FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

EFFECTS OF BORON DEFICIENCY ON THE ROOT ANCHORAGE AND INCIDENCE OF RESIN POCKETS IN *PINUS RADIATA*

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Report No. 48 May 1998

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EXECUTIVE SUMMARY

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ABSTRACT

The hypothesis that the addition of boron fertiliser improves the root anchorage of radiata pine on boron deficient sites was tested by performing a winching study to determine the maximum resistive bending moments of fifty-eight radiata pine trees grown under different fertiliser treatments and located in two separate compartments at Ashley Forest, Canterbury and in a replicated fertiliser trial at Rerewhakaaitu Forest, Bay of Plenty. The maximum tensile strengths of small diameter (<15 mm) roots collected from both fertilised and unfertilised trees at Ashley Forest were determined in order to ascertain whether any increase in root anchorage was due to an increase in this property.

Results from both forests showed that trees which were located in areas which had received an application of fertiliser had significantly higher maximum resistive bending moments than those in areas which had not. These differences appear to be due to other factors (e.g., site variability) as the level of foliar boron in a tree did not have a significant effect on M_c once a dummy variable to incorporate these was included in the analysis. In addition to this, the mean tensile strengths of the roots sampled in the fertilised stand at Ashley Forest were not significantly different from those sampled in the unfertilised stand.

All trees winched over were cut into discs which were assessed for the presence resin pockets. The incidence of resin pockets was higher at Ashley Forest than at Rerewhakaaitu Forest. Type 1 resin pockets were the most common, however there was no difference in the incidence of this type or the total incidence between fertilised and unfertilised trees.

KEYWORDS: Boron, maximum resistive bending moment, radiata pine, resin pockets, root anchorage, tree stability, wind damage.

INTRODUCTION

Boron deficiency affects tree growth, form and timber quality of radiata pine (*Pinus radiata* D. Don) in New Zealand (Will 1978; Will 1985; Stone 1990). The major areas of boron deficiency in the South Island occur on low rainfall inland hill and stony soils, and granite and Moutere gravel soils (Figure 1), while in the North Island they occur on coarse pumice soils (Will 1985). Severe deficiency is usually associated with boron levels in P. radiata of 8 ppm or less, with marginal deficiency in the range of 8-12 ppm (Lambert and Turner 1977). The visible effects of boron deficiency are distinctly seasonal in occurrence and become recognisable in the leading shoots from midsummer onwards. This is usually followed by the death of the apex of each leading shoot and proliferation of buds below the damaged portion.

