New Zealand Forest Site Management Cooperative

DEVELOPMENT OF A BORON DECISION SUPPORT SYSTEM FRAMEWORK

by

Sonya Olykan, Malcolm Skinner, Tim Payn and Doug Graham

Report No. 120 **MAY 2002**

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EXECUTIVE SUMMARY

The objectives of this project were to provide the framework for a Boron Decision Support System and to identify key areas of boron nutritional management in forestry that require further research to enable the development of a comprehensive B DSS in the future.

General conclusions:

- The BDSS framework is based on relationships between foliar B and a number of factors including rainfall, types and rates of B, silviculture, and site factors such as climate, soils, and weed competition.
- Existing data sets will be used to validate the relationships for the wide range of environmental domains in New Zealand.
- Recent data from historical trials show that soluble B fertilisers can maintain foliar B concentrations above control values in the long-term.
- Forest companies generally have a sound approach towards the management of B nutrition in their forest estate based on monitoring foliar B or using standard practice to determine the need for B fertiliser.
- The fact sheets developed in this project will provide relevant and up-to-date information about the management of B nutrition in New Zealand forests.

INTRODUCTION

In the 1970's a variety of fertiliser trials with boron at both time-of-planting and at early ages (2-4 years) examined the foliar boron (B) nutrition of pines fertilised with borax. Later age foliar analyses showed that early silviculture (thinning and pruning) could "reverse" the decline in foliar B often associated with the use of soluble B fertilisers. In the 1980's work on ulexite (a mineral form of B) was undertaken to assess ulexite potential as relatively "insoluble" sources of B for long-term effectiveness. In the late 1980's, the New Zealand Forest Site Management Cooperative (NZFSMC) trial work commenced with both ulexite and colemanite (of various grades) to further develop the "longevity of response" story. In the late 1990's the NZFSMC extended the boron project to assess rates of B application in relation to soil B, climate and genotype performance in the FR358 series of trials "Effect of Boron and wood quality".

Currently our focus within the PGSF Programme is developing an understanding of the benefits to B fertilising - risk and insurance against poor crop performance in relation to growth and wood fiber properties. To ensure better management of boron nutrition in future forests and focus on key areas of boron requiring further research, we would like to initiate the construction of a framework for a Boron Decision Support System (B DSS). We anticipate that it will be able to integrate fertiliser type ("solubility") and rate with:

- silviculture
- weed competition
- soil B fertility and
- climate

to achieve the benefits of :

- ensuring maintenance of foliar B at desired level
- insurance against likelihood of drought causing stem malformation (site specific information on rate of B in relation to weed competition)
- specificity in wood fibre properties (pulping properties, strength).

Given the forest industry's continuing interest in B, particularly from a wood quality perspective, and the proposed focus on B within the new PGSF program, it seems timely that a B DSS framework be developed. The development of this B DSS framework will identify the forest industry requirements for managing B. This in turn will provide the impetus for further targeted B research, within the FR358 trial series and the proposed PGSF program, which will provide the necessary information for a working B DSS in the future.

Objectives ("testable hypotheses")

- Provide the framework for a Boron Decision Support System.
- Identify key areas of boron nutrition in forestry that require further research to ensure a comprehensive B DSS is developed in the future.

DESIGN OF B DSS FRAMEWORK

There were two components to the framework:

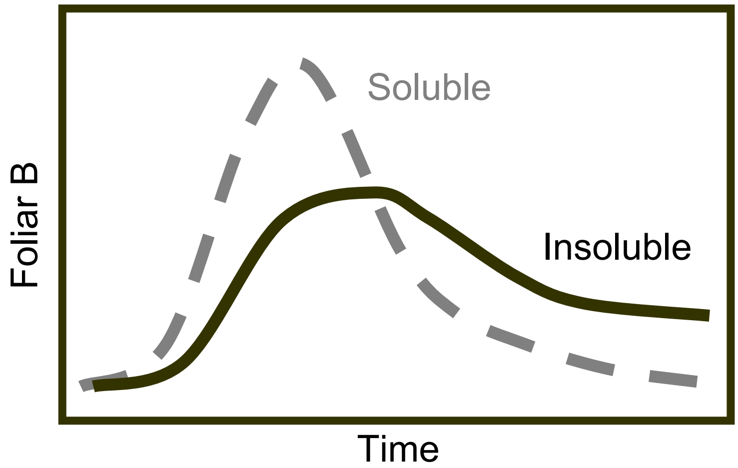
- the basic function developing the relationship between foliar B and fertiliser addition over time
- fact sheets covering a range of topics relating to boron in forestry.

B DSS function

Foliar B response curve

The original function was based on the effect of fertiliser types (e.g. soluble to insoluble) on foliar B (see graph below).

Different regions (e.g. Canterbury, Northland, NI central plateau) having different climatic and soil variables may require their own critical values of foliar B for visual symptoms (tip dieback), wood properties, and species (e.g. Douglas fir, Eucalypts).



It was also believed that other factors would need to be incorporated into the basic function included weed control, silvicultural regime (pruning), end product (pulp v sawlog), soils (e.g. depth, texture) and moisture supply (rainfall).

Location

Foliar B is a function of a number of major interacting factors:

- rainfall - adequate amounts
- soil B - amount of plant available (organic matter)
- soil structure - depth, texture, organic matter: water holding capacity

There are a number of management issues

- Managing B for a particular forest - what basic information is required?
- Understanding the relative importance of location factors for a forest or region.
- High risk areas: standard application of B at young age.
  reapplication of B necessary within the rotation?
  increase foliar B critical level.
  rate of B required to resist probability of a drought 1 year in 8?
- Low risk areas - reduce foliar B critical values. Monitor to determine if B required.
- Stresses causing expression of B deficiency symptoms could be drought, frost, or factors associated with ex-pasture sites (e.g. fast growth and/or nutrient imbalances)
- The future may include genotypes as a tool to manage B nutrition.

What 'national' information is already available?

- Rainfall maps
- Soil type maps
- Foliar B map (new nutritional atlas) – based on soil type.

It has already been shown that rainfall is an important determinant of B nutrition in forestry. What is the interaction between rainfall and B fertiliser solubility? How do the relationships between foliar B and B fertiliser vary over time in different rainfall regimes?

The following hypothetical relationships have been developed to highlight how location, silvicultural regime and fertiliser type may interact and affect foliar B.

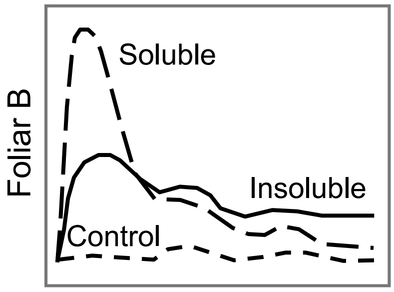
Rainfall

It has already been shown that rainfall is an important determinant of B nutrition in forestry. What is the interaction between rainfall and B fertiliser solubility? How do the relationships between foliar B and B fertiliser vary over time in different rainfall regimes? The following graphs explore the possible relationships. Some of the information presented we are confident of. For instance, on a low rainfall site rainfall during the growing season will have an affect foliar B in the preceding foliage sample.

Rainfall vs soil B supply

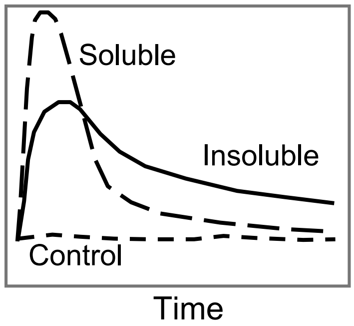
Hypothetical relationships

Low



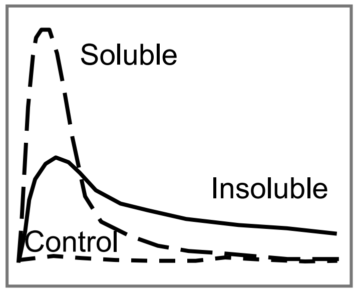
- Foliar B may fluctuate more seasonally because of the influence of rainfall.
- Controls low because of inadequate spring/summer rainfall.
- Rainfall is the major driver of foliar B.
- Fertiliser B retained in the soil long-term.

Adequate



- Foliar more stable seasonally (rainfall adequate).
- Foliar B adequate in the controls (sufficient rainfall).
- Soil B more important.
- Fertiliser B effect less long – term than a low rainfall environment (B leached) especially insoluble source.

High



- Foliar B relatively stable.
- Foliar B low in the controls (low soil B).
- Risk of B deficiency governed by soil B.
- Fertiliser B effect of soluble B comparatively short-lived.

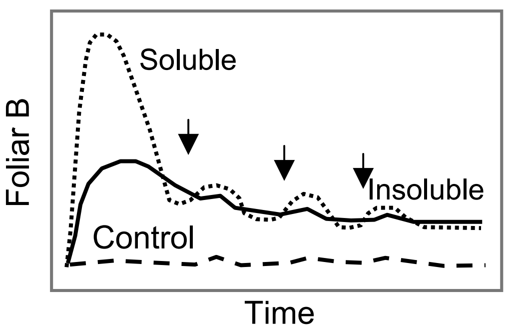
<u>Silvicultural regime</u>

Pruning and thinning trees returns nutrients to the site. Boron can be leached from the slash or released during breakdown. The B is then plant available and can elevate or maintain foliar B concentrations. High concentrations of B are likely on the slash from B-fertilised trees.

