AN INVESTIGATION INTO THE EFFECTS OF BORON FERTILISER ON WOOD PROPERTIES AND CLEARWOOD DEFECTS IN RADIATA PINE

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Report No. 69 May 2000

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EXECUTIVE SUMMARY

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A tree winching study investigating the effects of Boron (B) fertiliser on the root anchorage and root morphology of 11-year-old radiata pine on a B deficient site (Boron Types Trial FR24/2, Cpt. 273 Rerewhakaaitu Forest) provided the opportunity to also quantify the effects on wood properties and clearwood defects (internal checking, resin pockets and blemishes) using destructive sampling techniques. Two treatment schedules were sampled: control (no fertiliser applied) and B (applied as Ulexite at age two years) both with no weed control. All treatment types were thinned and pruned at age five years in conjunction with the surrounding compartment.

Fifteen trees were sampled from each treatment with 5mm breast height outerwood cores collected prior to tree winching. Following tree winching, a full set of discs were cut at 5m intervals, including the breast height (1.4 m). A 2m long billet was removed from immediately above the breast height position and was later sawn to produce two random width boards which after kiln drying were assessed for clearwood defects which included internal checks, resin pockets and blemishes. The remaining section of the tree stem was crosscut at regular 0.3 m intervals and the incidence of clearwood defects documented. Foliage samples were collected and Foliar B levels were determined for each tree which showed clear differences between treatments, with the Control and B treatments averaging 9 ppm and 18 ppm respectively.

For the outerwood cores standard errors of difference of the means suggest no evidence of a difference between treatments for outerwood density and growth rate. For the wood properties measured on the discs standard errors of difference also indicated no evidence of a difference between treatments. Results for both cores and discs are included in the following table.

		Control	**Boron**
Cores	Outerwood density (kg/m^3)	351	348
	Growth rate (mm/ring)	12.3	12.5
Discs	Total tree volume (m^3)	0.45	0.45
	Heartwood (%)	3	3
	Compression wood (%)	8	7
	Basic density (kg/m^3)	342	335

From the other form of B treatment at the trial (applied as sodium borate - Borax at age two years) twenty five 5mm breast height pith-to-bark cores were collected from three replicates and analysed using an X-ray densitometer. Results were compared to an earlier study on Control and Ulexite samples. Comparison of results from all three treatments produced no significant treatment or treatment by year interaction for ring width, ring mean, earlywood and latewood densities and latewood percent.

The whole stem crosscutting and sawn board strategies failed to identify differences between the Control and B treatment in clearwood defects which included internal checking, resin pockets and blemishes.

INTRODUCTION

In recent years there has been much interest in the effects of B on wood properties of radiata pine, with claims of distortion in timber and lower strength associated with a deficiency of B. A summary on the findings of B effects to date are listed with the following conclusions (some unpublished data with limited numbers of samples):

1) typical effects of fertiliser application on wood properties were observed in fertiliser/trace element trials ie. brief drop in density, (due to reduced latewood production) and increase in incidence of compression wood were recorded but attributed simply to the increase in growth rate. Effects of B could not be isolated, however they were less for B alone than in combination with nitrogen (N) and phosphorus (P). Tracheid length, shrinkage, spiral grain and resin content were unaffected by fertiliser application (Cown and McConchie 1981).

2) lower strength properties of timber from B deficient sites compared to non-boron deficient sites of equivalent basic density (G.Parker and R.Britton, *pers. comm.*)

3) differences in cellular structure between B treated and untreated trees (Singh and Tan presentation to N.Z. Site Management Coop., 1990). Untreated trees showed:
    - indistinct growth rings
    - smaller and more variable earlywood cells
    - cavities in cell corners
    - shorter tracheids

4) no conclusive results as to effect of B availability on latewood percentage or within-ring density variation (Young and Skinner 1990).

5) using a trial established on a B deficient site, densitometric analyses showed similar pith-to-bark trends for ring mean, earlywood minimum and latewood maximum densities for both the Control and B treated plots (McKinley and McConchie 1997).

Proposed long term research aims to further enhance knowledge of suggested relationships between foliar B concentration, tracheid dimensions and lignification which could be related to the increasingly important problems of within-ring internal checking (Skinner and Singh unpublished data) and resin pocket formation.

With the high interest in B effects on wood properties, an opportunity arose to assess wood quality using destructive sampling procedures on trees winched over to investigate the effects of B fertiliser on root anchorage and morphology of radiata pine grown at Rerewhakaaitu, a B deficient site. This opportunity also fits in with our commitment to the PGSF funded component of the "Predicting Forest Growth and Quality" project to determine relationships between foliar B levels and wood properties, including resin pocket incidence and propensity to form within-ring internal checks.

METHOD

The Rerewhakaaitu B trial (FR24/2) was established in 1988. Details of the trial are provided by Skinner *et al.* (1996) with the stand history presented in Table 1.

Four fertiliser treatments have been applied with three replications:

- Control - no fertiliser
- Borax (sodium borate)
- Colemanite
- Ulexite

Table 1 - Stand History*

Date	Operation	Stocking (stems/ha)
June 1986	Established -268 series	1000
Sept 1988	Fertiliser applied	
Feb 1991	Pruned to 2.1m	
Apr 1991	Waste thinned	517
Nov 1992	Pruned to 3.2m	
June 1994	Pruned to 5.4m	
May 1995	Pruned to 6.1m	

* Details provided by G.D. Young, Fletcher Challenge Forests

In addition to the fertiliser treatments, half the plots have received weed control while the other half have not. The trial layout is shown in Appendix I.

McKinley and McConchie (1997) investigated the effects of low B levels on wood density at this trial, comparing trees from weed controlled Control and Ulexite plots. As discussed earlier, densitometric analysis showed similar pith-to-bark trends between treatments for the ring properties measured.

For the winching study a total of 30 trees were winched over; 15 from the unfertilised Control plots and 15 from the Ulexite fertilised plots (5 trees from each of three replications in the buffer zones of each plot). Due to the patchy results from the weed control (Malcom Skinner *pers. comm.*) all trees were selected from plots where no weed control had taken place.

Details and preliminary results of the tree winching study are provided in the Meeting Proceeding's of the 20 & 21 May 1998 Forest and Farm Plantation Management Cooperative meeting. At the time of winching total height, dbh and pruned height, sectional measurements were recorded and foliage samples collected for analysis to determine the foliar B level of each tree.

Prior to tree winching, two 5mm breast height outerwood increment cores were collected from the 15 Control trees and 15 B treated trees. In the laboratory the outer 5 growth ring section was cut from the outerwood cores and measured in length to provide a measure of growth rate prior to gravimetric basic density determination using the maximum moisture content procedure (Smith, 1954).

As an extra to this study, twenty five 5mm pith-to-bark cores (a minimum of seven trees from each of three replicates) were collected for densitometry from the Borax treated plots. McKinley and McConchie's (1997) study showed similar pith-to-bark trends for ring mean, earlywood minimum and latewood maximum densities for both the Control and B treated plots. B treatment in this recent study utilised the Ulexite treated plots, as this fertiliser was identified as that most commonly used in industry and this form of B maintains foliar B concentrations over the forest rotation. Presumably due to the slow release nature of ulexite, the impact of B addition on within ring wood properties was negligible. Therefore it is proposed, by examining trees from the Borax treated plots (a more soluble form of B), the response to B addition and its impact on densitometric characteristics will be more evident over the subsequent years following application. These results will be compared to those documented by McKinley and McConchie (*op. cit.*)

Following tree winching, 50mm thick discs were sampled from the butt, 1.4m, 5m, and consecutive 5 intervals down to an inside bark diameter of approximately 100mm. Discs were measured for DOB, DIB, heartwood and assessed for compression wood prior to sectioning into samples for the measurement of basic density and spiral grain. A radial strip has been retained for assessments of cell dimensions and chemistry if required.

An additional 40mm thick disc was cut at 1.4 m to provide two samples for the measurement of radial MoE (Rolf Booker) and a pith-to-bark strip for microscopy analyses (Lloyd Donaldson and Adya Singh).

From each of the 30 trees, two billets were cut. The first, measuring 2m in length from directly above the 1.4 m sampling height was live sawn at a local sawmill to produce two 50mm random width flitches adjacent to a 50 mm random width board centred on the pith. Both boards were dried using a 90°C/60°C kiln schedule prior to the assessment of clearwood defects which included internal checking, resin pocket and blemish incidence. 20mm boards will be cut from the 50 mm flitches to provide material for MoE and MoR small clear testing (T.E. required to undertake small clear testing).

The second billet, measuring 0.4 m in length was removed from directly below the breast height position and sawn to produce a 40 mm flitch centred on the pith to provide samples for comparing MoR (Rolf Booker) and also assessing toughness (T.E. required to undertake toughness test). The slabs from either side of the 40mm flitch will be labelled and retained along with the flitch.

The remaining section of each tree stem was crosscut at 300mm intervals (within the pruned section) and the number, type and position of resin pockets recorded along with blemish incidence.

The x-ray density analysis for the increment cores from the Borax treated plots involved passing the machined sample between a radioactive source (Fe^{55}) and a scintillation counter. The source decays at a constant rate creating x-ray emissions. The scintillation counter measures the penetration of x-rays through the wood sample, which is related to the wood density. The instrument is controlled and data is collected by custom software that was created for ***Forest Research*** (***FR***) by the Institute of Geological and Nuclear Sciences in Wellington. Each pith-to-bark sample was scanned in steps of 0.3 mm.

The data were then processed by another ***Forest Research*** software program called IDAS (Integrated Densitometer Analysis System). IDAS identifies the latewood and earlywood boundaries using density thresholds that can be entered by the operator. The earlywood/latewood density boundary is normally set at 500kg/m^3 and has been the standard for both radiata pine and Douglas-fir at ***Forest Research*** and in Canada (Cown and Clement 1983; Jozsa *et al.* 1989). Using this value, the earlywood and latewood widths identified by the software are similar to those determined visually. However, as for the earlier study, the 500kg/m^3 threshold level was found to be too high which resulted in the detection of very few latewood bands. A cutoff point of 450kg/m^3 was therefore used - as for a recent agroforestry study (McKinley and Ball 1997).

The IDAS software was then used to calculate the following parameters: ring width, earlywood width, latewood width, latewood %, ring density, earlywood density, latewood density, minimum density, maximum density, density range (maximum density - minimum density) and density uniformity (latewood density - earlywood density). The patterns of ring width and density variation were then described for each treatment.

RESULTS AND DISCUSSION

Foliar Boron Analysis:
Results for the foliar B analysis for the three replicates (block) per treatment are given in Table 2. Analysis was completed by the Soils Nutrition laboratory at ***Forest Research***. For the Control treatment foliar B levels averaged 9 ppm and ranged from 3 ppm to 17 ppm for individual trees compared to B treated plots which averaged 18 ppm and ranged from 9 ppm to 28 ppm for individual trees.