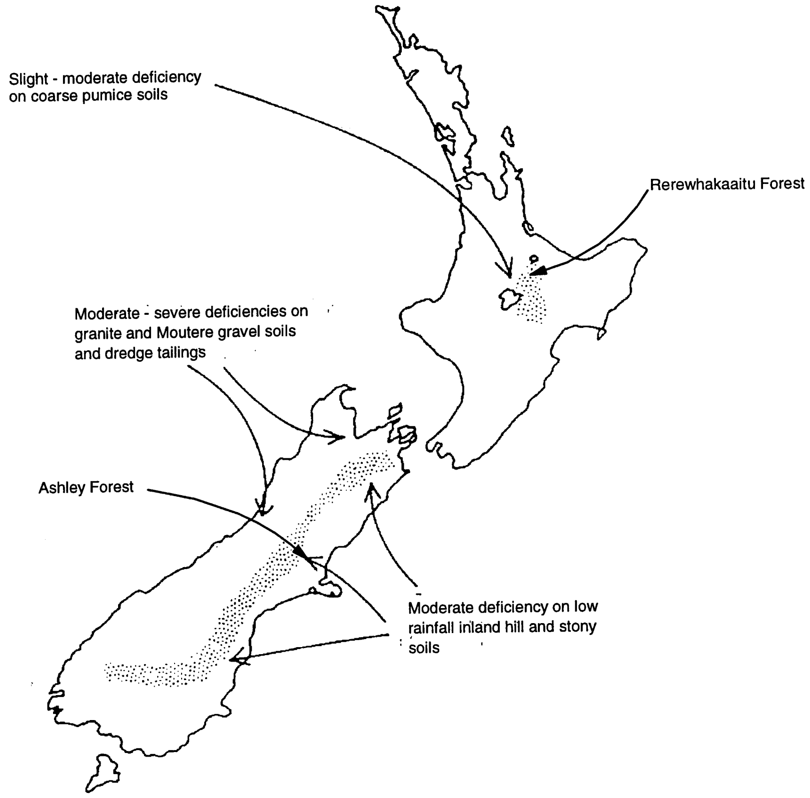

FIG.1-Areas in New Zealand prone to boron deficiency (from Will 1985)

Studies documenting the effects of boron deficiency on tree roots are limited. Stone (1968) suggested that sub-acute boron deficiency affects root development, while Lambert and Turner (1977) noted that the roots of *Pinus* species under conditions of severe boron deficiency are reduced in size and number. For Scots pine (*Pinus sylvestris* L.) Raitio (1983) found that the macroscopic symptoms in roots resembled those in shoots with death and forking of root tips resulting in a dense and short root bundle. These observations coupled with some evidence suggesting that timber from boron deficient sites may have reduced strength properties when compared with non boron deficient sites of equivalent basic density (G. Parker and R. Britton pers. comm.) suggests that the addition of boron fertiliser may improve the resistance of a tree to both uprooting and stem breakage on a boron deficient site.

To test the hypothesis that the addition of boron fertiliser improves the root anchorage of radiata pine on boron deficient sites, a winching study was undertaken to determine the maximum resistive bending moment of trees under different boron fertiliser treatments. The effects of boron fertiliser on root tensile strength and the incidence of resin pockets were also assessed.

MATERIALS AND METHODS

Site and Sample

The trees selected to be winched over were located at Ashley Forest, Canterbury and at Rerewhakaaitu Forest, Bay of Plenty. The soils at Ashley Forest are classified as Makerikeri Hill soils (DSIR Soil Bureau 1968) and are mostly made up of stony silt loams which have developed on interbedded greywacke gravels, silts and sands. Selected trees were located in two separate, non-adjacent stands. Both were established in 1979 and the initial stocking for stand 17/4 was 1250 stems/ha with a spacing of 4 × 2 metres, while stand 26/3 had an initial stocking of 1667 stems/ha at a spacing of 3 × 2 metres. At age 4 years stand 17/4 was fertilised with 30.8 kg/ha of a 3:1 colemanite/neobor mix. In 1984 both stands were low pruned and thinned to waste in 1984, with a second pruning and thinning in 1986. The prescribed final stocking of both stands is 190 stems/ha.

TABLE 1 - Minimum, maximum and mean values of tree height and dbh measurements for trees winched over. Foliar boron levels are stand averages which were determined in 1994.

Forest	Stand	Foliar boron level (ppm)	Dbh (cm)			Height (m)		
			min	mean	max	min	mean	max
Ashley[a]	17/4	18.0	36.5	46.6	53.3	16.7	22.5	25.1
Ashley	26/3	8.0	35.8	45.0	52.2	19.9	23.6	26.9
Rerewhakaaitu[a]	263/1	21.5	25.3	30.5	38.0	14.4[b]	17.9	20.2
Rerewhakaaitu	263/1	4.5	25.7	30.5	39.4	15.9	17.9	21.1

[a] fertilised with boron
[b] the shortest tree winched over was 12.6 m however it had a broken top