Silvicultural regime

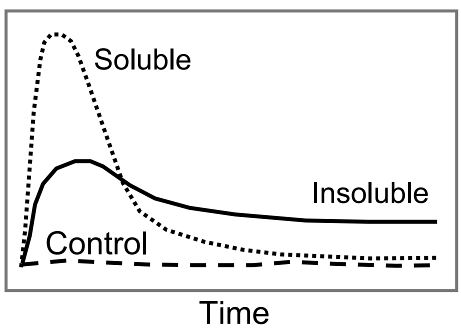
Regular thinning & pruning

Initial high stocking ⇒low stocking



No thinning or pruning

Initial low stocking



Developing data sets to validate the B DSS framework.

The next step is to develop data sets and GIS layers that can validate the B DSS framework and create a functioning B DSS. For each 'region' data sets will used to:

- identify the key factors affecting foliar B and
- develop relationships that can be used in the DSS.

GIS Layers

Existing GIS-based national data sets include:

- soil type
- rainfall
- foliar B atlas (by soil type)[1]

Data sets:

Historical B trials and other trials with B treatments or components

- Soluble B trials
- Other tree species (High Country trials)
- Other FRI trials

Current B trials

- Rerewhakaituu (soluble versus insoluble B fertilisers)
- FR 358: rates of ulexite (0-32 kg B/ha)
weed control x B
genotype x B
- Long-Term Site Productivity trials (aka Intensive Harvesting studies)

Forest company data sets

These data sets show the impact and longevity of operationally applying fertiliser B on foliar B. Data sets are available from a number of regions in New Zealand.

Other data sets

- "75" soils and foliar nutrients. This is a comprehensive data set which includes the measurement of a number of soil variables, including hot-water-soluble B, as well as foliar B. It is believed that addition of relevant rainfall measurements to this data set will allow the testing of some key relationships influencing foliar B.

Requirements to complete next step

- Assemble data sets
- Add additional information: geo-reference
rainfall value
- Analyse data sets and extract significant relationships
- Identify gaps in current data

Discussion

This project has identified and developed relationships that need to be validated so that a working B DSS can be constructed. These relationships seek to identify the effect of rainfall, B fertiliser type and silviculture on foliar B concentrations. To achieve this, the next phase will be to collect and expand data sets that can be used for the validation process. These data sets will come from forest companies and Forest Research trials.

In addition, the incorporation of GIS layers will provide important background information especially relating to climate and soils. It is envisaged that a national map showing the risk of B deficiency will be developed.

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[1] Soil texture may be more relevant than soil type (Andrew Dunningham, *pers. comm.*)

Fact sheets

Eleven fact sheets have been developed to accompany the B DSS. These fact sheets cover a wide range of topics relating to B nutrition and management in forestry. They will be located on the website and updated periodically. The following is a list of the fact sheets in **Appendix 1**:

1: Role of Boron in plants and boron uptake by plants
2: Boron deficiency in radiata pine and the effect on tree form and growth
3: Effect of Boron on wood fibre properties
4: Soil boron and the role of rainfall/soil moisture in B availability
5: Monitoring foliar B and variation in critical concentrations
6: Forest tree genotypes and boron
7: Types of boron fertiliser - their specifications and cost
8: Understorey vegetation - competing for soil water and boron
9: The FR358 B trial series
10: Summary of Boron trials containing soluble (and other) B fertilisers
11: Boron bibliography – a list important boron-related references

The fact sheets provide a general background to B and will require updating periodically.

REVIEW AND DEVELOPMENT OF SOLUBLE B FERTILISER DATA

Introduction

The objective of this section of work was to develop relationships between the use of soluble B, foliar B concentrations and silvicultural practices by reviewing the data from the early B trials. This work was required because the historic soluble B data is complementary to the current work in the FR358 B trial series, which is focussed on less-soluble B fertilisers, and it was believed that soluble B will have a place in the management of B nutrition of radiata pine in the future because:

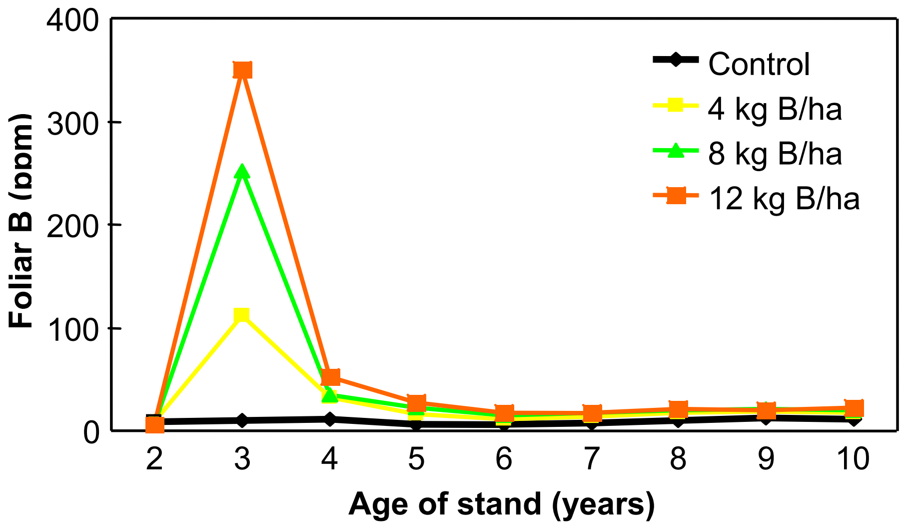
- Soluble B fertiliser gives a quick response and thinning/pruning may maintain foliar B (B is recycled through the slash)
- Trials with soluble B fertiliser were sampled from 0-5 years. However, long-term results are now available to reassess the effectiveness of soluble B fertilisers.

Results and discussion

CY451 (McLeans Island, Canterbury): rates of soluble B

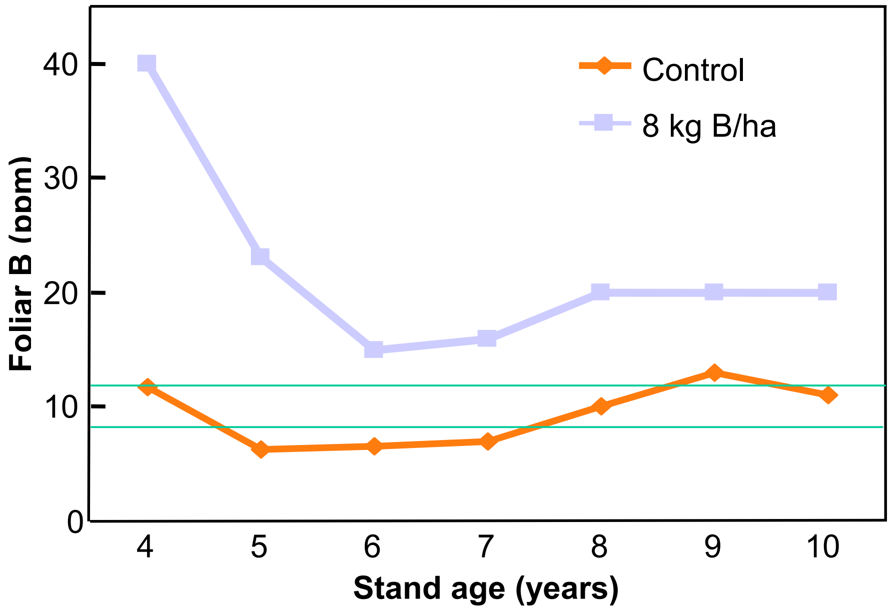
The addition of soluble B fertiliser (Borax) in this trial rapidly elevated foliar B concentrations. One year after application of 12 Kg B/ha, foliar B concentrations were 350 ppm. Concentrations in the other treatments were also high – 120 and 250 ppm for the 4 and 8 kg B/ha treatments respectively.

After the initial increase foliar B declined quickly.



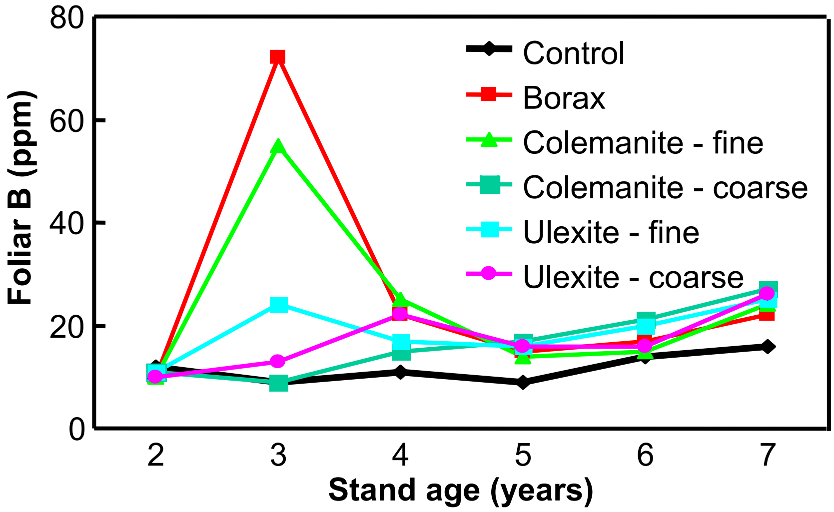
Eight years after B application (i.e., at stand age 10), the addition of 8 kg B/ha was maintaining foliar B concentrations above the control values. This was particularly important in years 5-7 when the control concentrations were less than 8 ppm.