Table 2 – Foliar Boron levels by treatment

W.Q. no.	Trial Block no.	Trial Tree no.	Foliar B level (ppm)
Control			
1	7	1	17
2	7	2	10
3	7	3	10
4	7	4	10
5	7	5	10
6	15	1	5
7	15	2	8
8	15	3	5
9	15	4	5
10	15	5	7
11	24	1	3
12	24	2	10
13	24	3	9
14	24	4	13
15	24	5	17
Mean			9
Min.			3
Max.			17
S. dev.			4

W.Q. no.	Trial Block no.	Trial Tree no.	Foliar B level (ppm)
Boron			
16	8	1	14
17	8	2	28
18	8	3	18
19	8	4	22
20	8	5	20
21	13	1	25
22	13	2	16
23	13	3	18
24	13	4	24
25	13	5	18
26	23	1	10
27	23	2	13
28	23	3	15
29	23	4	12
30	23	5	9
Mean			18
Min.			9
Max.			28
S. dev.			6

Presented in Table 3 are the standard B foliage analysis values for radiata pine (Will, 1985) which help provide an indication of the trial's B status. Most of the Control trees fit into the Low to Marginal category while the B treated trees generally exceeded the 12 ppm limit for the Satisfactory category with the exception of Tree 30 (9 ppm). Within the replicates for both treatments distinct foliar B levels were observed with Blocks 15 and Block 23 of the Control and B treatments respectively having particularly low levels. The relationship between foliar B levels and whole tree basic density will be discussed later in this report.

Table 3 - Foliar B analysis values for Pinus radiata (Will, 1985)

Low	Marginal	Satisfactory	Confidence rating
8 ppm	8-12 ppm	12 ppm	**

** Good prediction of responsive sites in the low range but not in the marginal range

Increment Core Outer 5 Growth Ring Properties:

Table 4 presents individual results and summaries for outer 5-ring density and growth rate from the breast height 5 mm increment cores for both treatments. Differences between treatments for both outer 5 ring density and growth rate were negligible with values of approximately 350 kg/m^3 and 12.5 mm/ring respectively. Standard errors of difference (s.e.d.) of the means suggest there is no evidence of a difference for the measured properties of outer 5 ring density and outer 5 ring width (s.e.d. for outer 5 ring density = 8 kg/m^3 and s.e.d. for outer 5 ring width = 4.2 mm).

Table 4 - Outerwood density and outer 5 ring width by treatment

W.Q. no.	Trial Block no.	Trial Tree no.	Basic density (kg/m^3)	Growth rate (mm/ring)	W.Q. no.	Trial Block no.	Trial Tree no.	Basic density (kg/m^3)	Growth rate (mm/ring)
Control					**Boron**				
1	7	1	374	12.6	16	8	1	324	15.9
2	7	2	377	11.1	17	8	2	369	12.7
3	7	3	340	13.5	18	8	3	340	12.4
4	7	4	353	11.6	19	8	4	358	14.5
5	7	5	369	8.6	20	8	5	390	8.9
6	15	1	356	13.9	21	13	1	335	12.6
7	15	2	377	8.7	22	13	2	348	16
8	15	3	367	13.3	23	13	3	378	13.4
9	15	4	347	12.1	24	13	4	368	13.2
10	15	5	325	12.6	25	13	5	319	8.6
11	24	1	331	17	26	23	1	346	10.9
12	24	2	370	12.8	27	23	2	360	13.2
13	24	3	338	11.8	28	23	3	326	8
14	24	4	330	13.6	29	23	4	356	14.4
15	24	5	323	11.6	30	23	5	308	13.2
Mean			351	12.3	Mean			348	12.5
Min.			323	8.6	Min.			308	8
Max.			377	17	Max.			390	16
S. dev.			20	2	S. dev.			23	2.5

Current study results compare well with those documented by McKinley and McConchie (1997), given the two year age difference (outer 5-ring density 335 kg/m^3 and growth rate approximately 13 mm). The earlier study also showed no suggestion of a difference between the Control and B treated plots for either property.

The lack of difference in outer 5-ring density between the Control and B treated plots was discussed in the earlier report by McKinley and McConchie (1997) where the result was not unexpected and was consistent with previous findings. Past studies have shown in the subsequent 3-5 years following fertiliser application, density-related properties invariably revert back to pre-treatment levels unless an additional treatment is applied.

In the national radiata pine wood properties survey (Cown *et. al.* 1991a) outerwood density values for 12 year-old trees grown in this region (designated medium density) equated to approximately 360kg/m^3. The density values established in the current study compare favourably to these survey results.

Disc Properties:
Table 5 details the average values and standard deviations for each disc sampling height by treatment (individual measurements are presented in Appendix II). Heartwood percent was calculated as the proportion of cross-sectional area of the entire disc. Compression wood was visually assessed and therefore was subjective, with no attempt made to describe distribution or severity.

Table 5 - Average disc dimensions and selected wood properties by treatment and combined

Disc ht. (m)	No. of Samples	DIB (mm)		Bark depth (mm)		Heartwood (%)		Comp. wood (%)		Basic density (kg/m^3)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control											
0	15	318	29	22	4	2	1	7	8	358	19
1.4	15	276	28	14	3	5	2	5	3	346	19
5	15	229	26	7	2	3	2	10	8	332	19
10	15	140	24	5	1	0	1	7	10	317	26
Boron											
0	15	317	27	21	3	2	2	7	6	353	18
1.4	15	277	28	13	2	5	3	5	6	346	18
5	15	226	24	6	1	3	2	7	8	323	21
10	15	150	23	4	1	1	1	6	7	305	18
Combined											
0	30	318	28	21	4	2	1	7	7	355	18
1.4	30	277	27	14	2	5	3	5	5	346	18
5	30	227	24	7	1	3	2	9	8	327	20
10	30	145	24	4	1	1	1	7	8	311	23

Generally speaking the normal radiata pine patterns for DIB, bark depth, heartwood percent, compression wood and basic density were observed, with similar results recorded for both the Control and B plots. Further discussion along with some statistical analysis will be presented with the log and tree properties.

Log and Tree Properties:
In Table 6 the disc values from Table 5 have been used to calculate results for individual log height classes and for whole trees. Smalian's formula was used for the calculation of volume. Due to the young age of the trial only the butt and second log height classes have been assessed. Values for individual trees by treatment are presented in Appendix III.

By 12 years of age, tree volume averaged 0.45 m^3 for both the Control and B trees with the butt log accounting for approximately two thirds of this volume. Individual trees ranged from 0.30 m^3 to 0.68 m^3 with no discernible difference in range between treatments. S.e.d. of the means suggest there is no evidence of a difference for tree volume (s.e.d. = 0.033 m^3).

Bark depth on a whole tree basis averaged 13 mm and 12 mm for the Control and B treated plots respectively. In practical terms this difference is insignificant.

As would be expected for trees of this age heartwood levels were low. It is well known for radiata pine, heartwood formation begins between the ages of 12 and 14 years and advances outwards from the pith at a constant rate of about half a growth ring per year (Cown, 1992). Average whole tree heartwood values of 3 % were measured for both treatments and s.e.d. of the means suggest there is no evidence of a between treatment difference (s.e.d. = 0.6 %).

Whole tree compression wood values were also similar for the Control and B treated plots with average values of 8 % and 7 % respectively. Again, s.e.d. of the means suggest there is no evidence of a difference for whole tree compression wood values (s.e.d. = 1.8 %).

Basic density decreased from the butt to second log for both the Control and B treatments with the combined 30 trees averaging 346 kg/m^3 at the butt and decreasing to an average of 323 kg/m^3 for the second log. Mean tree density for the Control treatment averaged 342 kg/m^3 and ranged from 318 kg/m^3 to 373 kg/m^3 compared to an average of 335 kg/m^3 and range of 302 kg/m^3 to 358 kg/m^3 for the B treated plots. S.e.d. of the means indicate no evidence of a difference between the Control and B treated plots for basic density (s.e.d. = 6.4 kg/m^3).

Table 6 - Average log and tree properties by treatment and combined

Log Height class	No. of samples	Volume (m^3)		Bark depth (mm)		Heartwood (%)		Comp. wood (%)		Basic density (kg/m^3)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control											
Butt	15	0.31	0.06	16	3	3	1	7	5	348	18
2nd	15	0.14	0.03	6	1	2	2	9	7	328	20
Tree	15	0.45	0.10	13	2	3	1	8	5	342	17
Boron											
Butt	15	0.30	0.05	15	2	3	2	7	5	344	18
2nd	15	0.15	0.03	5	1	2	2	7	6	317	18
Tree	15	0.45	0.08	12	2	3	2	7	5	335	18
Combined											
Butt	30	0.30	0.05	15	2	3	2	7	5	346	17
2nd	30	0.14	0.03	6	1	2	2	8	7	323	20
Tree	30	0.45	0.09	12	2	3	2	7	5	338	17

Using the relationships established in the radiata pine wood properties survey for the prediction of whole tree and log densities from outerwood density values (Cown *et al.* 1991a), predicted whole tree and butt log densities (339 kg/m^3 and 342 kg/m^3 respectively) compare favourably with the combined results presented in Table 6 – based on an average outerwood density of 350 kg/m^3 for both treatments.

Relationships Between Outerwood Density at Breast Height and the Density of the Whole Tree and Log Components:

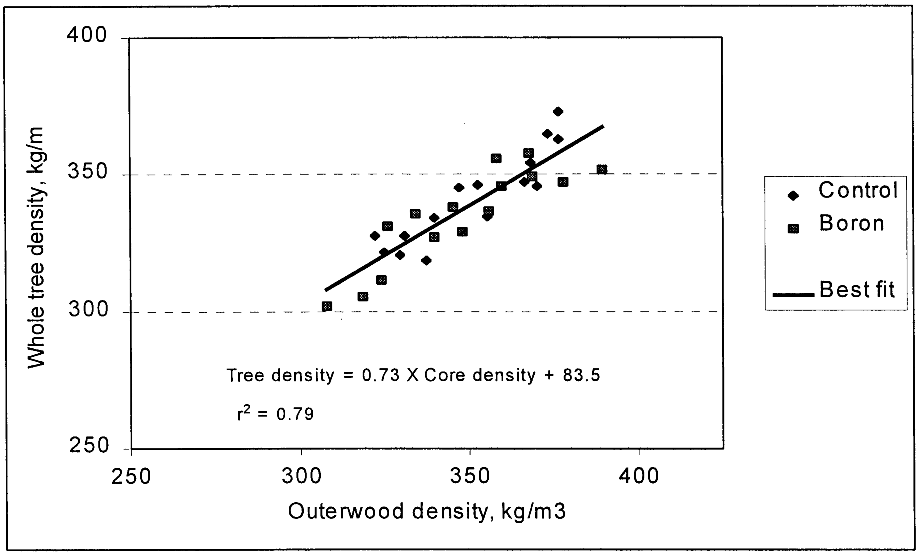
The relationship between breast height outerwood density and the density of the whole tree, and also the relationships between whole tree density and the density of the individual logs are given in Table 7 for the Control and B treatments combined. These relationships were all found to be significant at the 99% level. Figure 1 depicts the relationship between breast height outerwood density and the density of the whole tree.