The trees sampled from Rerewhakaaitu Forest were located in the FR24/2 boron fertiliser trial which was established in 1988 when the trees were 2 years old (Skinner *et al.* 1996). The trial was planted in 1986 at an initial stocking of 1000 stems/ha. In 1988 three different types of boron fertiliser (soluble boron, calcium borate and sodium calcium borate) were applied with and without weed control. There are also unfertilised control plots. Each treatment is replicated 3 times giving 24 plots which are arranged in a randomised block design. Soils at the site are classified as Matahina Hill soils which are recent soils derived from Tarawera ash. The stand has been pruned to 6.1 m and waste thinned to a residual stocking of 517 stems/ha. Trees selected to be winched over came from the three unfertilised control plots which had not received weed control and the three plots which had received ulexite fertiliser (sodium calcium borate) and which also had not received weed control. Fertiliser was applied at a rate of 6 kg B/ha. The approximate locations of both forests are shown in Figure 1 and the range of diameters at breast height (dbh) and total heights of the trees selected to be winched over are shown in Table 1.

Root Anchorage

Between July 1997 and March 1998, fifty-eight trees were pulled over using a winch, cable and pulley system as shown in Figure 2. The system was similar to that used by Krasowski *et al.* (1996) except that the trees did not have their tops removed prior to winching. The force input to the system was provided by a Habeggar HITTRACK 16 motorised winch and was measured using a Reliance SSM-5500 load cell. The maximum tension recorded in the cable was resolved into a horizontal force which was multiplied by the height of cable attachment to give the maximum applied bending moment. The bending moment due to the self weight of the tree was assumed to be negligible and hence the maximum resistive bending moment was assumed to be equal to the maximum applied bending moment.

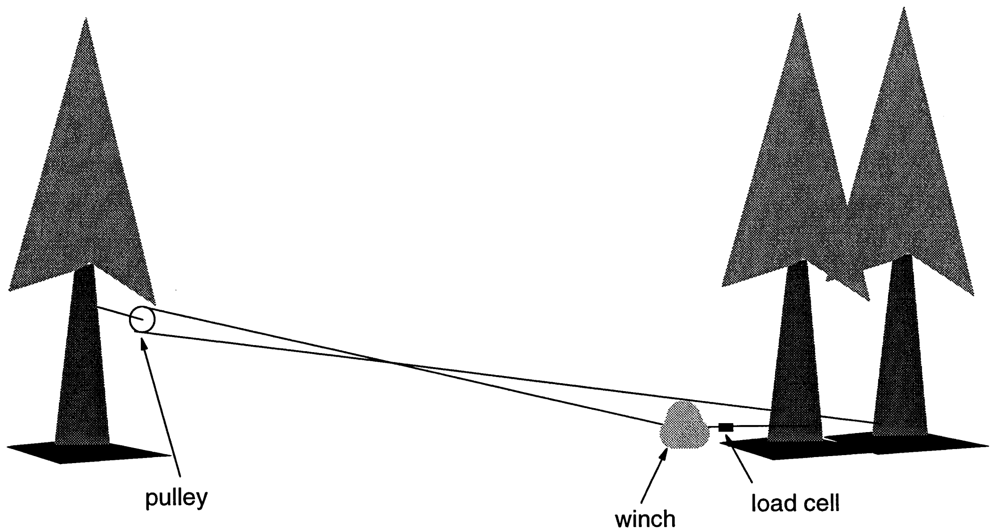

FIG 2-Schematic diagram of the tree winching system.

Prior to winching the dbh and total height of each tree were measured. Once the tree was winched over its stem volume was calculated from sectional measurements. If the tree failed by uprooting, four root plate dimensions were measured (Figure 3). The root plate width (2 times the average of measurements 1, 2 and 3) was taken to be the distance from the centre of the tree stem to the edge of the central mass of roots and soil. The root plate depth was also measured (measurement 4). At Rerewhakaaitu Forest the soil was removed from the root plates and the length and diameter at base of each structural root (>10 mm) on the windward side of the tree was measured. Root were also grouped into three categories; laterals, sinkers and tap roots. If a tree failed by stem fracture the height of the fracture point was measured. Foliage samples were collected from each tree and analysed in the Forest Nutrition Laboratory at ***Forest Research*** to determine the foliar boron level of each tree.