It is interesting to note the increase of foliar B concentrations in the control and fertilised treatments in years 8 and 9. At present, there is no explanation for this increase and it can only be speculated that either rainfall or silviculture may have been involved.



CY581 (Ashley Forest, Canterbury): B fertiliser types (including "fineness")

One year after B application, borax and fine colemanite had dramatically increased foliar B concentrations. Fine ulexite raised B to 24 ppm while coarse ulexite and colemanite had little impact. After 2 years, all B fertilisers elevated foliar B compared to the control. The range was 15 to 25 ppm compared to 11 ppm in the control.

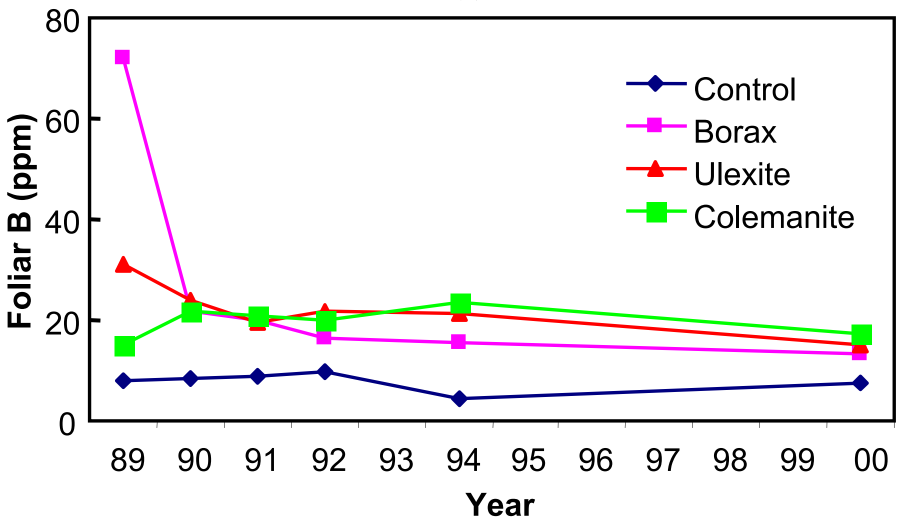


From age 3 to 4, there was a large decrease in foliar B in the borax and fine colemanite treatments. The affect of the B fertilisers stabilised from age 5 to 7 generally tracking above the control values (except fine colemanite at age 6). There was a rise in foliar B for all treatments at age 6 and 7. As mentioned for CY451, there is no explanation for the increase at present. However, data sets for this trial are available and it may be possible to explain the increase after examining the data.

FR24/1 (Rerewhakaaitu Forest, Central North Island): B types

This trial was established in a 2 year-old stand of radiata pine. The B fertilisers were applied at 6 kg B/ha.

The results from this trial again showed a big increase in foliar B concentrations in response to the addition of B fertiliser, especially borax. Foliar B concentrations peaked for borax and ulexite in 1989 (6 months after B addition) and for colemanite in 1990 and 1994 (1.5 and 5.5 years after addition).



All B fertilisers maintained foliar B above control levels 11.5 years after addition (Skinner *et al.* 2000). Apart from the initial peak, there was little difference between the B fertiliser types.

General discussion

Results from the B trials where soluble and insoluble sources of B fertiliser were compared indicate that soluble B fertilisers, such as Borax, can maintain foliar B concentrations above control values in the long-term. In a future B DSS, the option of using a soluble B fertiliser will be need to be included especially if the management of the stand includes silviculture.

The role of silviculture in the historical trials is still being investigated. Previous research has shown that the addition of B fertiliser can significantly increase B concentrations throughout the tree (Olykan *et al.* 1995). Assuming that the affect of soluble B on foliage B concentrations, compared to insoluble B, occurs throughout the tree, the return of slash to the site by pruning and thinning could provide a significant input of B for subsequent tree uptake.

BDSS FRAMEWORK QUESTIONNAIRE

Rationale for the questionnaire

The aims of the questionnaire were to:

- Find out how is B managed in forests by asking about current practices
- Identify forest industry requirements for managing B
- Ensure a B DSS meets industry requirements and promotes best practices for B nutrition

Structure of the survey

The questionnaire was divided into the following 3 sections:

- Identifying visual symptoms of B deficiency
- Monitoring foliar B
- B fertiliser application

The questionnaire also asked about the availability of industry data sets that monitored foliar B after B fertiliser application.

Results and discussion

There were 19 replies from 13 companies. The basic results are presented in **Appendix 2**. The following summarises and discusses the results.

Identifying visual symptoms of B deficiency in the forest

All of the respondents had observed symptoms of B deficiency. The main ones were tip dieback, multi-leaders, bushy growth and resin bleeding. 84% of respondents identified these symptoms using surveys, monitoring systems and visits to confirm low foliar B concentrations.

Monitoring foliar B

80% of respondents regularly monitored foliar B in young stands. Sampling appeared to be targeted to areas prone to B deficiency, times after dry summers, or to confirm the presence of visual symptoms.

Some companies routinely monitor foliar nutrients across their forest estate. Half (47%) of the respondents indicated that resampling took place. This was dependent on a range of variables including after B addition, history of region, FR recommendations etc.

A higher percentage (63%) monitored foliar B after B fertiliser addition.

B fertiliser application

Most companies (79%) applied B fertiliser to prevent tip dieback and/or as insurance against summer droughts. There was a mixed response to the suggestion that B fertiliser was applied because there was a link between B and wood fibre properties. The response ranged from 'Yes' to 'Is there a link between B and wood fibre properties?'

The application of B fertiliser occurred as standard practice at a certain age, in response to low/marginal foliar B concentrations or the presence of visual symptoms, or if recommended by Forest Health. 47% of respondents indicted that different forests within the estate had their own criteria for B addition based on rainfall, soils or history of B deficiency. B fertiliser was generally applied as ulexite at 6 to 7 kg B/ha.

47% of respondents stated that budgets influenced which stands were fertilised with B. Criteria used to prioritise which stands received B included treating in high risk areas with low B first, not treating stands unless they were very deficient, fertilising stands to be pruned, or delaying application for a year.

Conclusions

The key points to emerge from the questionnaire are:

- Symptoms of B deficiency have been observed by all respondents
- Most forest companies are monitoring foliar B in young stands (range of 2 to 8 years when fist sampled)
- Many companies are resampling foliage after B fertiliser addition (1 to 6 times after up to age 15 or depending on rainfall.
- Fertiliser B is applied to prevent tip dieback and as an insurance against summer drought.
- There are a range of criteria used to apply B fertiliser such as standard practice (0 to 5 years of age) and foliar B concentrations (6 to <14 ppm).
- Forests within an estate are treated differently
- Ulexite at 6-7 kg B/ha is the major B fertiliser currently used.
- Budgets do affect fertiliser addition decision making.

GENERAL DISCUSSION

The two objectives of this project were to provide the framework for a Boron Decision Support System and to identify key areas of boron in forestry that require further research to enable the development of a comprehensive B DSS in the future. It will be important that the final B DSS design fits in with development of other DSS within the NZ Forest Site Management Cooperative.

Boron Decision Support System framework

The framework, on which a working DSS could be based, consists of a number of key factors that influence foliar B. The factors include rainfall, types and rates of B, silviculture, and site factors such as climate, soils, and weed competition. While some of the relationships are already generally accepted, such as the one between foliar B and rainfall, existing datasets will be used to validate the relationships for the wide range of environmental domains in New Zealand.

Accompanying the framework are a set of fact sheets which have been developed to provide forest managers with relevant and up-to-date information about the management of B nutrition in New Zealand forests. These fact sheets will be updated as new information comes available from the NZ Forest Site Management Cooperative trials and the published literature.

The questionnaire indicated that forest mangers have modified the prescribed standard practices for managing foliar B, as described by Will (1985), to reflect regional differences. For instance, modification included the range of foliar B concentrations (i.e., 6 to <14 ppm) used as criteria to determine the application B fertiliser.

The B DSS framework will provide a sound set of rules and guidelines to support this.

Identifying key areas of boron nutrition for further research

The relationships influencing nutrition are many and interacting as highlighted in **Appendix 3**. However, the main factors appear to be those influencing B uptake particularly soil moisture availability. The current Forest Site Management Cooperative B trials, FR358, offer a huge opportunity to further B research particularly in the areas of rates of B addition, the interaction with genotypes, the effect of weed control and differences in climate and site. In addition, these trials can provide material to study the relationship between B and wood quality.

The validation of the relationships that are believed to influence foliar B may highlight new areas of B research.