Table 7 - Relationships between breast height outerwood density, whole tree density and the density of individual logs

Log height class	No. of logs	Intercept	*x* *	Correlation	R-square	Residual st. dev.
Butt	30	15.3	0.98	0.98	0.97	4
2nd	30	-34.7	1.06	0.94	0.88	7
Tree	**30**	**83.5**	**0.73**	**0.89**	**0.79**	**8**

* *x* = outerwood density

Figure 1 - Relationship between outerwood density to whole tree density

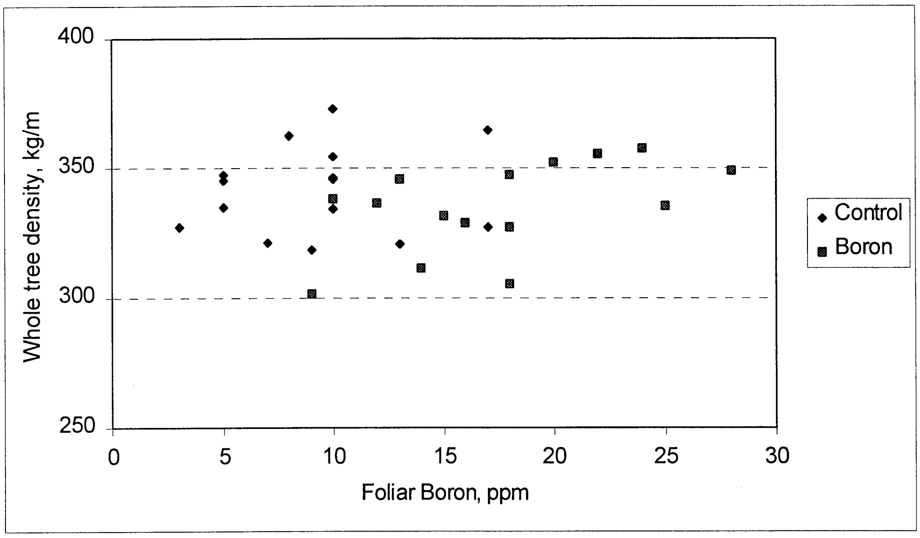


The raw data used to produce the above regressions have been included in this report as Appendix IV.

Relationship Between Foliar Boron Levels and the Whole Tree Basic Density:

No clear relationship was found between the weighted whole tree density and the foliar B value which generally reinforces earlier findings. Figure 2 graphically illustrates this result.

Figure 2 - Relationship Between Foliar Boron Levels and the Whole Tree Basic Density



Spiral Grain:

Appendix V presents the individual disc spiral grain measurements for rings 2, 4, 6, 8 and 10 from the pith for the fifteen trees of each treatment. All the observations conform well to the normal distribution (Figures 3 and 4 for the Control and B treatments respectively) with means of 3.7° and 3.3° and standard deviations of 2.6° and 2.9° for the Control and B treatments respectively. The variation with height is shown in Table 8 and Figure 5 for both treatments. Table 8 also presents averages for the Control and B treatments combined. In general, spirality patterns for both treatments were similar and follow those described for 25-year-old radiata pine (Cown *et al.* 1991b) with the greatest spirality occurring near the pith and increasing with height up the stem.

Figure 3 – Grain angle frequency distribution – Control treatment

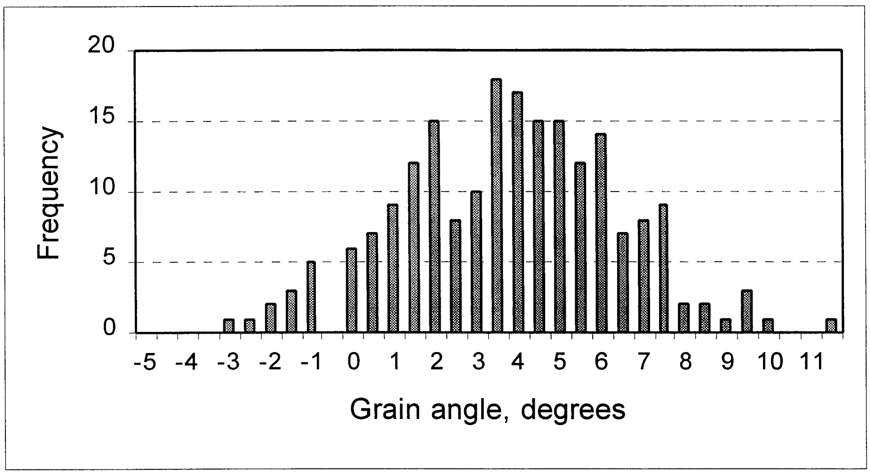


Figure 4 – Grain angle frequency distribution – Boron treatment

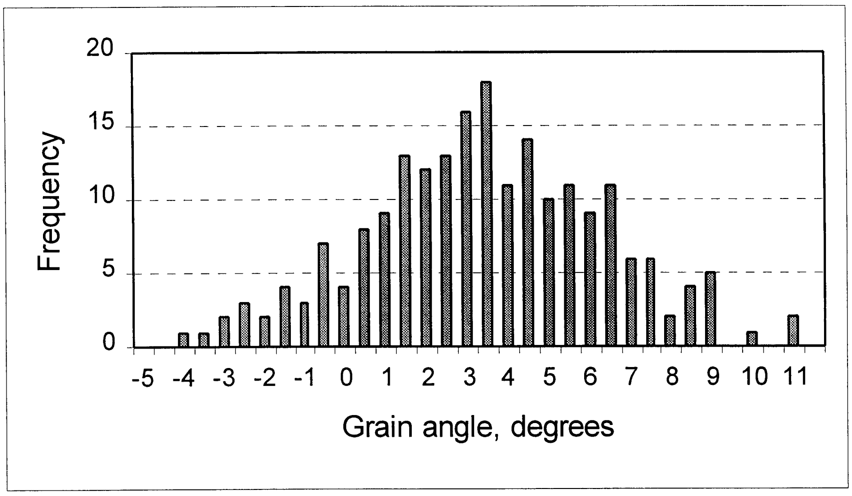
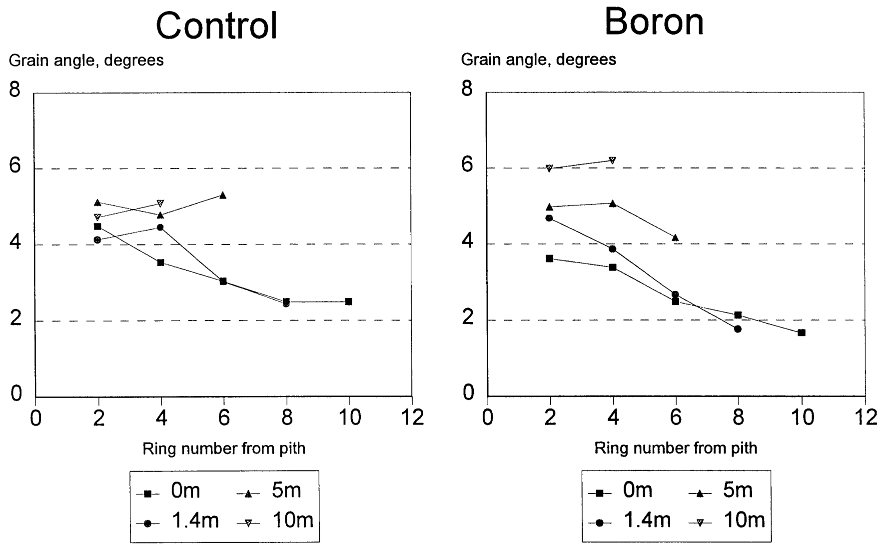


Table 8 - Mean pattern of spiral grain by treatment and combined

Disc ht. (m).	No. of samples	Spiral grain (°) by ring number from the pith 2	4	6	8	10
Control						
0	15	4.5	3.5	3.0	2.5	2.5
1.4	15	4.1	4.5	3.0	2.4	
5	15	5.1	4.8	5.3		
10	15	4.7	5.1			
Boron						
0	15	3.6	3.4	2.5	2.1	1.7
1.4	15	4.7	3.9	2.7	1.8	
5	15	5.0	5.1	4.2		
10	15	6.0	6.2			
Combined						
0	30	4.1	3.5	2.8	2.3	2.1
1.4	30	4.4	4.2	2.8	2.1	
5	30	5.1	4.9	4.7		
10	30	5.4	5.7			

Figure 5 - Variation in spiral grain by sampling height and treatment

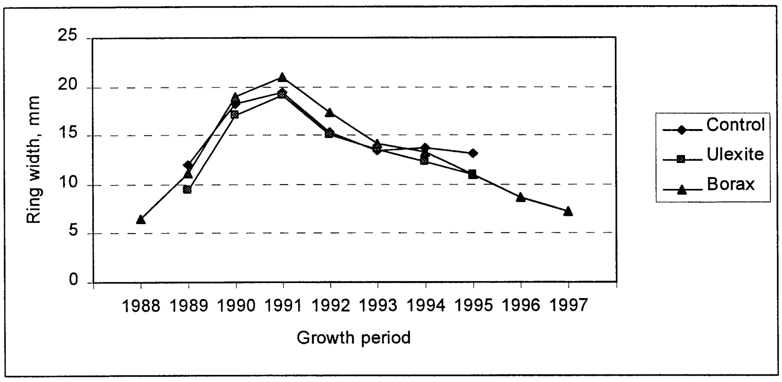


Densitometry:
Presented in Appendices VIa to VIc are the ring width and ring density component averages by year of ring formation for the Control and Ulexite treatments from the earlier study (McKinley and McConchie, 1997) along with the Borax treatment for the current study.

Analysis of covariance was performed on the data for ring width, ring mean, earlywood and latewood densities testing the effect of treatment, and also year of ring formation and treatment interaction, using year and $year^2$ as repeated measures covariates.

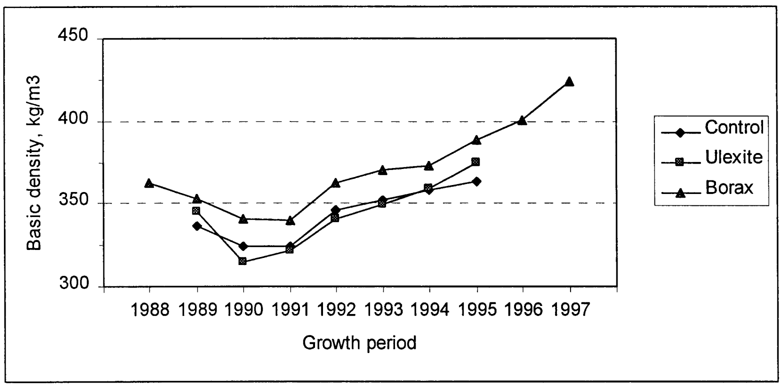
Ring width
Figure 6 presents the average ring width trend by year for the Control, Ulexite and Borax treatments, all of which show the typical radial pattern expected for radiata pine. Differences between treatments are not obvious in the graph and the covariance analysis confirmed this showing no significant result of a treatment or year by treatment interaction.