Root Tensile Strength

Approximately 20 small diameter (<15 mm) root samples were collected from each tree winched over at Ashley Forest and sealed in plastic bags which were kept in cool storage for subsequent tensile strength testing using a floor model 1195 Instron Universal Testing

Machine equipped with a reversible load cell of 10 kN maximum capacity. Each root was strained in tension at a rate of 20 mm/min until rupture occurred. After each test was completed, the mean root diameter at the rupture point and the root length were measured. Test results were automatically recorded on a PC. The maximum tensile strength of each root was calculated by dividing the maximum tensile load by the cross-sectional area at the rupture point.

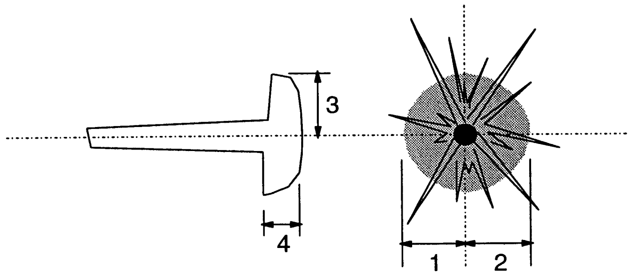

FIG 3-Measurements taken for uprooted trees.

Resin Pocket Assessment

The winched over trees Ashley Forest were cut into discs at 0.5 m intervals in the pruned section and at the midpoint of each internode in the unpruned section. At Rerewhakaaitu Forest, two billets were removed from each tree for subsequent wood quality analysis (which will be reported separately. Russell McKinley pers comm) with the remaining pruned section cut into discs at 0.3 m intervals. The diameter under bark (dib) of each disc was recorded and where resin pockets occurred their type and location (i.e. number of growth rings in from cambium) were noted. Resin pockets were classified according to the descriptions given by Somerville (1980). The incidence of resin pockets in the cross-sectional plane were converted into the expected incidence in the sawing plane using conversion factors developed by Somerville (unpublished data).

Data Analysis

The data from the tree winching, root tensile strength and resin pocket studies were analysed using the SAS System (SAS Institute (Inc.) 1994). Regression equations were developed to relate the maximum resistive bending moment, M_c, to tree height, dbh, stem volume and root plate size. Analyses of covariance were used to investigate the effects of foliar boron levels on M_c.

RESULTS

Root Anchorage

Significant linear relationships were found between M_c and dbh, tree height and stem volume (Table 2). Stem volume explained the greatest proportion of the variance in M_c ($r^2 = 0.84$). An analysis of covariance found no difference in M_c between forests ($p = 0.41$ when stem volume was the covariate; $p = 0.31$ when dbh was the covariate). Stem taper did not affect M_c ($p=0.18$ when stem volume was used as a covariate).

TABLE 2-Relationships between maximum resistive bending moment and tree height, dbh and stem volume

Model	Parameter estimates	p value	RMSE	r^2
[1] $M_c = a_1$ dbh + b_1	$a_1 = 8.37$	0.0001	31.73	0.844
	$b_1 = -208.74$	0.0001		
[2] $M_c = a_2$ height +b_2	$a_2 = 17.24$	0.0001	55.87	0.518
	$b_2 = -241.49$	0.0001		
[3] $M_c = a_3$ volume + b_3	$a_3 = 137.15$	0.0001	32.00	0.842
	$b_3 = -27.45$	0.0032		
[4] $M_c = a_4$ root plate width	$a_4 = 33.39$	0.0001	49.70	0.516
[5] $M_c = a_5$ root plate depth	$a_5 = 89.5$	0.0001	65.03	0.179
[6] $M_c = a_6$ root volume index + b_6	$a_6 = 10.35$	0.0001	45.87	0.594
	$b_6 = 34.37$	0.0007		