GENERAL CONCLUSIONS

- The BDSS framework is based on relationships between foliar and a number of factors including rainfall, types and rates of B, silviculture, and site factors such as climate, soils, and weed competition.
- Existing data sets will be used to validate the relationships for the wide range of environmental domains in New Zealand.
- Recent data from historical trials show that soluble B fertilisers can maintain foliar B concentrations above control values in the long-term.
- Forest companies generally have a sound approach towards the management of B nutrition in their forest estate based on monitoring foliar B or using standard practice to determine the need for B fertiliser.
- The fact sheets developed in this project will provide relevant and up-to-date information about the management of B nutrition in New Zealand forests.

ACKNOWLEDGEMENTS

The authors acknowledge and thank the following members of the project team for their contribution: Mark Bryant, Nigel Heron, Greg Herrick and Bill Wheeler.

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Olykan, S.T.; Adams, J.A.; Nordmeyer, A.; McLaren, R.G. 1995 "Micronutrient and macronutrient uptake by *Pinus radiata*, and soil boron fractions, as affected by added nitrogen and boron". *New Zealand Journal of Forestry Science* 25(1): 61-72.

APPENDICES

Appendix 1: Fact sheets developed for the B DSS.

Please note that the most current copies of the Fact Sheets will be located on the NZ Forest Site Management Cooperative website.

FACT SHEET 1: ROLE OF BORON IN PLANTS

and boron uptake by plants

Boron uptake by plants

It is currently accepted that the uptake of boron into the plant is via the transpiration stream i.e., in the mass flow of water into the plant roots. This is 'passive' uptake. While evidence has been published suggesting that B may also be actively taken up by plants (e.g., Bowen and Nissen 1977[2]), Hu and Brown (1997) suggested that an unequivocal conclusion about the B uptake mechanism could not yet be made.

What form of B is taken up?

Boron is taken up into the plant as undissociated boric acid:

$$B(OH)_3 \text{ or } H_3BO_3$$

Boron in the plant

Once boron is in the plant, it is currently believed to be immobile in most species. This is commonly demonstrated by the symptoms of boron deficiency that appear primarily in the younger tissues. However, it has been shown that boron is mobile in species where polyols such as sorbitol, mannitol or dulcitol are the primary photosynthetic products. In these species, boron is transported in a complex with polyols (Brown and Hu, 1996; Brown and Shelp, 1997). It has been shown that environmental conditions affect the boron mobility by influencing which sugar is the primary photosynthetic product. When polyols are not being produced in high quantities in these species, the amount of boron transport goes down significantly (Delgado *et al*., 1994).

Once B has been taken up, the process of B absorption is a passive diffusion of free boric acid into the cell followed by the rapid formation of B-complexes within the cytoplasm and the cell wall (Hu and Brown 1997).

Role of boron in plant processes

The question of boron's function in plants is difficult to approach for a number of reasons:

- for most plant species the concentration range of boron required for optimal growth is fairly narrow,
- different species have different boron requirements,
- because boron is a micronutrient the plant requires very small amounts of it to function normally, and
- there are many physiological disorders that result from removing boron. These disorders can occur rapidly, making it difficult to identify the primary response from other consequent, or indirect, responses.

Boron has a key role in many plant processes including:

- flowering, germination & fruiting
- cell division at the meristem
- elongation growth of primary and lateral roots
- cell wall development
- protein synthesis (nitrogen metabolism)
- sugar translocation
- salt (nutrient) absorption
- hormone movement and action

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[2] References are in Fact Sheet 11: Boron Bibliography.

- water relations of cells
- pollen germination
- carbohydrate synthesis
- transport of nutrients across cell membranes
- metabolism of pectins
- calcium efficiency within the plan

Boron in forestry

In forestry, B is currently the micronutrient that receives the most research input. While B is essential to plants and has been identified as a key nutrient in many important plant metabolic processes, there are still many questions remaining about the potential role of B in wood formation (see **Fact sheet 3**) and how B deficiencies (in association with climate) and imbalances between B and other nutrients may affect wood 'quality'. These questions are being investigated in the NZFSMC Boron trial series, FR358 (see **Fact sheet 9**).

FACT SHEET 2: BORON DEFICIENCY IN RADIATA PINE

and the effect on tree form and growth

Boron deficiency in radiata pine

History

Boron deficiency was identified in forest trees (especially planted pines and eucalypts) in the 1960's in many countries: Africa, Australia, Brazil, Chile, Columbia, Fiji, Madegascar, Malaya, New Guinea and New Zealand (Stone 1990[3]).

Important points

- Boron deficiency is the most common micronutrient limitation in forest plantations (Stone 1990).
- The meristematic tissues require a low but continuous supply of B/ Even a single dieback episode leaves persistent stem defects (Stone 1990).
- Plants low in boron are generally more susceptible to frost and drought (Borough *et al*. unpublished).
- Damage to the vascular system of the roots and shoots, as a result of B deficiency, results in reduced water flow and subsequent tip die-back.
- There is a relatively narrow range between deficiency and toxicity.
- Genetic variation in susceptibility to boron deficiency is apparent but the potential has not yet been utilised (Stone 1990).
- Brackke (1983) theorised that B deficiency stress was "released" by drought, frost, and interaction with other nutrients. In other words, a stress situation can trigger the development of symptoms of an existing B deficiency.

Symptoms of deficiency

A range of symptoms has been associated with B deficiency in pines:

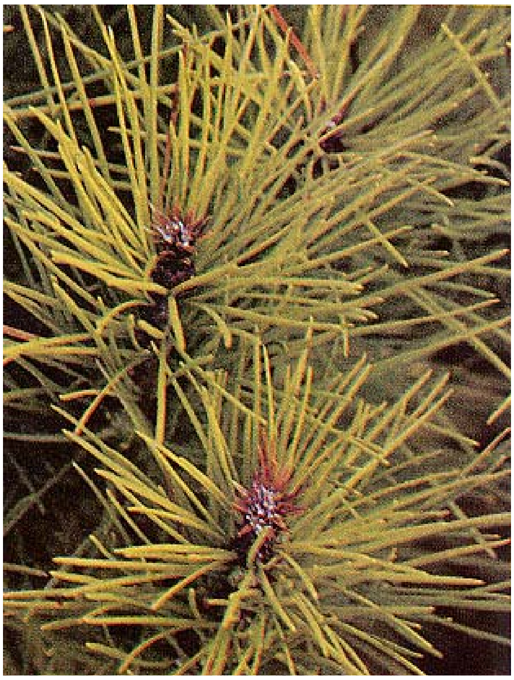
- resin bleeding visible on the stem
- disturbances to the terminal bud which is small, malformed or dead
- swelling, bending, cracking of the stem
- butt sweep
- death of the leader (characteristic inverted 'J')
- multiple stems
- 'wavy' branches and main stem (sinuosity)
- darkening of the pith and formation of cavities in the pith
- Needles near the affected tips are often short and deformed and may be discoloured (e.g. completely yellow).

Symptoms may progress until the tree is dead. This has been called 'red death of pines' where the needles turn reddish brown in dry periods (Crane and Borough 1987).

[3] References are in Fact Sheet 11: Boron Bibliography.

Pictures from Will (1985):
tip dieback, inverted ‘J’,

cross-section of dead shoot & yellowing of needles.



NB: resin on stem and dead buds

Boron deficiency has an adverse effect on tree form

← "Bushiness" due to leader die-back. Lateral branches were no longer suppressed. (Photo: Tarawera Forest)

'Hockey stick' trees → Tip dieback results in stem core defects which are revealed after pruning

In older trees B deficiency continues to affect form (Will 1985).

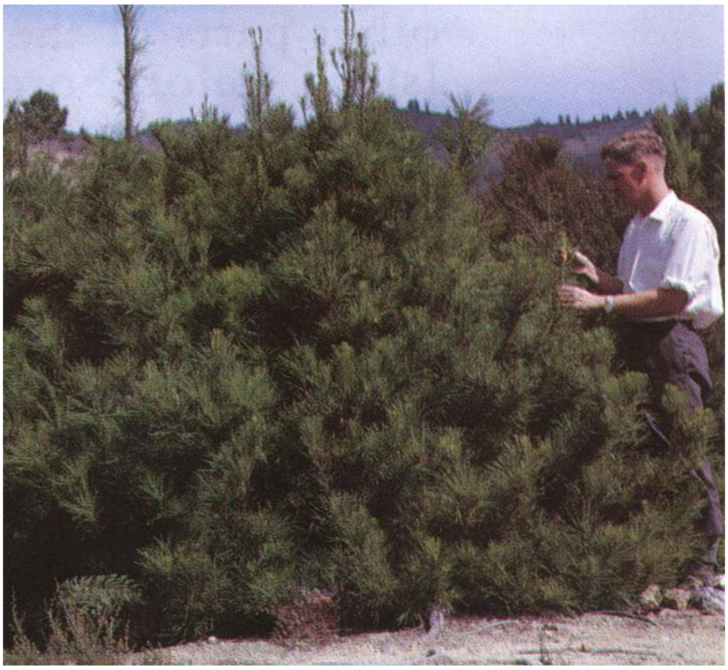
In these trees, leader death has resulted in the development of basket whorls. Sinuosity (twisting) is clearly visible in the main stem.

In 1987, Borough *et al*. (unpublished) noted that some stands of radiata in eastern Australia had such poor form, which was believed to be associated with boron deficiency, that they were unmerchantable.