Figure 6 – Average ring width by treatment



Ring mean density
The average ring mean density radial trends for the Control, Ulexite and Borax treatments are given in Figure 7. Although ring mean densities for the Borax plots appeared higher than those recorded for the Control and Ulexite plots, the covariance analysis showed no significant treatment (p=0.11) or year by treatment interaction (p=0.83).

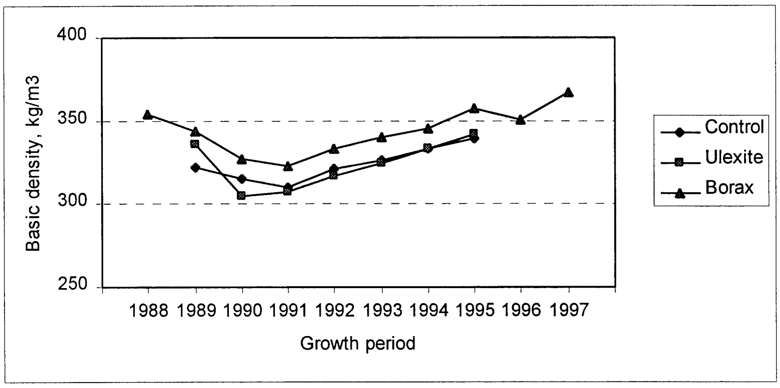
Figure 7 – Average ring mean density by treatment



Earlywood density

Average earlywood densities by treatment are given Figure 8. A marginal treatment effect on earlywood density was found (p=0.063) with the trees from the Borax plots having significantly higher earlywood densities compared to those from the Control and Ulexite treatments. This effect appeared uniform over the entire measurement period with no significant year by treatment interaction (p=0.76).

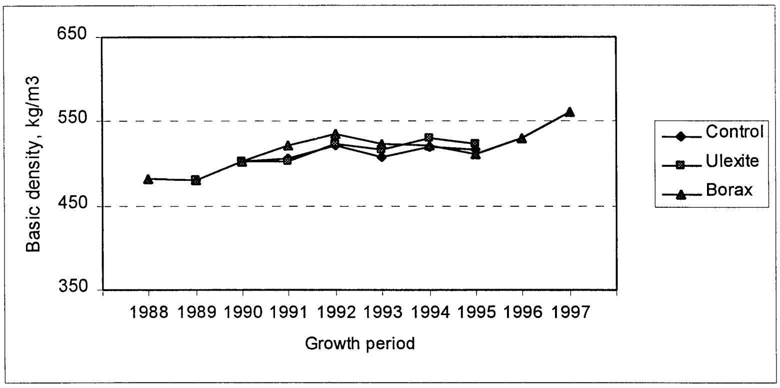
Figure 8 – Average earlywood density by treatment



Latewood density

Figure 9 presents the average latewood densities by year for the Control, Ulexite and Borax treatments. Overall no treatment effect was found (p=0.16) and there was no significant treatment by year interaction (p=0.085).

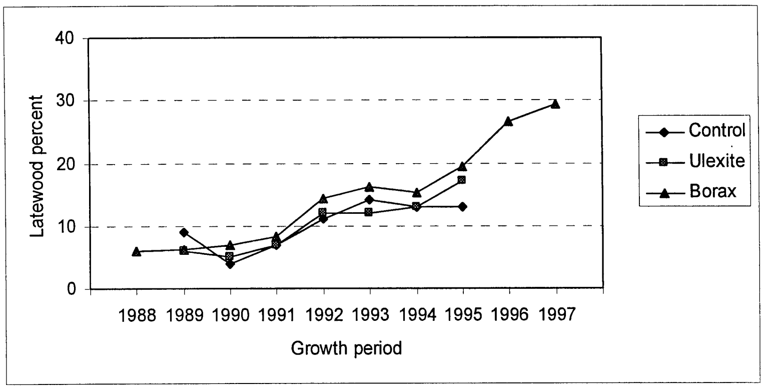
Figure 9 – Average latewood density by treatment



Latewood percent

The average latewood percent radial trends for the Control, Ulexite and Borax treatments are given in Figure 10. Although latewood percent for the Borax plots appeared higher than those recorded for the Control and Ulexite plots, the covariance analysis showed no significant treatment (p=0.55) or year by treatment interaction (p=0.34).

Figure 10 - Average latewood density by treatment



Internal checking:

Whole stem cross cutting

No internal checking was observed in the green wood at any of the 300mm cross cuts of the pruned section of the stem.

Random width boards from the 2m billet

Appendix VIIa details the internal checking incidence by tree stem height from the two random width boards for both treatments which were cross cut at 300 mm intervals after kiln drying using a $90^{o}C/60^{o}C$ schedule.

For both treatments a similar number of trees were shown to be susceptible to internal checking with nine of the Control trees being affected compared to ten of the B treated trees. The range of checking incidence within individual trees was also similar for both treatments – 2 to 95 and 4 to 79 for the Control and B treatments respectively.

Figure 11 summarises the results by tree stem height for both treatments and shows a higher incidence of checking was observed for the 1.7 m, 2 m and 2.3 m stem heights within the B treated random width boards. A chi-square test however did not show any evidence of a difference between the treatments at any individual stem height level. The analysis was based on testing the independence between the treatment and the internal checking assessed as a category based on the four groupings 0 checks, 1–5 checks, 6-10 checks and >10 checks.

Figure 11 – Internal checking incidence by stem height and treatment

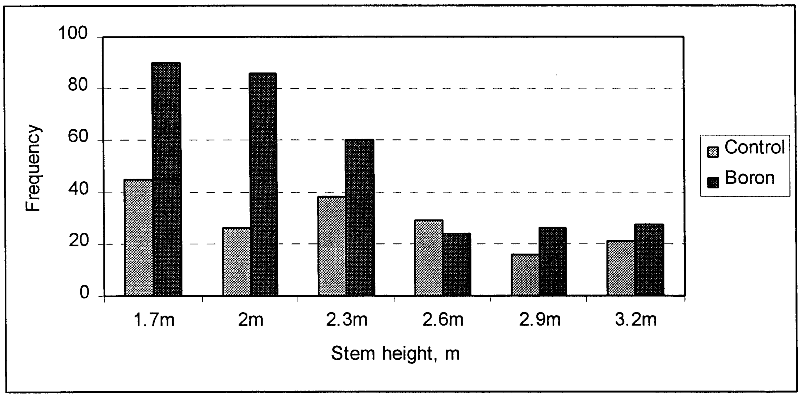
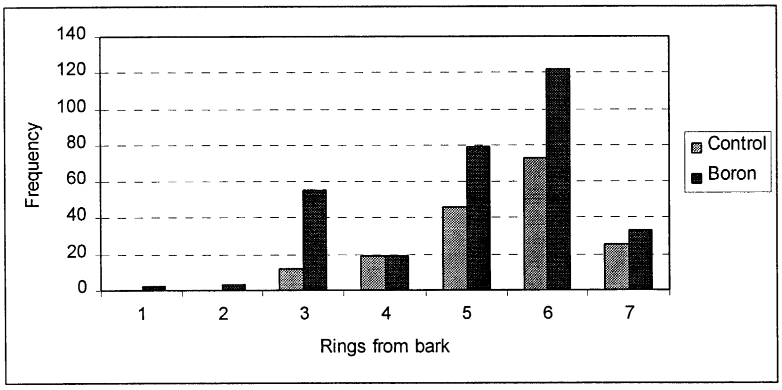


Figure 12 summarises the incidence of internal checking for the two random width boards by ring position from the bark for both treatments (full results presented in Appendix VIIb). Of the nine affected Control trees only three showed internal checking in both random width boards. For the B samples of the ten affected trees, nine were shown to have internal checking in both random width boards. Statistical analysis using the chi-square test did not show any evidence of a difference between the treatments for internal checking incidence by ring position from the bark using the category groupings for the earlier chi test.

Broadly speaking for both treatments the most severely affected rings were 5 and 6 from the bark and with generally higher levels towards the lower end of the flitch. Preliminary results from more recent studies also indicate a higher incidence of internal checking in the lower portion of the stem with most of the checks occurring outside the heartwood zone.

Figure 12 – Internal checking incidence by ring position from bark and treatment



Resin Pockets:

Whole stem cross cutting

Appendix VIII details the incidence of resin pockets combined with blemishes by stem height and treatment. For each resin pocket found the ring position from the bark was also documented. A total of seven resin pockets were recorded for the Control plots from four trees while three resin pockets were found in the B treated plots arising from three trees.

Tables 9a and 9b summarise the findings by stem height and ring position from the bark respectively. Previous resin pocket research has indicated that it is unusual to find this defect occurring within the first 10-12 rings of the pith (*pers. comm.* Jim Park)

Table 9a – Whole stem resin pocket distribution

Treatment	Number of resin pockets		
	0m - 1.4m	3.6m - 5.0m	Whole Stem
Control	1	2	7
Boron	-	3	3

Table 9b – Ring position from the bark resin pocket distribution

Treatment	Number of resin pockets				
	Ring position from bark				
	1	3	4	5	6
Control	1	1	3	-	2
Boron	-	-	2	1	-

Random width boards from the 2m billet
For the two random width boards sawn from the 2m billet, a breakdown of resin pocket incidence by rings from the bark and stem height (1.4m to 3.4 m) are given in Appendix IX for both treatments. Seven of the Control trees and six of the B treated trees were shown to have resin pockets with a maximum of three recorded in one of the B treated trees (Tree 27). For both treatments ring 5 from the bark (equating to 1993) yielded the highest number of resin pockets (Control 4 resin pockets and B 5 resin pockets). Within the billet length four resin pockets were recorded for the two treatments for both the lower 1m and upper 1m portions, equating to 1.4 m to 2.4 m and 2.4 m to 3.4 m stem positions respectively.

Generally speaking there appears to be no difference between the treatments and the sawing process was shown to yield higher counts of resin pockets compared to the whole stem cross cutting method. This is due to the larger surface area exposed on the sawn boards as opposed to the smaller surface area exposed by the whole stem cross cutting method. As stem diameters were not recorded at all cross sectional sampling points for the whole stem cross cutting method nor dimensions recorded for the random width boards, resin pocket incidence cannot be expressed as number/m^2.

It is interesting to note that the two trees identified with resin bleeding on the stem prior to winching and further breakdown were found to contain resin pockets.

Blemishes:
Whole stem cross cutting
Appendix VIII details the incidence of blemishes combined with resin pockets by stem height and treatment as discussed earlier. It should be noted that blemishes were for the most part categorised as any clearwood defects other than resin pockets although small Type 3 resin pockets with minimal associated resin could possibly have been included. Differences between the two treatments were negligible with four Control trees and 6 B trees found to contain blemishes using the whole stem cross cutting method. Within the affected trees, the number of blemishes recorded ranged from one up to a maximum of five, recorded for Tree 24 of the B treatment. Generally most of the blemishes occurred in the lower 1.4 m of the stem.

Random width boards from the 2m billet
As for the resin pocket findings, the larger surface area exposed on the sawn boards has also revealed larger numbers of blemishes (Appendix X) compared to the whole stem cross cutting method. The differences between the two treatments were negligible, as for the whole stem cross cutting method albeit with a higher incidence ie. 13 Control trees and 12 B trees contained blemishes. Within the affected trees the number of blemishes recorded on the two random width boards per tree ranged from 1 to a maximum of 29 (again Tree 24 of the B treatment, as identified earlier in the whole stem cross cutting method).

