all the native provenances tested had some virtues.

For especially frost-prone planting sites such as the top of the Kaingaroa plateau or frost hollows at the foot of hills, where *E. delegatensis* R.T. Bak. might be considered a safer alternative (Wilcox 1980), it will be necessary, or at least prudent, despite their slower early growth, to plant only the hardiest provenances of *E. fastigata* such as those studied here from Oberon (Vulcan State Forest) and Barrington Tops (Stewarts Brook State Forest), New South Wales. Pilot commercial plantings of these two provenances were made in Kaingaroa Forest in September 1980. Once further experience has been gained in planting *E. fastigata* on a range of sites over several seasons, it should become clearer to what extent provenances of near-maximum frost-hardiness, but probably sub-optimal growth rate, are really needed, and whether further seed importations of these should be made.

There appear to be no seed sources in New Zealand of the higher altitude ecotypes of *E. fastigata* such as those studied in the test from Rossi (Tallaganda State Forest) and the Badja Mountain area, nor from southern localities such as Bombala and Bendoc. It is proposed that future commercial seed importations should concentrate on populations from the Great Dividing Range in New South Wales around 1000 m altitude, extending from Tallaganda State Forest southwards to the Bombala district, and to the Errinundra Plateau of Victoria. Such provenances should combine good frost-hardiness, fast early growth, and relative freedom from early malformation. The single South

African provenance sampled was also considerably more hardy and less forked than New Zealand provenances, and could be a useful source of seed.

No New Zealand population seems to have much immediate value as a commercial seed source, and some are positively worthless. The very rapid early growth of the Oakura and Hunterville provenances has been a feature of the results, but on these test sites they showed poor frost tolerance and severe forking. They perhaps could be used to advantage for planting on milder sites where frost risk is slight.

An important need in *E. fastigata* is the improvement of its poor branching. This early assessment of forking will be valuable, but direct selection of families with superior branching must wait until the tests are at least 4 years old. A multi-trait selection programme incorporating the early results on frost-hardiness and forking will enable suitable families (or clones) to be chosen for use in seed orchards. It may be desirable to breed two separate strains of *E. fastigata,* one giving extra emphasis to frost-hardiness and therefore based on the very hardiest provenances, and the other concentrating mainly on yield.

ACKNOWLEDGMENTS

Those who helped variously with seed collection, nursery propagation, site preparation, planting, assessment, and computing were D. R. Briscoe, R. L. Cameron, T. Faulds, D. A. Franklin, C. B. Low, M. Miller, J. T. Miller, O. Mohrdiek, B. R. Poole, J. D. Tombleson, and T. G. Vincent.

Suppliers of seedlots from Australia were CSIRO Division of Forest Research (Canberra), L. Langley (Robertson), and W. McCreaddie (Gilgandra). Miss K. M. Nixon supplied the seed from Natal, South Africa.

Within New Zealand the following kindly gave access to trees: Cambridge Borough Council (Te Koutu Park); E. O'Reagan (Ngahinapouri); J. G. Wells (Tikitere); PTY Homes Ltd (Carr Estate, Rotorua); R. R. White (Waimana); New Plymouth City Council (Lake Mangamahoe); H. M. Daamen (Oakura); J. Goodwin (Hunterville); W. M. Greensill (Broughton Bay, Kenepuru Sound); and the Management Board of Orton Bradley Park (Charteris Bay).

Special thanks go to N.Z. Forest Products Limited for providing the trial site in the Kinleith Forest, and to P. A. Painter and workers at Murupara for support with various phases of the Kaingaroa test.

REFERENCES

BODEN, R. W. 1958: Differential frost resistance within one **Eucalyptus** species. **Australian Journal of Science 21:** 84–6.

ROEDER, K. 1980: Early provenance performance of **Eucalyptus fastigata** in South Africa. **South African Forestry Journal 112:** 30–2.

SHERRY, S. P.; PRYOR, L. D. 1967: Growth and differential frost-resistance of topoclinal forms of **Eucalyptus fastigata** D. & M. planted in South Africa. **Australian Forestry 31:** 33–44.

WILCOX, M. D. 1980: Genetic improvement of eucalypts in New Zealand. **New Zealand Journal of Forestry Science 10:** 43–59.

WILCOX, M. D.; ROOK, D. A.; HOLDEN, D. G. 1980: Provenance variation in frost resistance of **Eucalyptus fastigata** Deane & Maid. Paper presented at IUFRO Symposium on "Genetic Improvement and Productivity of Fast-growing Tree Species". Sao Paulo, Brazil, August 1980.

WILCOX, M. D.; FAULDS, T.; VINCENT, T. G.; POOLE, B. R. 1980: Genetic variation in frost tolerance among open-pollinated families of **Eucalyptus regnans** F. Muell. **Australian Forest Research 10:** 169–84.