Boron deficiency has an adverse effect on tree growth

Growth, in terms of height and dbh, and therefore volume, can be severely affected when B deficiency is serious and ongoing. The continual dieback of the growing tip and the subsequent proliferation of multileaders prevents the development and growth of a 'normal' tree.

8 year-old radiata pine 'bushes' ➔
(Will 1985)



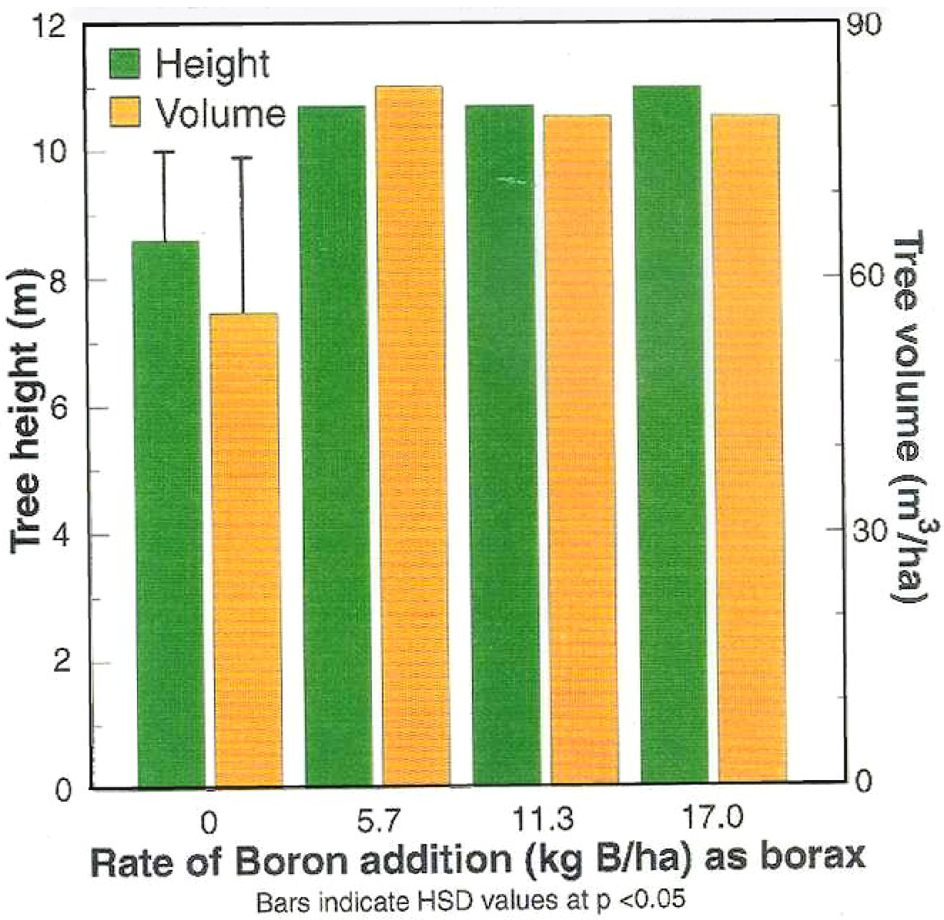
Hopmans & Clerehan (1991): Effect of borax-Boron on radiata form and growth

Background

In Australia, boron was added as borax (0, 5.7, 11.3 & 17 kg B/ha) to radiata pine at age 2. The trial was measured at age 8.

Results:

- Boron addition increased the % of trees with single leaders.
- Boron addition increased tree height (+ 2.1 m or + 24%) & volume (+ 25 m3/ha or + 42%) compared to the control. ➔
- No differences were found between the rates of added boron. All rates resulted in values significantly greater than control.



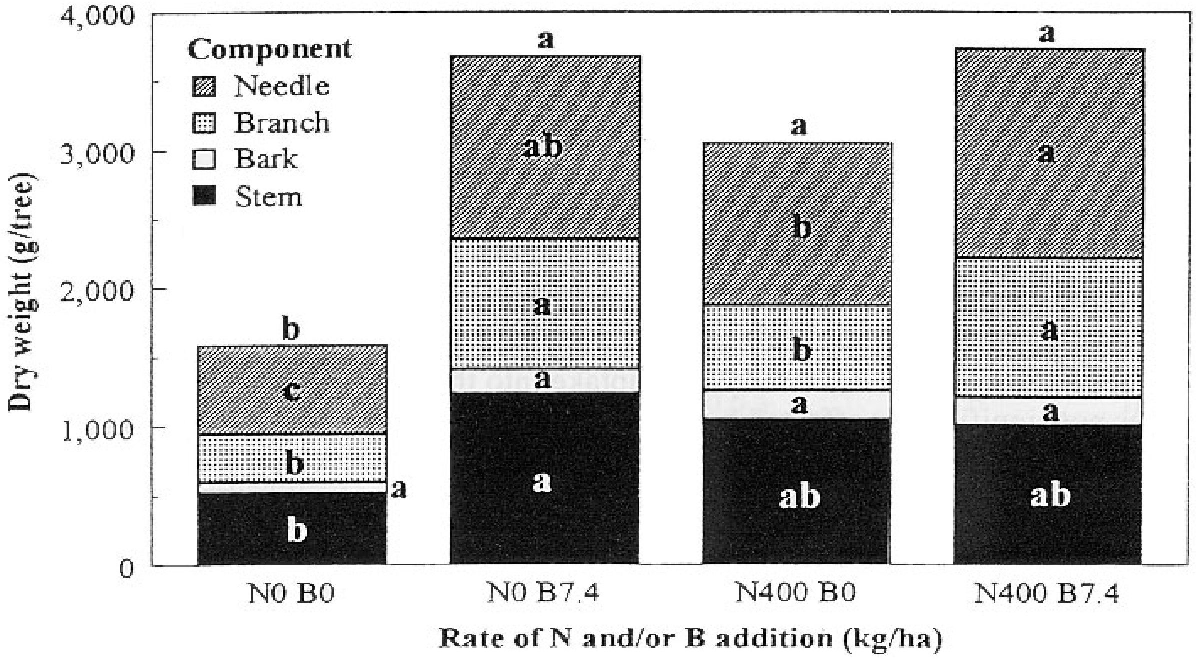
Olykan *et al.* (1995): Effect of boron and nitrogen on radiata biomass

Background

A N by B trial was installed in a 3 year-old radiata pine stand in Ashley Forest, Canterbury. Boron was added as ulexite. One year later, 3 trees from 4 of the treatments in Block 1 of the trial (on a ridge top) were biomassed. The treatments were N_0B_0, $N_0B_{7.4}$, $N_{400}B_0$ and $N_{400}B_{7.4}$.

Results

- There were significant above-ground dry weight responses to both N and B addition alone and together. The addition of B alone (i.e., $N_0B_{7.4}$) resulted in a greater weight of needles, branch, bark and stem compared to the control (N_0B_0).



Three years after fertiliser addition the whole trial was measured. No significant tree height or diameter responses to N or B addition were found. It is believed that the biomass response to B (and N) addition identified by Olykan *et al*. (1995) was probably due to the location of the biomassed trees on a ridge top. Soil nutrient availability and depth on the ridge were at their lowest, for the site, and potential responses to fertiliser addition were likely to be greatest.

Boron uptake increased more than four-fold after B application. Significant increases in B uptake occurred in all four biomass components in nearly all age classes, but most markedly into current and one year-old growth (Olykan 1993).

Effect of boron on root growth

Lambert and Turner (1977): "Severe B deficiency in *Pinus* species… also the roots are reduced in size and number."

Borough *et al*. (unpublished) suggested that the effect of B deficiency on roots was tip death with the formation of new roots behind the dead tip resulting in club-like root tips and poor root development.

It is believed that where there is severe B deficiency:

- less soil volume is exploited by the tree roots so water and nutrient uptake is reduced.
- trees may be less stable (dependent on factors such as the root:shoot ratio, rooting depth, planting stock etc.).

Boron, root growth and nutrient & water uptake

The above comments suggest that boron addition will improve root growth and therefore the uptake of nutrients and water from the soil. In an indirect way, the data of Olykan *et al*. (1995) support this. They found that total nutrient uptake was improved where B alone was applied to young radiata trees. While N and N+B addition also promoted radiata growth in this study, these treatments did not result in an increase in total nutrients. Hopmans and Clerehan (1991) found similar results where the uptake of N, P and K was higher in trees that had received boron fertiliser six years earlier.

One can therefore speculate that the difference in nutrition was the result of an increase in the rooting ability, and therefore nutrient uptake, of the B treated trees. However, there were no root measurements taken to support this. While there are indirect indications of the effect of B on roots, there is currently no direct quantitative scientific data relating to forest trees.

Boron, root growth and stability

There is a need to research the effect of boron on the root growth of growing trees. The FR358 boron trials offer an excellent opportunity to study the effect of boron fertiliser addition on tree root growth.

Boron has often been linked with tree stability and toppling. There are many issues that affect a trees tendency to topple and these probably relate to the structure of the soil – available rooting depth, soil moisture, impact of site preparation on bulk density - as well as the shoot:root ratio and general nutrition of the growing trees. There is also evidence that the kind of planting stock used in some situations (cuttings better than seedlings) significantly affects tree stability.