Generally speaking rings 4, 5 and 6 from the bark (relating back to 1994, 1993 and 1992) yielded the highest number of blemishes for both treatments. For resin pockets, ring 5 from the bark (1993) was identified as showing the highest incidence for the random width boards. The internal checking results also identified rings 5 and 6 from the bark (equating to years 1993 and 1992) as the most severely affected rings.

One possible explanation for these results could include a silvicultural link as the stand had received a three lift pruning operation over the period 1992 to 1995. A further explanation or contributing factor could be related to some climatic effect. Metrological records from Rotorua Airport show over the 21 year period from 1976 to 1997, 1992 was a year with low spring rainfall, 1993 low summer rainfall and in 1994 the lowest combined spring and summer rainfalls.

A further contribution to the formation of blemishes may be the presence of Sirex wasps. Sirex were observed at the stand during sample collection and are known to cause small resinous blemishes in radiata pine timber.

CONCLUSIONS

- Results from the foliar B analysis generally indicated significantly lower levels of B for the Control plots compared to B treated plots. Within each treatment there was considerable range between trees and replicates with the difference in replicates indicating possible micro-site effects within the trial.

- As for the earlier study at this trial there was no evidence to suggest a difference between outerwood density and growth rate for the Control and B treatments. This result confirms that the impact of fertiliser application (B) and silviculture (thinning and pruning) on wood and growth properties if present do not extend far beyond the treatment date. Average outerwood density values compared well to those sampled in the national radiata pine wood properties survey for this region and age.

- The normal radiata pine patterns for volume, bark depth, heartwood percent, compression wood, basic density and spiral grain were evident for both the Control and B treated plots. Standard errors of the mean suggest no evidence of a difference between the two treatments.

- No relationship was found between individual tree foliar B measurements and respective weighted whole tree densities.

- Analysis of the Control, Ulexite and Borax densitometric results produced no significant treatment or treatment by year interactions for ring width, ring mean, earlywood and latewood densities and latewood percent. The theory that the more soluble form of B applied as Sodium borate rather than Ulexite would provide a more obvious effect on densitometric properties was not substantiated.

- Strategies using whole stem crosscutting and sawn boards failed to identify differences in internal checking, resin pocket and blemish incidence for the Control and B treatments. It was interesting to note i) that two trees with visible resin bleeding on the stem were also found to contain resin pockets and ii) most of the blemishes occurred in the lower 1.4m of the stem.

- For both treatments rings 4, 5 and 6 from the bark generally contained the highest number of internal checks, resin pockets and blemishes. These rings correspond to years 1994, 1993 and 1992 and at that time the stand had received a three lift pruning operation and a combination of low spring and summer rainfalls. Results from this study generally support existing knowledge on these clearwood defects but further research is still required aiming to isolate the roles of silviculture, climate or some other factors.

ACKNOWLEDGEMENTS

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REFERENCES

Cown, D.J. 1992: New Zealand radiata pine and Douglas-fir: Suitability for processing. Ministry of Forestry, Forest Research Institute. Bulletin No. 168.

Cown, D.J. and Clement, B.C. 1983: A wood densitometer using direct scanning with X-rays. Wood and Science Technology, 17:91-99.

Cown, D.J. and McConchie, D.L. 1981: Effects of thinning and fertiliser application on wood properties of *Pinus radiata*. N.Z. Journal of Forestry Science. **11**(2) : 79-91.

Cown, D.J., McConchie, D.L. and Young, G.D. 1991a: Radiata pine wood properties survey. Ministry of Forestry, Forest Research Institute, Bulletin No. 50 (revised edition).

Cown, D.J., Young, G.D. and Kimberley, M.O. 1991b: Spiral grain patterns in plantation-grown *Pinus radiata*. New Zealand Journal of Forestry Science 21 (2/3) : 206-216.

Jozsa, L.A., Richards, J. and Johnson, S.G. 1989: Relative density. In Second growth Douglas-fir: Its management and conversion for value. Forintek Canada Corp. SP-32: 5-22.

McKinley, R.B. and Ball, R. 1997: Wood density of radiata pine as affected by genetics, silviculture and site - an update. Forest Research Institute, Project Record No. 5893 (unpubl.).

McKinley, R.B. and McConchie, D.L. 1997: An investigation into the effects of low boron levels on wood density in radiata pine. Forest Research Institute, Project Record No. 5994.

Skinner, M.F., Graham, J.D., Hunter-Smith, J.A.C. and Kimberley, M.O. 1996: The effect of boron fertilisers and weed control on the boron nutrition of young radiata pine. Results after 6 years. NZ Forest Research Institute. Project Record No. 4709.

Smith, D.M., 1954: Maximum moisture content method for determining the specific gravity of small wood samples. United States Forest Service, Forest Products Laboratory Paper No. 2014, 8pp.

Will, G. 1985: Nutrient deficiencies and fertiliser use in New Zealand exotic forests. NZ Forest Service, Forest Research Institute. Bulletin No. 97.

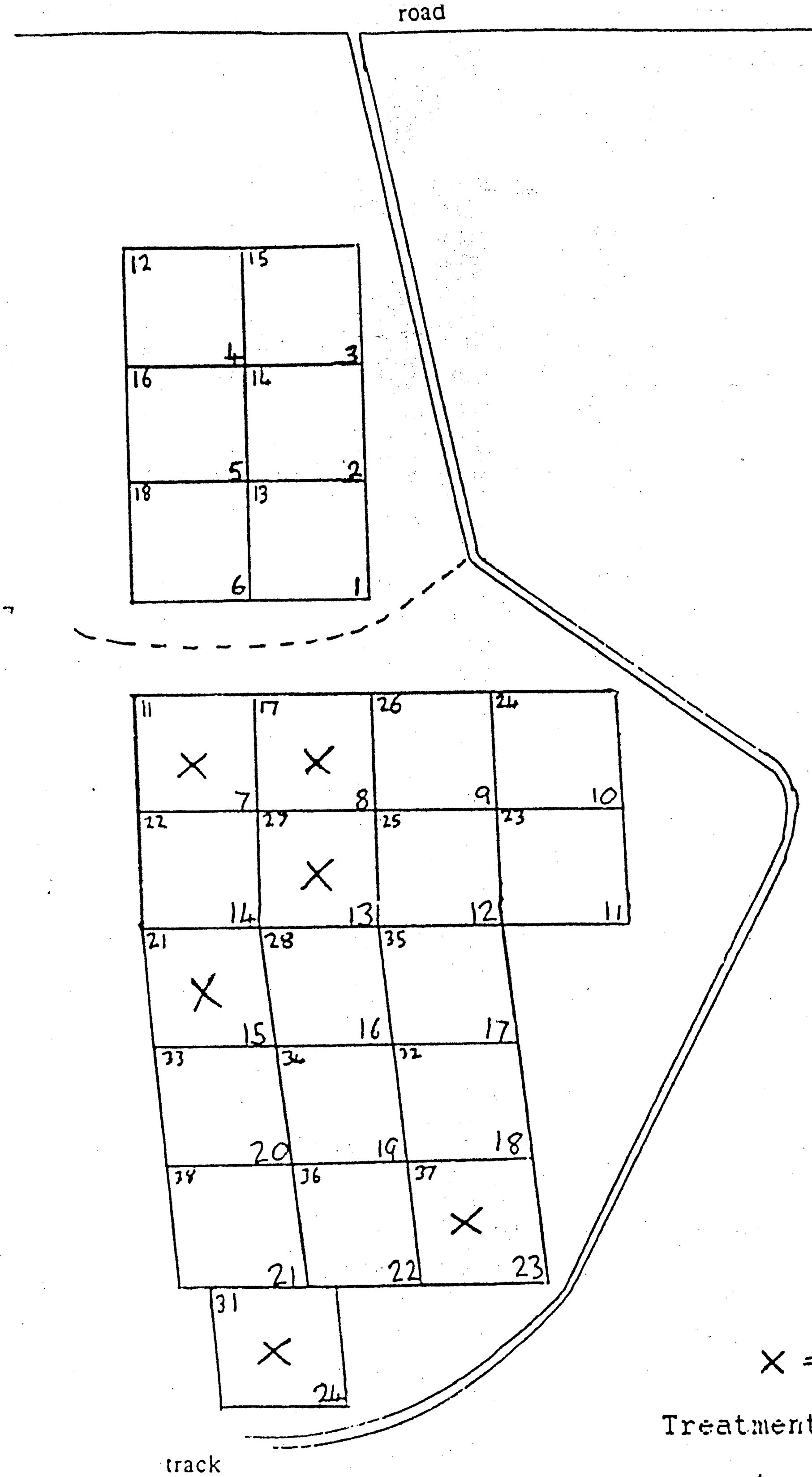
Young, G.D. and Skinner, M.F. 1990: Some effects of fertiliser levels on wood density. Forest Research Institute, Project Record No. 2588 (unpubl.).

Smith, D.M., 1954: Maximum moisture content method for determining the specific gravity of small wood samples. United States Forest Service, Forest Products Laboratory Paper No. 2014, 8pp.

Will, G. 1985: Nutrient deficiencies and fertiliser use in New Zealand exotic forests. NZ Forest Service, Forest Research Institute. Bulletin No. 97.

Young, G.D. and Skinner, M.F. 1990: Some effects of fertiliser levels on wood density. Forest Research Institute, Project Record No. 2588 (unpubl.).

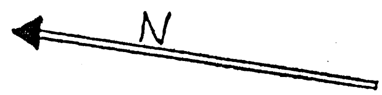
Appendix I - Boron trial layout, Rerewhakaaitu (FR24/2)

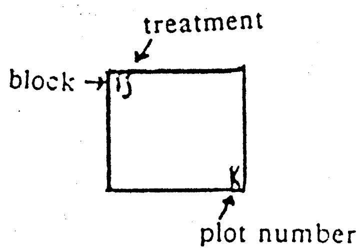


Scale 1 cm = 20 m

planted 1986
trial established 1988
site previously farmland

External plot size 35 x 35 m
Internal plot size 25 x 25 m





X = sampled plots

Treatment No	Fertiliser	Weed control
1	Control	no
2	Control	yes
3	Borax	no
4	Borax	yes
5	Colemanite	no
6	Colemanite	yes
7	Ulexite	no
8	Ulexite	yes

Appendix II - Individual disc measurements

Tree no.	Disc ht. (m)	DOB (mm)	DIB (mm)	Bark depth (mm)	Heart wood (mm)	Heart wood (%)	Comp. wood (%)	Basic density (kg/m^3)
Control treatment								
1	0	346	300	23	55	3	5	386
	1.4	289	263	13	70	7	5	373
	5	232	220	6	40	3	5	349
	10	136	128	4	0	0	5	339
2	0	338	297	21	55	3	30	375
	1.4	263	238	13	60	6	5	363
	5	198	186	6	25	2	10	383
	10	135	127	4	0	0	0	351
3	0	344	315	15	60	4	5	356
	1.4	302	282	10	70	6	5	339
	5	269	254	8	47	3	15	327
	10	169	159	5	20	2	10	297
4	0	358	316	21	50	3	5	342
	1.4	312	285	14	60	4	5	346
	5	252	240	6	35	2	15	343
	10	190	177	7	15	1	35	363
5	0	306	267	20	35	2	5	372
	1.4	260	233	14	70	9	0	361
	5	200	189	6	55	8	0	342
	10	112	106	3	15	2	0	323
6	0	398	358	20	55	2	5	348
	1.4	332	306	13	65	5	5	341
	5	255	242	7	20	1	15	324
	10	166	156	5	0	0	10	314
7	0	344	301	22	40	2	5	379
	1.4	275	254	11	75	9	10	369
	5	229	219	5	40	3	10	346
	10	169	160	5	0	0	15	363
8	0	417	350	34	55	2	0	378
	1.4	339	298	21	60	4	10	360
	5	284	264	10	55	4	5	339
	10	197	186	6	30	3	0	321
	15	121	112	5	0	0	0	314
9	0	351	309	21	45	2	15	367
	1.4	296	267	15	65	6	5	359
	5	233	218	8	40	3	5	327
	10	148	138	5	0	0	0	313
10	0	387	345	21	60	3	10	336
	1.4	323	297	13	70	6	5	335
	5	258	243	8	40	3	25	307
	10	135	126	5	0	0	5	282

Appendix II - Individual disc measurements (contd.)