Three distinct modes of tree failure were observed; stem failure, root failure and uprooting. Descriptions of these are given in Somerville (1979). Four of the 58 trees winched over exhibited stem failure, five root failure and the remaining 49 failed by uprooting. All three failure modes were observed at Ashley Forest while all trees at Rerewhakaaitu Forest failed by uprooting. A comparison of mean values of M_c adjusted for dbh and stem volume (Table 3) showed that trees which failed by stem fracture did so at higher maximum resistive bending moments than those trees which failed by uprooting or root failure. The root plate depths of trees which failed by uprooting ranged between 0.6 m and 1.8 m with root plate widths ranging between 0.8 m and 6.1 m. A root volume index (RVI) was calculated for these trees from their gross root plate dimensions using Equation [1].

$$RVI = \frac{2}{3}\pi RW_{12} \times RW_3 \times RD \qquad [1]$$

where RW_{12} is the average of measurement 1 and 2 (see Fig 3), RW_3 is measurement 3 and RD is the root plate depth (measurement 4). Maximum resistive bending moment was strongly correlated with RVI (r^2=0.59) and average root plate width (average of measurements 1, 2 and 3; r^2=0.52). There was only a weak correlation between M_c and root plate depth (r^2=0.18). No differences in average root plate width (p=0.93), root plate depth (p=0.61) or root volume index (p=0.55) were found between fertiliser treatments.

TABLE 3 - Comparisons of M_c between failure modes.

Mode of Failure	Mean M_c (adjusted for dbh) (kNm)	Mean M_c (adjusted for stem volume) (kNm)
Stem failure	166.55 a*	174.18 a
Root failure	86.69 b	99.11 b
Uproot	105.65 b	103.76 b

*Means followed by a different letter are significantly different at the 5% level.

Foliar boron levels in the trees winched over at Ashley Forest ranged between 5-15 parts per million (ppm) in the unfertilised stand and between 12-40 ppm in the fertilised stand. The corresponding levels at Rerewhakaaitu Forest were 3-17 ppm and 9-28 ppm respectively. Mean levels of foliar boron were 9 ppm and 20 ppm for the unfertilised and fertilised trees, respectively (significantly different at $p<0.01$).

Trees located in areas which had received an application of boron fertiliser had higher maximum resistive bending moments than those growing in unfertilised areas (Table 4a). Trees with higher foliar boron levels also had higher maximum resistive bending moments. Because the trees were located in three different stands a site variable was included in the analysis in order to determine whether differences in M_c were due to boron levels or instead due to other site differences. This revealed that once the effects of tree size, mode of failure and site had been accounted for, the level of foliar boron in a tree did not have an effect on Mc ($p=0.79$ when stem volume was used as a covariate; $p=0.26$ when dbh was used). Trees growing at the fertilised site at Ashley had higher maximum resistive bending moments than trees growing at the other two sites (Table 4*b*).

TABLE 4 - Comparisons of M_c between (a) fertilised and unfertilised trees and (b) tree sampling locations.

(a)

Fertiliser treatment	Mean M_c (adjusted for dbh and failure mode) (kNm)	Mean M_c (adjusted for stem volume and failure mode) (kNm)
Fertilised	126.94 a*	133.74 a
Unfertilised	111.01 b	115.95 b

(b)

Site	Mean M_c (adjusted for dbh, failure mode and foliar boron level) (kNm)	Mean M_c (adjusted for stem volume, failure mode and foliar boron level) (kNm)
Ashley fertilised	153.94 a	145.06 a
Ashley unfertilised	119.19 b	120.28 a
Rerewhakaaitu	109.68 b	103.04 b

*Means followed by a different letter are significantly different at the 5% level

Root Tensile Strength

Of the 432 roots tested, 216 were considered suitable for analysis, the results of which are listed in Table 5. The mean diameter of roots sampled from the fertilised stand was 5.2 mm and their mean tensile strength was 19.2 MPa for a mean root diameter of 5.2 mm. Corresponding values from the unfertilised stand were 5.4 mm and 21.3 MPa. There was no difference in mean root tensile strength between stands ($p=0.27$).

TABLE 5 - Tensile strength of roots sampled from fertilised and unfertilised stands at Ashley Forest.