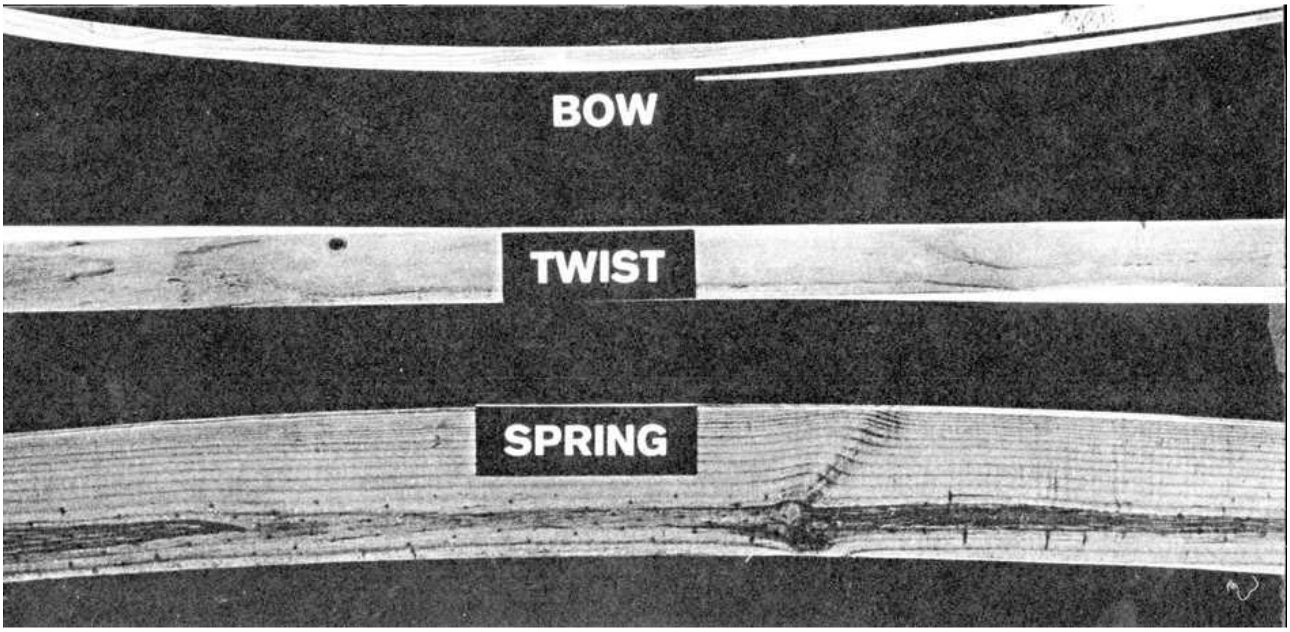
FACT SHEET 3: BORON AND WOOD FIBRE PROPERTIES

The anecdotal evidence

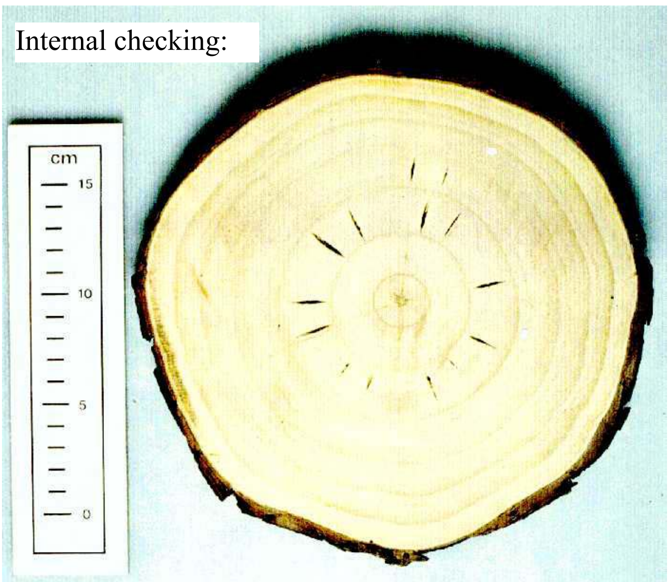
There is anecdotal evidence supportinging the positive effect of B on forest trees is associated with wood properties. This has originated from the observations of foresters and saw millers, particularly on the East Coast of the South Island, there is no scientific data to support these specific allegations.

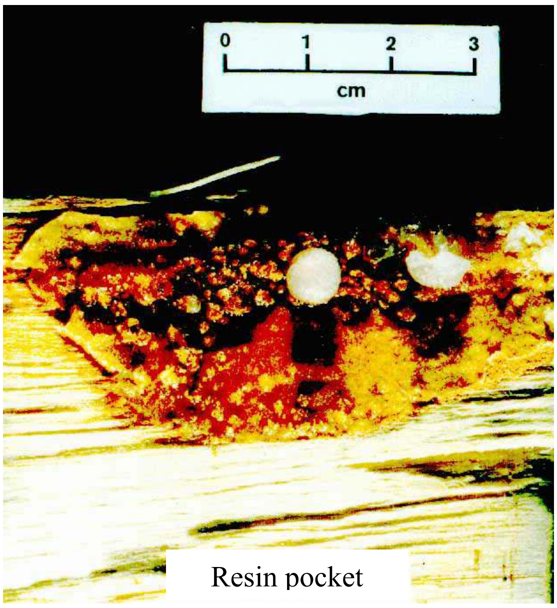
What is the anecdotal evidence?

The milling of trees that had not received B fertiliser and were grown in areas prone to B deficiency resulted in 'banana' wood.



Internal checking and resin pockets were not evident in the wood, in cross-sections of tree, which had been laid down after the trees had received boron fertiliser.

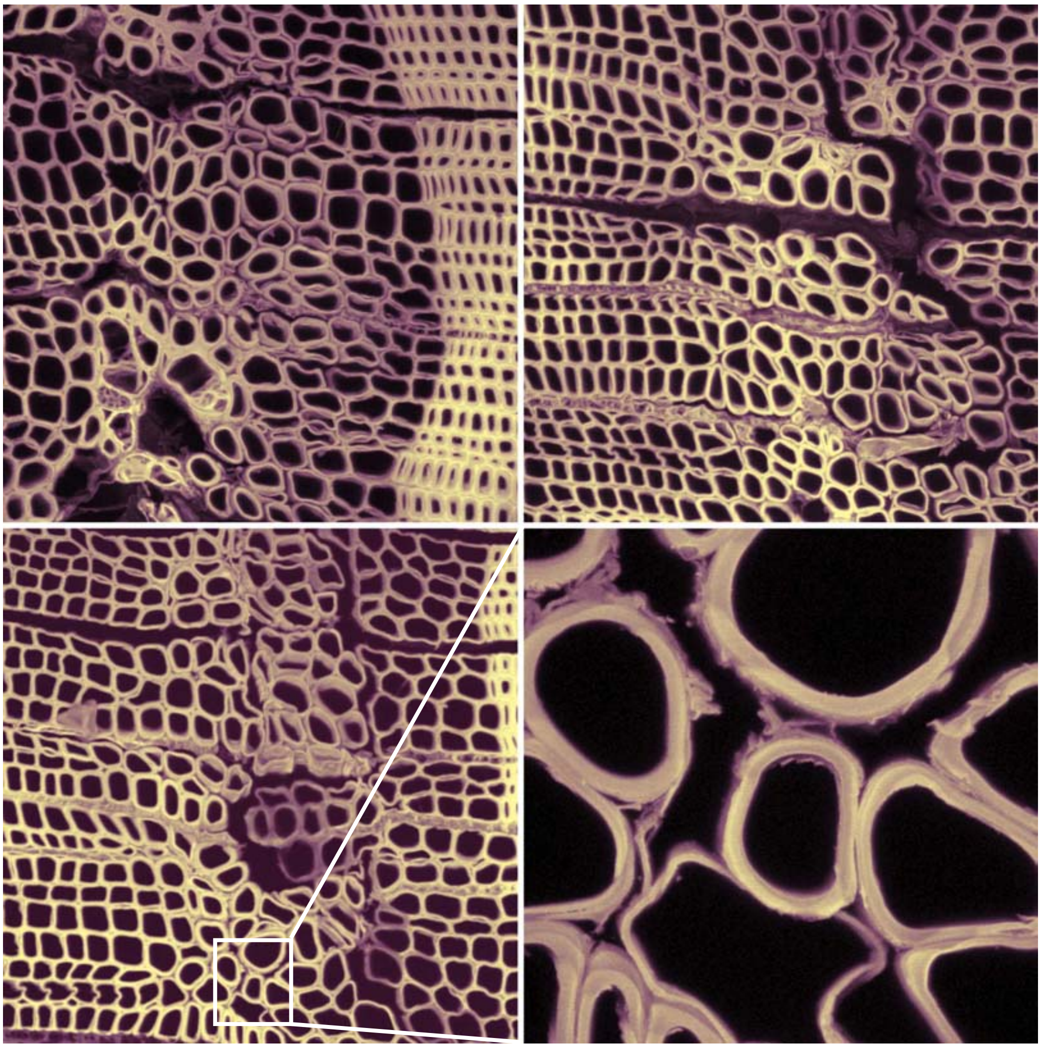




Radiata Log with Shelling

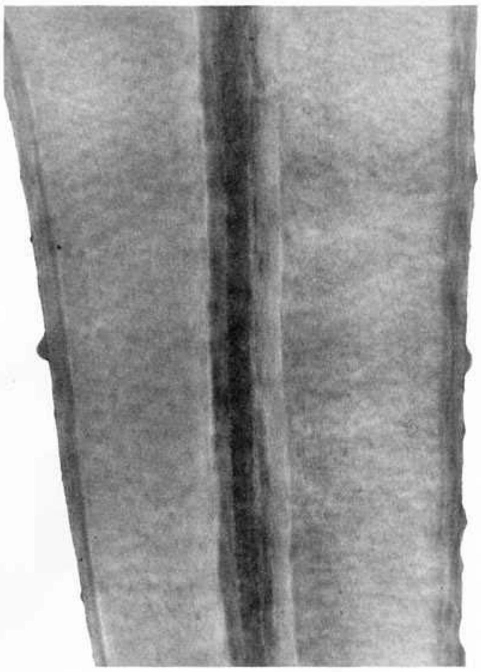
This log came from a sandhill site and had been subjected to periodic severe drought. The shelling was due to formation of bands of partially lignified traumatic tissue.