Tree no.	Disc ht. (m)	DOB (mm)	DIB (mm)	Bark depth (mm)	Heart wood (mm)	Heart wood (%)	Comp. wood (%)	Basic density (kg/m^3)
Control treatment (contd.)								
11	0	430	384	23	50	2	0	346
	1.4	373	340	17	70	4	0	318
	5	302	281	11	35	2	10	325
	10	159	150	5	0	0	5	295
12	0	361	311	25	40	2	0	373
	1.4	305	274	16	50	3	5	360
	5	224	212	6	15	1	0	322
	10	132	124	4	0	0	20	303
13	0	362	321	21	30	1	15	330
	1.4	314	286	14	25	1	10	323
	5	237	225	6	20	1	10	309
	10	106	100	3	0	0	0	291
14	0	337	300	19	30	1	5	336
	1.4	289	261	14	70	7	0	324
	5	228	216	6	25	1	0	311
	10	139	129	5	0	0	0	299
15	0	345	303	21	30	1	0	343
	1.4	292	259	17	45	3	5	317
	5	242	223	10	20	1	25	327
	10	142	134	4	0	0	5	306
Boron treatment								
16	0	400	350	25	30	1	5	326
	1.4	339	312	14	45	2	5	321
	5	287	274	7	40	2	0	300
	10	192	182	5	20	1	0	296
17	0	354	315	20	50	3	0	376
	1.4	284	261	12	65	6	0	360
	5	237	227	5	40	3	5	329
	9.5	184	174	5	25	2	25	323
18	0	331	294	19	55	3	0	347
	1.4	284	260	12	60	5	0	342
	5	228	217	6	25	1	0	323
	10	179	169	5	0	0	10	307
	15	107	99	4	0	0	5	291
19	0	357	319	19	35	1	5	369
	1.4	308	285	12	55	4	10	358
	5	241	229	6	40	3	25	355
	10	161	154	4	0	0	10	315

Appendix II - Individual disc measurements (contd.)

Tree no.	Disc ht. (m)	DOB (mm)	DIB (mm)	Bark depth (mm)	Heart wood (mm)	Heart wood (%)	Comp. wood (%)	Basic density (kg/m^3)
Boron treatment (contd.)								
20	0	337	293	22	35	1	0	380
	1.4	277	251	13	45	3	5	368
	5	225	214	6	40	3	5	333
	10	174	165	5	30	3	0	320
21	0	353	318	18	40	2	10	354
	1.4	320	291	15	50	3	20	351
	5	260	248	6	30	1	20	323
	10	162	154	4	20	2	10	300
22	0.3	429	379	25	80	4	0	343
	1.4	378	342	18	70	4	0	346
	5	283	270	7	45	3	0	311
	10	165	157	4	25	3	5	315
23	0	347	309	19	45	2	5	350
	1.4	293	269	12	55	4	10	360
	5	231	220	6	40	3	5	348
	10	166	158	4	25	3	0	312
24	0.3	349	305	22	60	4	5	372
	1.4	307	276	16	70	6	5	370
	5	244	227	9	55	6	5	350
	10	184	174	5	0	0	5	331
25	0	315	268	24	60	5	15	334
	1.4	255	229	13	80	12	5	312
	5	198	189	5	60	10	5	286
	10	134	127	4	0	0	5	280
26	0	346	309	19	20	0	15	355
	1.4	287	265	11	35	2	10	355
	5	215	205	5	20	1	15	318
	10	122	113	5	0	0	10	307
27	0	357	309	24	40	2	5	371
	1.4	290	265	13	50	4	0	347
	5	222	209	7	35	3	10	328
	10	119	111	4	0	0	5	318
28	0	366	316	25	35	1	20	342
	1.4	300	265	18	45	3	0	335
	5	216	201	8	25	2	10	330
	10	123	116	4	0	0	10	271
29	0	394	354	20	80	5	10	351
	1.4	342	313	15	90	8	0	352
	5	250	239	6	45	4	0	321
	10	162	153	5	0	0	0	307

30	0	337	310	14	25	1	10	322
	1.4	295	274	11	30	1	10	317
	5	233	222	6	20	1	5	283
	10	154	146	4	0	0	0	276

Appendix III - Log and tree volumes

Tree no.	Log height class	Volume (m^3)	Bark depth (mm)	Heart wood (%)	Comp. wood (%)	Basic density (kg/m^3)
Control treatment						
1	Butt	0.272	16	5	5	373
	2nd	0.127	5	2	5	347
	Tree	0.399	12	4	5	365
2	Butt	0.241	15	4	18	373
	2nd	0.100	5	1	7	373
	Tree	0.341	12	3	15	373
3	Butt	0.322	11	4	8	343
	2nd	0.176	7	3	14	319
	Tree	0.498	10	4	10	334
4	Butt	0.309	15	3	7	344
	2nd	0.175	6	2	22	350
	Tree	0.484	12	3	13	346
5	Butt	0.210	14	6	2	362
	2nd	0.092	5	7	0	337
	Tree	0.302	11	6	2	354
6	Butt	0.367	15	3	7	341
	2nd	0.163	6	0	14	321
	Tree	0.529	12	2	9	335
7	Butt	0.272	14	4	8	368
	2nd	0.144	5	2	12	352
	Tree	0.417	11	4	9	363
8	Butt	0.377	24	3	4	362
	2nd	0.205	9	4	3	333
	3rd	0.093	5	2	0	319
	Tree	0.675	16	3	3	347
9	Butt	0.281	16	4	9	355
	2nd	0.131	7	2	4	323
	Tree	0.411	13	3	8	345
10	Butt	0.350	15	4	12	329
	2nd	0.147	7	2	21	302
	Tree	0.497	13	3	14	321
11	Butt	0.445	18	3	2	332
	2nd	0.199	9	1	9	318
	Tree	0.644	15	2	4	327
12	Butt	0.278	18	2	2	358
	2nd	0.118	5	0	5	317
	Tree	0.397	14	2	3	346
13	Butt	0.302	15	1	12	323
	2nd	0.119	6	1	8	306
	Tree	0.421	12	1	11	318

Appendix III - Log and tree volumes (contd.)

Tree no.	Log height class	Volume (m³)	Bark depth (mm)	Heart wood (%)	Comp. wood (%)	Basic density (kg/m³)
Control treatment						
14	Butt	0.268	14	3	2	326
	2nd	0.124	6	1	0	308
	Tree	0.393	11	2	2	321
15	Butt	0.278	17	2	8	330
	2nd	0.133	8	1	20	321
	Tree	0.411	14	1	11	327
Boron treatment						
16	Butt	0.388	16	2	4	318
	2nd	0.212	6	2	0	299
	Tree	0.600	13	2	2	311
17	Butt	0.296	14	4	1	360
	2nd	0.145	5	3	12	327
	Tree	0.441	11	3	5	349
18	Butt	0.262	13	4	0	340
	2nd	0.149	5	1	4	317
	3rd	0.075	5	0	9	303
	Tree	0.486	10	2	3	327
19	Butt	0.303	14	2	11	362
	2nd	0.150	5	2	20	343
	Tree	0.452	11	2	14	356
20	Butt	0.258	15	2	3	365
	2nd	0.143	5	3	3	328
	Tree	0.402	12	3	3	352
21	Butt	0.319	14	2	16	345
	2nd	0.167	5	2	17	317
	Tree	0.487	11	2	16	336
22	Butt	0.400	19	4	0	337
	2nd	0.192	6	3	1	312
	Tree	0.591	14	4	0	329
23	Butt	0.283	14	3	7	353
	2nd	0.144	5	3	3	335
	Tree	0.427	11	3	6	347
24	Butt	0.267	17	5	5	366
	2nd	0.161	7	4	5	343
	Tree	0.427	13	5	5	358
25	Butt	0.211	16	9	9	316
	2nd	0.102	4	7	5	284
	Tree	0.313	12	8	8	306

Appendix III - Log and tree volumes (contd.)

Tree no.	Log height class	Volume (m^3)	Bark depth (mm)	Heart wood (%)	Comp. wood (%)	Basic density (kg/m^3)
Boron treatment						
26	Butt	0.270	13	1	13	347
	2nd	0.108	5	1	14	315
	Tree	0.378	11	1	13	338
27	Butt	0.273	16	3	4	354
	2nd	0.110	6	2	9	325
	Tree	0.383	13	2	6	346
28	Butt	0.275	19	2	11	337
	2nd	0.106	7	1	10	316
	Tree	0.381	16	2	11	331
29	Butt	0.358	15	6	4	345
	2nd	0.158	5	3	0	317
	Tree	0.516	12	5	3	337
30	Butt	0.285	11	1	9	312
	2nd	0.139	5	1	3	281
	Tree	0.424	9	1	7	302

Appendix IV – Basic density data for regression analyses

Treat-ment	Tree. no.	Basic density, kg/m^3			
		Outer wood *	Butt log	2nd log	Whole tree
Control	1	374	373	347	365
"	2	377	373	373	373
"	3	340	343	319	334
"	4	353	344	350	346
"	5	369	362	337	354
"	6	356	341	321	335
"	7	377	368	352	363
"	8	367	362	333	347
"	9	347	355	323	345
"	10	325	329	302	321
"	11	331	332	318	327
"	12	370	358	317	346
"	13	338	323	306	318
"	14	330	326	308	321
"	15	323	330	321	327
Boron	16	324	318	299	311
"	17	369	360	327	349
"	18	340	340	317	327
"	19	358	362	343	356
"	20	390	365	328	352
"	21	335	345	317	336
"	22	348	337	312	329
"	23	378	353	335	347
"	24	368	366	343	358
"	25	319	316	284	306
"	26	346	347	315	338
"	27	360	354	325	346
"	28	326	337	316	331
"	29	356	345	317	337
"	30	308	312	281	302