Stand (no. tested)	Root Diameter (mm)				Ultimate Tensile Strength (MPa)			
	Min	Mean	Max	s.d.	Min	Mean	Max	s.d.
17/4[a] (113)	2.1	5.2	8.0	3.7	7.6	19.2	44.2	7.0
26/3 (103)	2.5	5.4	9.1	7.0	8.0	21.3	40.9	6.3

[a] Fertilised with boron

Resin Pocket Incidence

The total number of resin pockets per square metre of cross-sectional area at Ashley Forest ranged between 0 and 40.01 for fertilised trees and 0 and 18.86 for unfertilised trees (Table 6). At Rerewhakaaitu Forest it ranged between 0 and 2.09 for fertilised trees and 0 and 4.46 for unfertilised trees. The most commonly occurring resin pockets at both forests were Type 1. For the two stands at Ashley Forest, the tree with the highest incidence of resin pockets was treated as an outlier and removed from the dataset. The mean number of resin pockets per square metre of cross-sectional area was not significantly different between fertilised and unfertilised trees ($p = 0.35$ at both Ashley and Rerewhakaaitu). The number of resin pockets per square metre of sawn surface area at Ashley Forest ranged between 0 and 13.43 for the fertilised trees and 0 and 6.34 for the unfertilised trees. Using the classification scheme of Park (unpublished data), 19 of the 28 trees sampled were classified as being clean or having only a minor problem with resin pockets (Table 7). At Rerewhakaaitu Forest number of resin pockets per square metre of sawn surface area ranged between 0 and 0.69 for the fertilised trees and 0 and 1.47 for the unfertilised trees. The incidence of resin pockets at Rerewhakaaitu Forest was very low with 28 of the 30 trees being classified as either clean or having only a minor problem with resin pockets.

No relationship was found between the incidence of resin pockets and either tree height or dbh ($p=0.66$ and $p=0.90$ respectively). There was no relationship between foliar boron levels and the incidence of resin pockets ($p=0.51$).

DISCUSSION

Root anchorage

These results of this study showed that trees growing in areas which had received an application of boron fertiliser had higher maximum resistive bending moments than trees growing in areas which had not. However these differences in M_c appear to be the result of site factors rather than the level of foliar boron in a tree. This result was strongly influenced by differences in M_c between trees from the two stands sampled at Ashley Forest. The mechanism by which site factors have affected M_c is unclear. Differences in M_c between trees growing in fertilised and unfertilised areas may be due to differences in the size and position of individual roots within their root systems as no differences were found between neither their mean root tensile strength nor gross root plate dimensions. The root systems of the trees growing in the fertilised stand at Ashley Forest may differ from those of the trees growing in the unfertilised stand due to an adaptive growth response to a higher wind loading on the trees as a result of differences in the level of exposure between the two sites.

The absence of measurable differences in gross root plate dimensions between fertilised and unfertilised trees at both Rerewhakaaitu and Ashley Forests treatments may simply be a result of the crudeness of these measurements and a more refined technique for assessing root systems is therefore required for future studies. More specifically, the type, size and position of structural roots need to be recorded for each tree winched over in order to determine whether differences in M_c are due to how root biomass is allocated spatially. A preliminary version of this technique was tested on trees growing at Rerewhakaaitu Forest. The basal diameter and length of all structural roots (ϕ>15 mm) were measured. However these measurements were still rather crude as the resources available did not enable the root systems to be excavated and cleaned to the extent that would have been ideal. Wide variation the root systems was observed, however, on average the total cross-sectional area (CSA) of structural roots for the fertilised and unfertilised trees was not significantly different ($p=0.94$). This preliminary result does not support the statement made by Lambert and Turner (1977) that the roots of *Pinus* species under conditions of severe boron deficiency are reduced in size and number, however their paper does not provide details as to the source on the information from which to make this statement.

TABLE 6-Incidence of resin pockets per square metre of cross-sectional area at Ashley and Rerewhakaaitu forests.