There is a link between drought and boron nutrition.



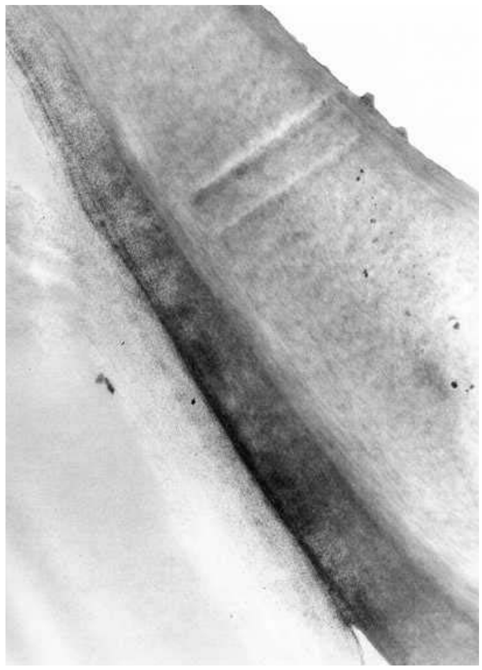
Electron microscope images of the cross-section above. Note separation of the cell walls symptomatic of tracheid collapse and separation of tracheids from each other.

Normal wood in a non-checking tree



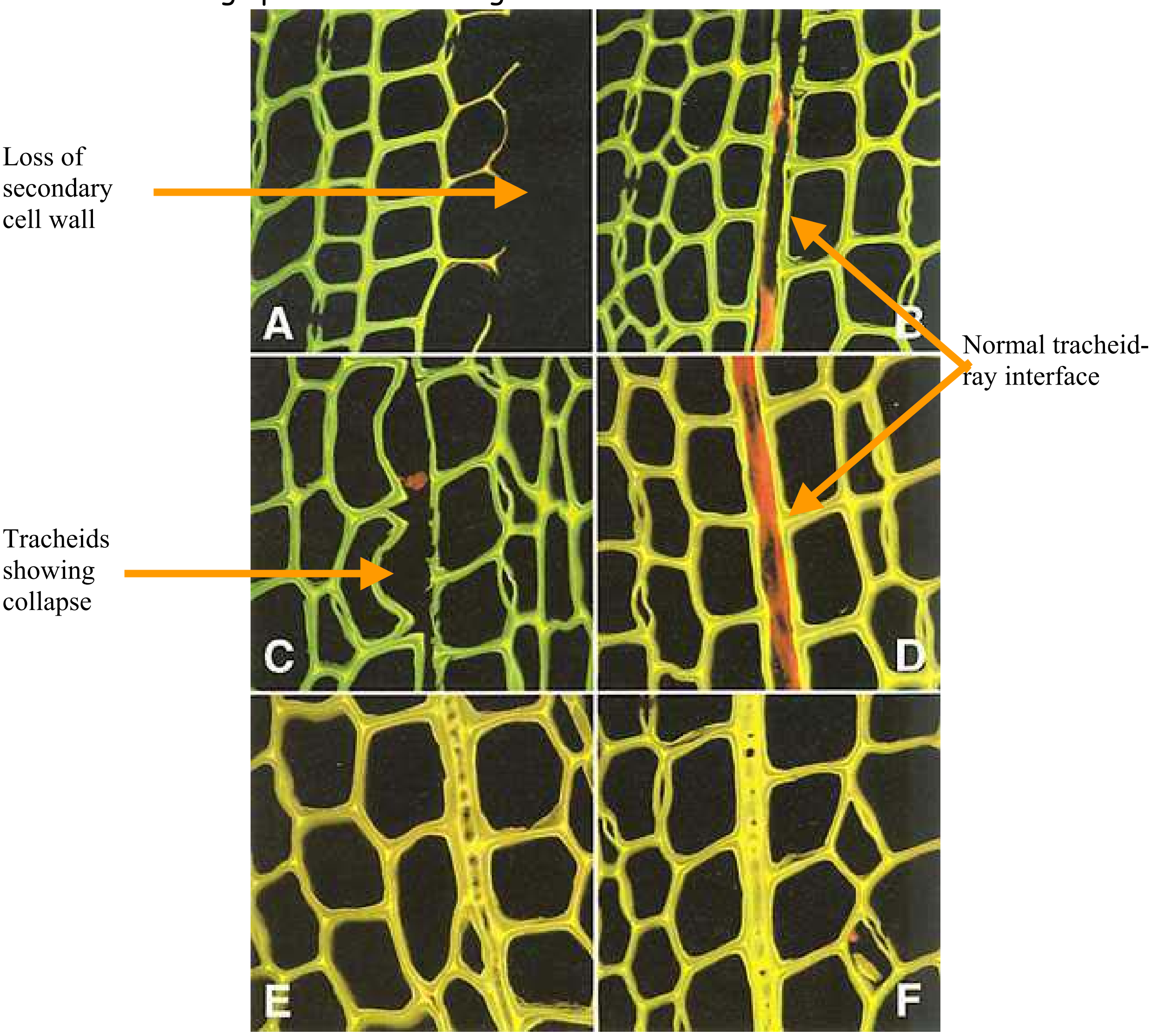
- dark and even middle lamella
- typical cell wall layers and lignification