* Outer 5 growth rings

Appendix V - Spiral grain by sampling position

Tree no.	Disc ht. (m)	Spiral grain (°) by ring number from pith				
		2	4	6	8	10
Control treatment						
1	0	3.25	2.75	1.00	0.50	0.00
	1.4	4.25	3.50	1.00	0.25	
	5	3.75	4.00	3.75		
	10	1.50				
2	0	5.75	6.00	5.50	1.75	1.25
	1.4	5.25	6.25	3.00	1.25	
	5	3.50	4.75	3.25		
	10	3.75	5.00			
3	0	7.50	6.00	6.75	8.00	7.50
	1.4	7.25	8.25	7.75	8.50	
	5	9.50	11.25	10.00		
	10	7.50	7.25			
4	0	1.50	2.75	0.50	0.50	-1.00
	1.4	3.50	1.75	2.25	2.00	
	5	3.00	5.00	5.50		
	10	5.25	5.75			
5	0	7.50	1.00	3.50	3.25	2.50
	1.4	7.50	4.50	3.25	2.25	
	5	9.00	2.00	4.50		
	10	6.75				
6	0	6.75	6.25	4.25	4.00	5.00
	1.4	5.75	6.50	3.50	3.50	
	5	3.00	4.50	9.25		
	10	5.00	7.25			
7	0	7.00	3.00	-1.75	4.00	1.50
	1.4	0.25	4.00	0.25	0.75	
	5	7.00	7.00	5.00		
	10	4.00	5.00			
8	0	4.25	-1.00	0.75	-0.25	-3.25
	1.4	1.75	1.75	-1.00	-1.75	
	5	5.00	4.50	3.75		
	10	5.25	4.00			
	15	3.50				
9	0	3.50	6.25	9.25	3.50	2.75
	1.4	4.50	7.50	4.75	0.00	
	5	5.75	6.25	7.00		
	10	6.75				
10	0	3.50	2.50	2.50	2.00	-0.25
	1.4	2.00	1.00	-2.00	-1.50	
	5	3.50	5.25	4.75		
	10	2.00				

NB. Negative spirality is right hand lean (at top of sample)

Appendix V - Spiral grain by sampling position (contd.)

Tree no.	Disc ht. (m)	Spiral grain (°) by ring number from pith 2	4	6	8	10
Control treatment (contd.)						
11	0	1.00	-0.25	-1.00	0.75	0.25
	1.4	2.50	5.00	4.50	5.75	
	5	6.00	4.75	6.25		
	10	5.50	5.75			
12	0	5.25	3.75	5.00	4.75	6.00
	1.4	2.25	5.75	5.25	1.75	
	5	5.50	4.25	5.50		
	10	4.50				
13	0	3.75	4.00	1.25	1.25	-2.75
	1.4	5.25	-2.25	3.25	1.25	
	5	6.50	1.25	1.00		
	10	3.25	2.00			
14	0	4.25	3.00	1.25	-1.00	-0.25
	1.4	4.25	5.75	2.00	1.75	
	5	3.75	3.25	4.75		
	10	3.75	3.75			
15	0	2.50	4.50	1.25	1.75	3.00
	1.4	5.75	3.00	1.50	4.25	
	5	2.00	3.75			
	10	6.00				
Boron treatment						
16	0	2.75	3.25	1.50	-0.50	-0.50
	1.4	4.50	1.50	4.25	1.50	
	5	5.25	5.00	6.75		
	10	7.00	5.25			
17	0	5.00	3.25	1.50	3.00	0.25
	1.4	6.50	6.00	4.75	2.50	
	5	8.25	7.00	6.25		
	10	8.50	6.75			
18	0	3.50	-0.50	-2.75	-1.50	-2.75
	1.4	3.00	2.25	1.75	0.50	
	5	4.25	2.75	1.25		
	10	3.25	4.75			
	15	4.50				
19	0	3.00	-3.25	2.50	5.25	1.00
	1.4	4.50	2.75	0.50	4.50	
	5	8.00	9.00	7.25		
	10	11.00	3.50			
20	0	3.50	3.00	0.00	1.25	2.00
	1.4	5.50	5.75	3.50	3.25	
	5	5.00	8.75	5.50		
	10	7.75	7.25			

NB. Negative spirality is right hand lean (at top of sample)

Appendix V - Spiral grain by sampling position (contd.)

Tree no.	Disc ht. (m)	Spiral grain (°) by ring number from pith 2	4	6	8	10
Control treatment (contd.)						
21	0	2.25	2.50	1.50	-0.50	-1.75
	1.4	5.50	4.50	2.25	-0.75	
	5	5.75	2.25	1.00		
	10	2.00	5.00			
22	0	6.50	5.25	4.00	2.75	5.75
	1.4	3.75	4.00	2.75	2.25	
	5	4.75	6.25	6.25		
	10	3.75	7.25			
23	0	0.50	-1.25	-3.50	-4.25	-2.00
	1.4	3.25	-3.00	-2.50	-2.00	
	5	4.50	1.00	-0.75		
	10	2.25	2.75			
24	0.3	3.50	1.25	0.25	2.50	1.00
	1.4	6.25	2.00	1.75	1.50	
	5	3.75	1.50	2.50		
	10	7.25	8.75			
25	0	3.75	3.25	3.50	1.50	0.25
	1.4	3.50	5.25	2.00	0.75	
	5	6.25	5.75	4.50		
	10	8.50	11.00			
26	0	5.00	8.25	6.75	5.00	1.75
	1.4	9.75	8.75	6.25	-0.50	
	5	3.75	6.50	3.25		
	10	3.50				
27	0	0.00	3.00	2.75	2.25	1.50
	1.4	3.50	2.50	-0.25	0.50	
	5	4.25	6.00	3.25		
	10	8.75				
28	0	7.50	3.00	0.50	1.00	-1.25
	1.4	1.00	1.25	4.00	0.75	
	5	2.00	4.00	4.25		
	10	3.00	6.50			
29	0	4.75	5.25	3.25	0.00	1.75
	1.4	4.00	6.50	1.75	4.00	
	5	7.00	4.50	4.25		
	10	6.00	5.50			
30	0	2.75	4.50	3.00	0.75	-1.50
	1.4	5.75	2.00	-1.75	-1.25	
	5	2.00	5.75	5.50		
	10	7.25				

NB. Negative spirality is right hand lean (at top of sample)

Appendix VIa - Average Ring Properties for Control group, Age 10 years

Year	Widths, mm				%	Areas, cm^2		Densities, kg/m^3								N
	Outer Rad.	Ring	Early Wood	Late Wood	LW	Incr.	Total	Ring mean	Cum. mean	E/Wd mean	L/Wd mean	Unif.	Min.	Max.	Rng.	
1989	12.2	12.0	10.1	1.0	9	5.5	5.5	336	338	322	481	153	269	475	205	14
1990	29.6	18.2	17.3	0.9	4	25.2	30.4	324	327	315	503	187	250	525	275	15
1991	49.0	19.4	18.0	1.4	7	48.7	79.1	324	325	310	506	196	252	538	287	15
1992	64.3	15.3	13.4	1.8	11	55.0	134.1	346	334	321	522	201	260	575	315	15
1993	77.7	13.4	11.6	1.8	14	60.9	194.9	352	339	326	507	181	269	568	299	15
1994	91.4	13.7	11.9	1.8	13	74.0	268.9	358	344	333	520	187	280	576	297	15
1995	104.5	13.1	11.5	1.7	13	83.9	352.8	363	349	339	516	176	287	580	293	15

Appendix VIb - Average Ring Properties for Boron (Ulexite) treated group, Age 10 years

Year	Widths, mm				%	Areas, cm^2		Densities, kg/m^3								N
	Outer Rad.	Ring	Early Wood	Late Wood	LW	Incr.	Total	Ring mean	Cum. mean	E/Wd mean	L/Wd mean	Unif.	Min.	Max.	Rng.	
1988	5.5	5.5	4.9	0.0	0	1.1	1.1	321	321	320	455	141	258	401	144	7
1989	11.8	9.4	8.0	0.5	6	4.2	4.6	345	340	336	480	136	278	459	181	16
1990	28.8	17.1	16.1	0.9	5	22.3	27.0	315	320	305	503	200	245	531	286	16
1991	47.9	19.1	17.7	1.4	7	46.5	73.5	322	321	307	503	195	247	541	294	16
1992	63.0	15.1	13.3	1.8	12	53.2	126.7	341	329	317	524	207	265	583	318	16
1993	76.6	13.6	11.9	1.7	12	60.4	187.0	349	336	325	516	191	265	577	313	16
1994	88.9	12.3	10.7	1.6	13	65.4	252.5	359	342	333	530	197	279	598	319	16
1995	99.9	11.0	9.2	1.7	17	67.0	319.5	375	349	342	523	180	290	595	305	16

Appendix VIc - Average Ring Properties for Boron (Borax) treated group, Age 12 years

Year	Widths, mm				%	Areas, cm^2		Densities, kg/m^3								N
	Outer Rad.	Ring	Early Wood	Late Wood	LW	Incr	Total	Ring mean	Cum. mean	E/Wd mean	L/Wd mean	Unif.	Min.	Max.	Rng	
1988	6.5	6.5	4.4	1.7	6	1.5	1.5	362	362	354	482	127	274	468	194	8
1989	15.5	11.1	10.0	0.7	6	7.2	8.3	353	354	344	481	130	288	477	190	19
1990	32.2	18.9	17.3	1.3	7	27.6	34.5	341	344	328	503	175	268	544	276	24
1991	51.8	21.0	19.2	1.8	8	55.1	88.2	340	341	323	521	198	255	559	304	25
1992	69.2	17.4	14.8	2.6	14	66.0	154.2	363	350	333	536	203	278	605	327	25
1993	83.4	14.2	11.9	2.3	16	67.6	221.8	371	356	340	523	182	271	596	325	25
1994	96.8	13.4	11.3	2.1	15	75.8	297.6	373	361	345	522	176	295	589	294	25
1995	107.7	10.9	9.0	2.0	19	71.9	369.5	388	366	357	511	153	302	584	283	25
1996	116.4	8.7	6.6	2.2	27	63.5	433.0	400	371	351	530	179	294	605	310	25
1997	123.7	7.3	5.4	1.9	29	56.9	489.9	424	377	367	560	193	322	641	320	25

Appendix VIIa – Internal checking incidence by stem height – 2 m billet

Tree no.	Number of internal checks						
	Stem height, m (within 2m billet)						Total
	1.7	2	2.3	2.6	2.9	3.2	
Control							
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	2	-	-	3	9	14
5	-	-	-	2	-	-	2
6	3	-	-	-	-	-	3
7	3	5	8	6	1	-	23
8	-	1	2	-	2	-	5
9	-	-	-	-	-	-	-
10	27	18	14	18	8	10	95
11	-	-	-	-	-	-	-
12	-	-	-	-	-	2	2
13	-	-	-	-	-	-	-
14	-	-	2	1	-	-	3
15	12	-	12	2	2	-	28
Total	45	26	38	29	16	21	175
Boron							
16	20	30	16	5	5	3	79
17	6	1	1	1	-	-	9
18	9	13	5	5	3	1	36
19	6	5	-	1	4	6	22
20	6	3	5	1	-	6	21
21	-	-	-	-	-	-	-
22	1	-	-	-	-	3	4
23	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-
25	10	11	9	4	4	-	38
26	5	1	7	-	1	-	14
27	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-
29	11	12	9	7	6	3	48
30	16	10	8	-	3	5	42
Total	90	86	60	24	26	27	313
Overall	135	112	98	53	42	48	488