Location	Incidence of Resin Pockets per Square Metre			
	Type 1	Type 2	Type 3	Total
Ashley				
Fertilised				
Min	0	0	0	0
Max	33.54	6.47	0.77	40.01
Mean	3.10	1.08	0.21	4.39
Mean (outlier removed)	0.76	0.66	0.22	**1.65**
Unfertilised				
Min	0	0	0	0
Max	15.54	3.33	3.49	18.86
Mean	2.55	0.53	0.64	3.72
Mean (outlier removed)	1.55	0.32	0.69	**2.56**
Rerewhakaaitu				
Fertilised				
Min	0	0	0	0
Max	2.09	0	0	2.09
Mean	0.29	0	0	**0.29**
Unfertilised				
Min	0	0	0	0
Max	4.46	1.47	0	4.46
Mean	0.56	0.10	0	**0.65**

TABLE 7- Incidence of resin pockets by degrade class in fertilised and unfertilised trees at (a) Ashley Forest and (b) Rerewhakaaitu Forest.

(a)

Degrade Class	Range (rp/m2) (sawn surface area)	Number of trees Fertilised	Number of trees Unfertilised
Clean	<0.40	7	8
Minor	0.40-0.79	4	-
Significant	0.80-1.19	-	-
Problem	1.20-1.99	1	2
Major	>2.00	2	2
Total		**14**	**14**

(b)

Degrade Class	Range (rp/m2) (sawn surface area)	Number of trees Fertilised	Number of trees Unfertilised
Clean	<0.40	13	11
Minor	0.40-0.79	2	2
Significant	0.80-1.19	-	1
Problem	1.20-1.99	-	1
Major	>2.00	-	-
Total		**15**	**15**

Incidence of Resin Pockets

A number of factors thought to be responsible for the formation of resin pockets have been identified by previous studies (Clifton 1969; Cown 1973; Harris and Maude unpublished data; Winter unpublished data). The most common of these are wind and drought, with wind identified as the most significant (Clifton 1969; Cown 1973). Tree size has also been suggested as a possible cause of resin pockets (Don McConchie pers. comm.). On average the incidence of resin pockets in the 12 year old trees at Rerewhakaaitu Forest was lower than for the 18 year old trees at Ashley Forest. However, the wind climates of the two areas are very different. The average number of hours per year when wind speed exceeds 15 m/s at Rotorua airport (closest long-term meteorological station to Rerewhakaaitu Forest) is approximately 4 while at Christchurch airport (closest station to Ashley Forest) it is approximately 16 (J Moore unpublished data). The applied load acting on trees within the stand Rerewhakaaitu Forest for a given wind speed will also be less its higher average stocking (517 stems/ha versus 190 stems/ha). Within Ashley Forest the two stands sampled had different degrees of wind exposure. Any effects that boron deficiency may have on the incidence of resin pockets between these stands are likely to be confounded by this difference in exposure. Future studies to investigate whether boron deficiency is a cause of resin pockets need to ensure that the soil moisture content and wind exposure of sampling sites are as similar possible so as not to confound results.

CONCLUSIONS

While this study was of a preliminary nature, the results indicate that boron deficiency affects neither the tensile strength of individual radiata pine roots nor the gross dimensions of the overall root systems. The increased root anchorage strength of boron fertilised trees was due to site factors other that the level of boron. Differences in the degree of wind exposure of the two sites studied at Ashley Forests may be responsible for the differences in the strength of root anchorage. More refined techniques for measuring root systems are needed in order to understand the mechanisms responsible for these differences.

No evidence was found to suggest that boron deficiency is a causal factor in the formation of resin pockets. As with the root anchorage study, differences in the degree of wind exposure of the two sites at Ashley Forest may have confounded this result. The initial focus of any further research into the effects of boron deficiency on the strength of root anchorage and the incidence of resin pockets should be locating sites where factors such as topography and exposure are as uniform as possible.

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