Appendix VIIb – Internal checking incidence by ring position from bark – 2 m billet

Tree no.	Number of internal checks							
	Rings from bark							Total
	1	2	3	4	5	6	7	
Control								
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
4	-	-	1	10	1	2	-	14
5	-	-	2	-	-	-	-	2
6	-	-	-	-	-	2	1	3
7	-	-	2	2	-	20	1	25
8	-	-	-	-	-	3	2	5
9	-	-	-	-	-	-	-	-
10	-	-	3	3	35	34	18	93
11	-	-	-	-	-	-	-	-
12	-	-	-	-	1	1	-	2
13	-	-	-	-	-	-	-	-
14	-	-	-	-	2	1	-	3
15	-	-	4	4	7	10	3	28
Total	-	-	12	19	46	73	25	175
Boron								
16	-	-	20	5	24	30	-	79
17	-	-	-	-	5	4	-	9
18	1	-	8	-	3	13	11	36
19	-	-	3	2	7	2	8	22
20	-	-	-	-	2	13	6	21
21	-	-	-	-	-	-	-	-
22	-	-	2	1	-	1	-	4
23	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-
25	-	-	-	2	8	26	2	38
26	1	-	12	1	-	-	-	14
27	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-
29	-	-	1	3	9	29	6	48
30	-	3	9	5	21	4	-	42
Total	2	3	55	19	79	122	33	313
Overall	2	3	67	38	125	195	58	488

Appendix VIII – Resin pocket and blemish incidence from whole stem cross-cutting

Tree no.	Number of resin pockets and blemishes																				
	Stem cross-sectional heights, m																				
	0	0.3	0.6	0.9	1.4	3.6	3.9	4.2	4.5	4.8	5	5.1	5.4	5.7	6	6.3	6.6	6.9	7.2	7.5	7.8
Control																					
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
3	-**	R 6/1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R 4/1	
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-		
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-					
9	-	-	-	-	-	-	-	-	-	-	-	-	R 6/1	R 3/1	-	R 1*/1	-	-			
10	-	-	-	-	-	R 4/1	-	-	-	-	-	-	-	-	-						
11	-	-	-	-	-	-	-	-	-	-	-	-									
12	-	-	-	-	-*	-	-	-	-	-											
13	-	-	-	-	-	-	R 4/2	-	-	-	-	-	-	-	-						
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
15	-	-	-	-	-*	-	-	-	-	-	-	-	-	-							
Boron																					
16	-*	-	-	-	-*	-	-	-	-	-	-	-	-	-	-						
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
20	-	-	-	-	-**	-	-	R 4/1	-	-	-	-	-	-	-	-	-	-	-		
21	-	-	-	-	-*	-	-	-	-	-	-*	-	-	-	-	-	-	-	-		
22	-*	-	-	-	-	R 5/1	-	-	-	-	-	-	-	-	-	-					
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
24	-	-*	-	-	-	-*	-	-*	-	-	-	-	-**	-	-	-	-	-			
25	-	-	-	-	-	R 4/1	-	-	-	-	-	-	-	-	-						
26	-	-	-	-	-	-	-	-	-	-	-	-	-								
27	-	-	-	-	-	-	-	-	-	-	-	-	-								
28	-	-	-	-	-	-	-	-	-	-	-	-	-								
29	-*	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-					

NB: R6/1 = Ring 6, 1 resin pocket
* = 1 blemish

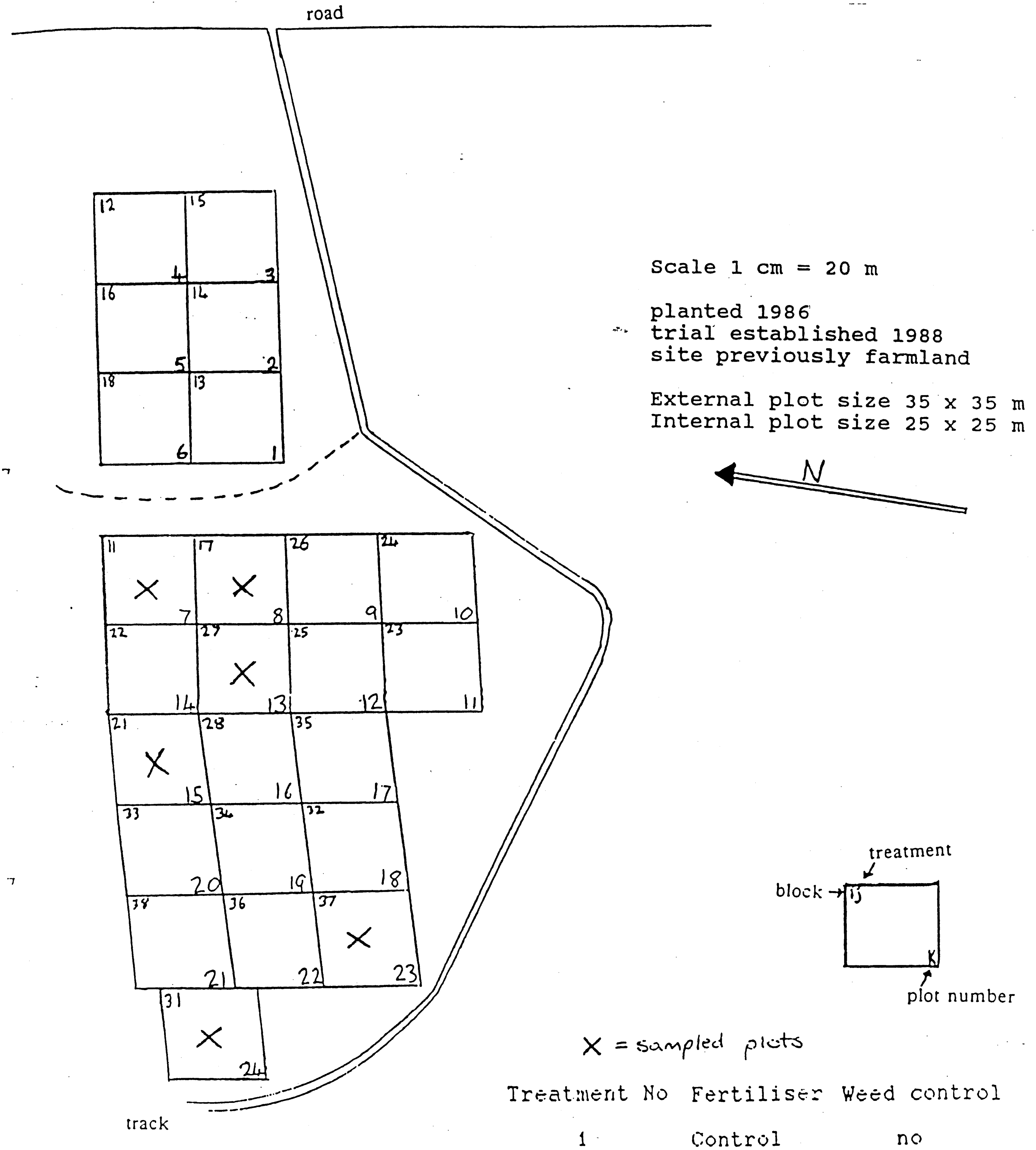
Appendix IX – Resin pocket incidence by ring, stem position and treatment – 2m billet

Tree no.	Number of resin pockets										
	Rings from bark								Position in stem, m		Total
	1	2	3	4	5	6	7	8	1.4 to 2.4	2.4 to 3.4	
Control											
1	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	1	-	-	-	1	1
3	-	-	1	-	1	-	-	-	2	-	2
4	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	1	-	-	1	1
8	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	1	-	-	-	-	1	1
10	-	-	-	-	1	-	-	-	1	-	1
11	-	-	-	-	1	-	-	-	-	1	1
12	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	1	-	1	-	1
Total	-	-	1	-	4	1	2	-	4	4	8
Boron											
16	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	1	-	-	-	-	-	1	1
19	-	-	1	-	-	-	-	-	-	1	1
20	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	1	-	1	-	1
25	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	3	-	-	-	2	1	3
28	-	-	-	-	1	-	-	-	1	-	1
29	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	1	-	-	-	-	1	1
Total	-	-	1	1	5	-	1	-	4	4	8
Overall	-	-	2	1	9	1	3	-	8	8	16

Appendix X – Blemish incidence by ring, stem position and treatment – 2m billet

Tree No.	Number of blemishes										
	Rings from bark								Position in stem, m		Total
	1	2	3	4	5	6	7	8	1.4 to 2.4	2.4 to 3.4	
Control											
1	-	-	-	-	1	-	1	-	1	1	2
2	-	-	-	1	2	-	-	-	3	-	3
3	-	-	-	1	-	-	1	1	3	-	3
4	-	-	-	-	2	-	2	-	2	2	4
5	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	3	1	-	-	4	-	4
7	-	-	-	-	2	-	-	-	2	-	2
8	2	-	-	4	4	2	-	-	7	5	12
9	-	1	1	2	1	-	-	-	3	2	5
10	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	1	-	-	-	-	1	1
12	-	-	-	2	-	-	-	-	1	1	2
13	-	-	-	2	2	-	-	-	2	2	4
14	-	-	-	-	3	-	1	-	1	3	4
15	-	-	-	6	4	2	1	-	7	6	13
Total	2	1	1	18	25	5	6	1	36	23	59
Boron											
16	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	2	3	-	-	5	5
18	-	-	-	2	-	-	1	-	-	3	3
19	-	-	-	1	-	-	-	-	1	-	1
20	-	-	-	1	-	-	1	-	2	-	2
21	-	-	-	5	2	-	-	-	6	1	7
22	-	-	-	-	-	3	1	-	2	2	4
23	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	3	8	13	5	-	19	10	29
25	-	-	-	1	1	-	-	-	2	-	2
26	-	-	-	-	1	-	-	-	1	-	1
27	-	-	-	-	2	-	-	-	1	1	2
28	-	-	-	2	2	-	-	-	1	3	4
29	-	-	-	-	3	4	1	-	6	2	8
30	-	-	-	-	-	-	-	-	-	-	-
Total	-	-	-	15	19	22	12	-	41	27	68
Overall	2	1	1	33	44	27	18	1	77	50	127

Appendix I – Trial layout - Boron Types Trial (FR24/2), Rerewhakaaitu



Treatment No	Fertiliser	Weed control
1	Control	no
2	Control	yes
3	Borax	no
4	Borax	yes
5	Colemanite	no
6	Colemanite	yes
7	Ulexite	no
8	Ulexite	yes