Wood from a checking tree

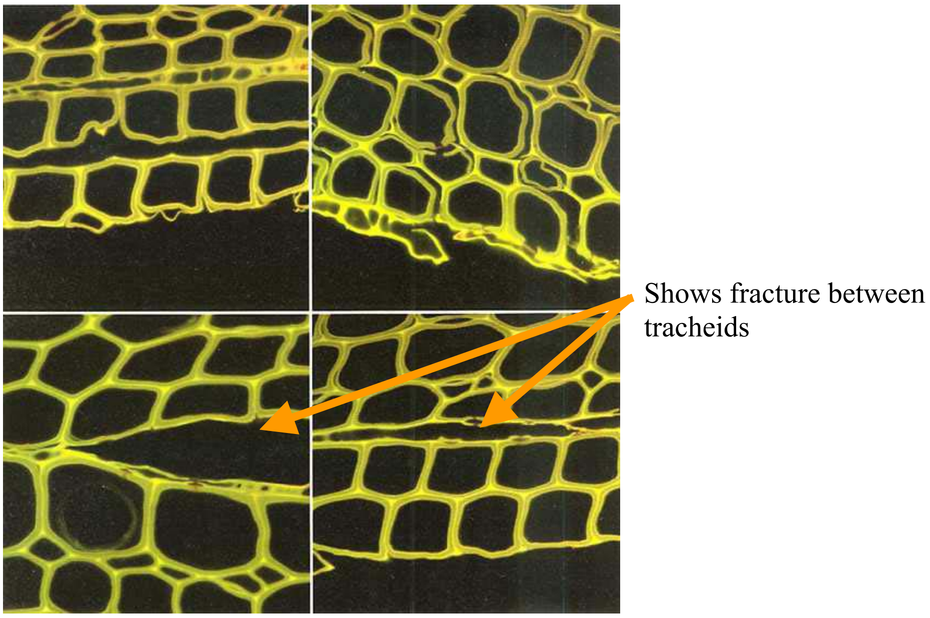


- middle lamella less dark and very patchy
- cell wall is unlignified

Tracheids in rings prone to checking



Tracheids adjacent to internal checks

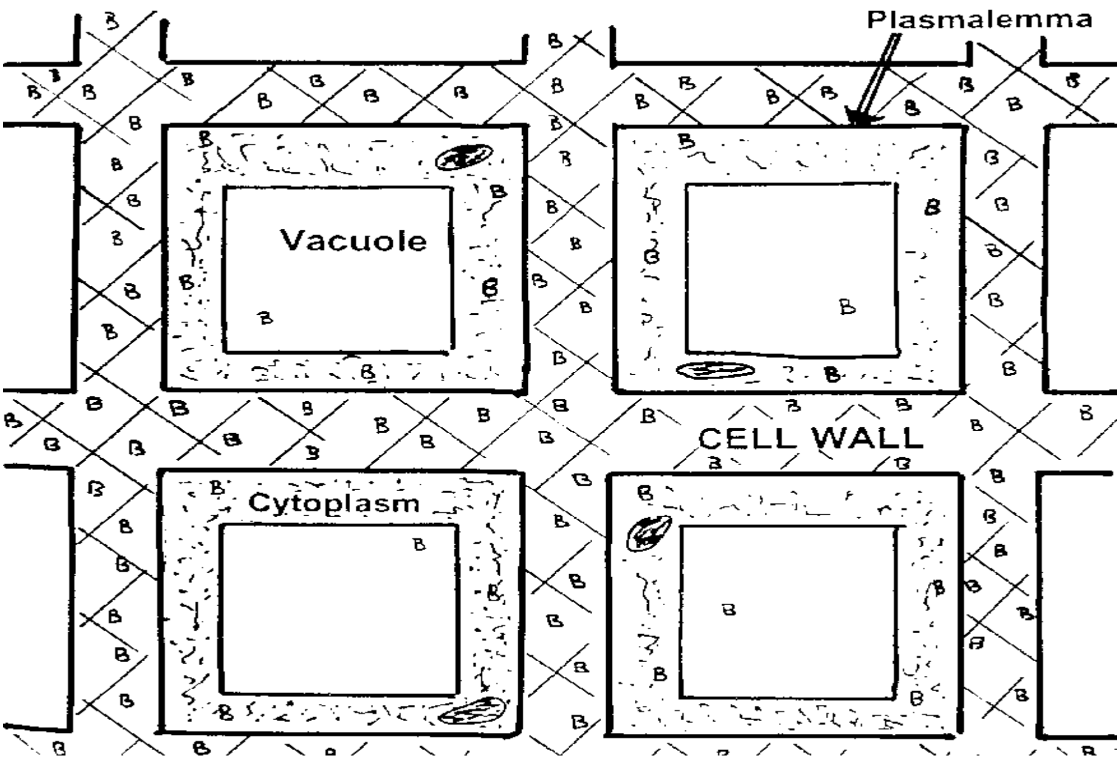


The anecdotal evidence suggests that boron is involved with the strength and structure of the cells that make up wood in trees. In order to understand the role of B it is necessary to look at the cellular structure of wood and, more specifically, the way that cells are bonded together.

Evidence for structural role for Boron in the Cell Wall

- majority of cell B is associated with pectins in cell wall (Hu and Brown 1994),
- cell wall extensibility greatly reduced under B deficiency (Hu and Brown 1994), and
- cell wall polysaccharides cross-linked by boron (borate-diester bonding) (Kobayashi *et al*, 1996).

In the cell walls, boron is incorporated into the hemi-cellulose fraction and has role in the structural element of cell walls:



Boron complexes with pectins (Matoh *et al*. 1993, Hu and Brown 1994) and these cell wall components play an important role in early cell wall development. O'Neil *et al*. (1996) found that boron cross-linked with Rhanogalacturanan-II, a pectic polysaccharide, in cell walls. Under boron deficient conditions primary cell walls become inelastic which inhibits meristematic growth and leads to cell death.

In the process of lignification, low boron levels inhibit lignin formation from phenolics.

A scientific study

Skinner *et al.*: Boron addition improved cellular structure and strength

Background

This study investigated the quantitative effect of boron deficiency on the wood cell characteristics of radiata pine (Skinner *et al*., in preparation).

The site was located at Ashley Forest in Canterbury. It was planted with radiata pine in 1982. An experiment (CY581), which compared borax fertiliser with different types of ulexite fertiliser at 6 kg B/ha, was established in 1984. The design was a randomised complete block with 3 replications. At the time of wood sampling (1990) the trees were age 8 years. The affect of the B fertilisers on foliar B is described in Olykan *et al*. (2002).

Results

Foliage analysis indicated that the control (no B) had B concentrations ranging from 7-14 ppm compared to 20 ppm where B fertiliser had been applied indicating the B nutrition of the trees was different.

Quantitative effect of boron deficiency on wood cell characteristics (Skinner *et al*., unpublished data). There were significant differences between boron treatments on tracheid[4] dimensions in early and late wood (see table below).

	Fertiliser B		Statistical test	
	No	**Yes**	F ratio	Pr>F
Tracheid properties for earlywood				
Tracheid length (mm)	2.7	3.0	1.6	0.332
Lumen diameter (µm)	**23**	**30**	22	**0.043**
Cell wall thickness (µm)	5.6	7.5	6.6	0.123
Tracheid properties for latewood				
Tracheid length (mm)	2.1	2.4	7.6	0.110
Lumen diameter (µm)	10.5	15.4	15	0.062
Cell wall thickness (µm)	**6.7**	**8.4**	29	**0.032**

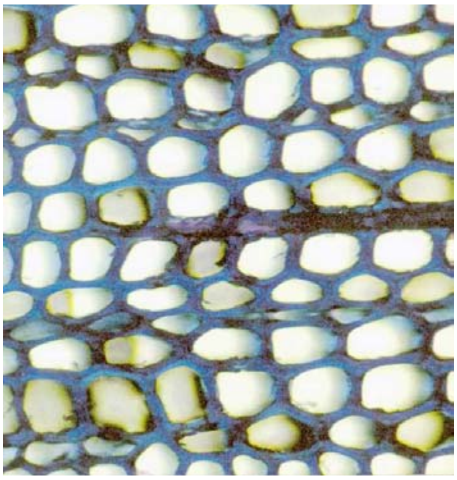
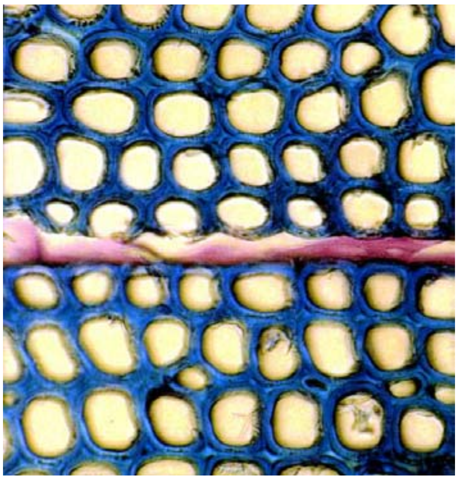
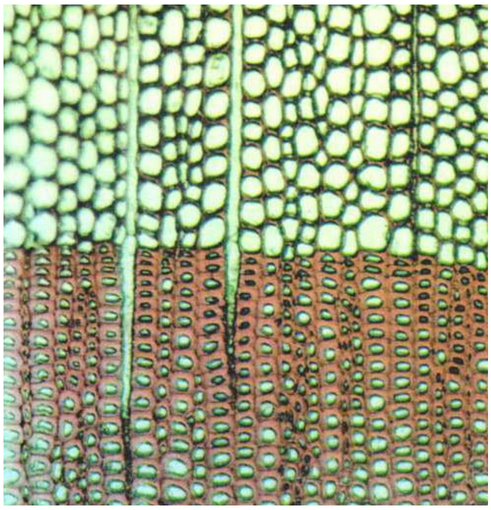
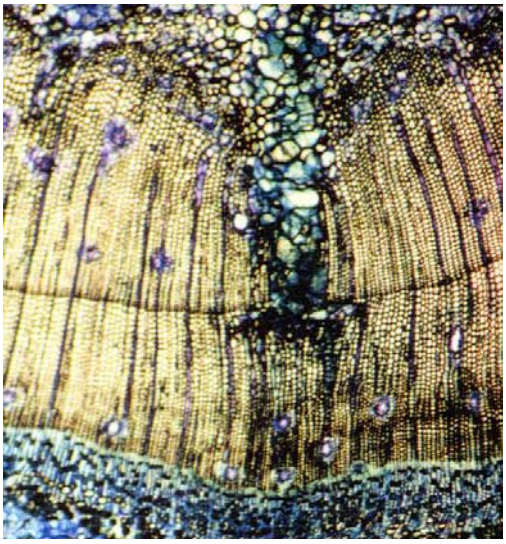
In early and late wood the lumen[5] diameter was significantly larger where B fertiliser had been applied.

Photomicrographs of sections of young radiata wood (next page) indicate that the addition of boron resulted in reduced cell wall distortion (during the slicing of wood for this procedure), good staining of the cell walls with a lignin-specific stain, distinct growth rings and normal rays.

[4] A tracheid is a non-living element of the xylem formed from a single cell. The cell is elongated with tapering ends and has thick, lignified and pitted walls. It is a long, empty, firm-walled tube running parallel with the long axis of the tree, overlapping with adjacent tracheids and in communication with them by the pits. Their function is water conduction and mechanical support.

[5] The lumen is the space or cavity enclosed by the cell wall.

Photomicrographs of sections of young radiata wood:

No boron applied	**Boron applied**
 Cell wall distortions; poor lignin staining.	 Little cell wall distortion; good lignin staining
 Growth ring indistinct; poor lignin staining	 Growth ring distinct
 Abnormal rays[6]	 Normal rays

[6] A ray is a radial band of cells traversing the conducting elements in woody stems.

Future research

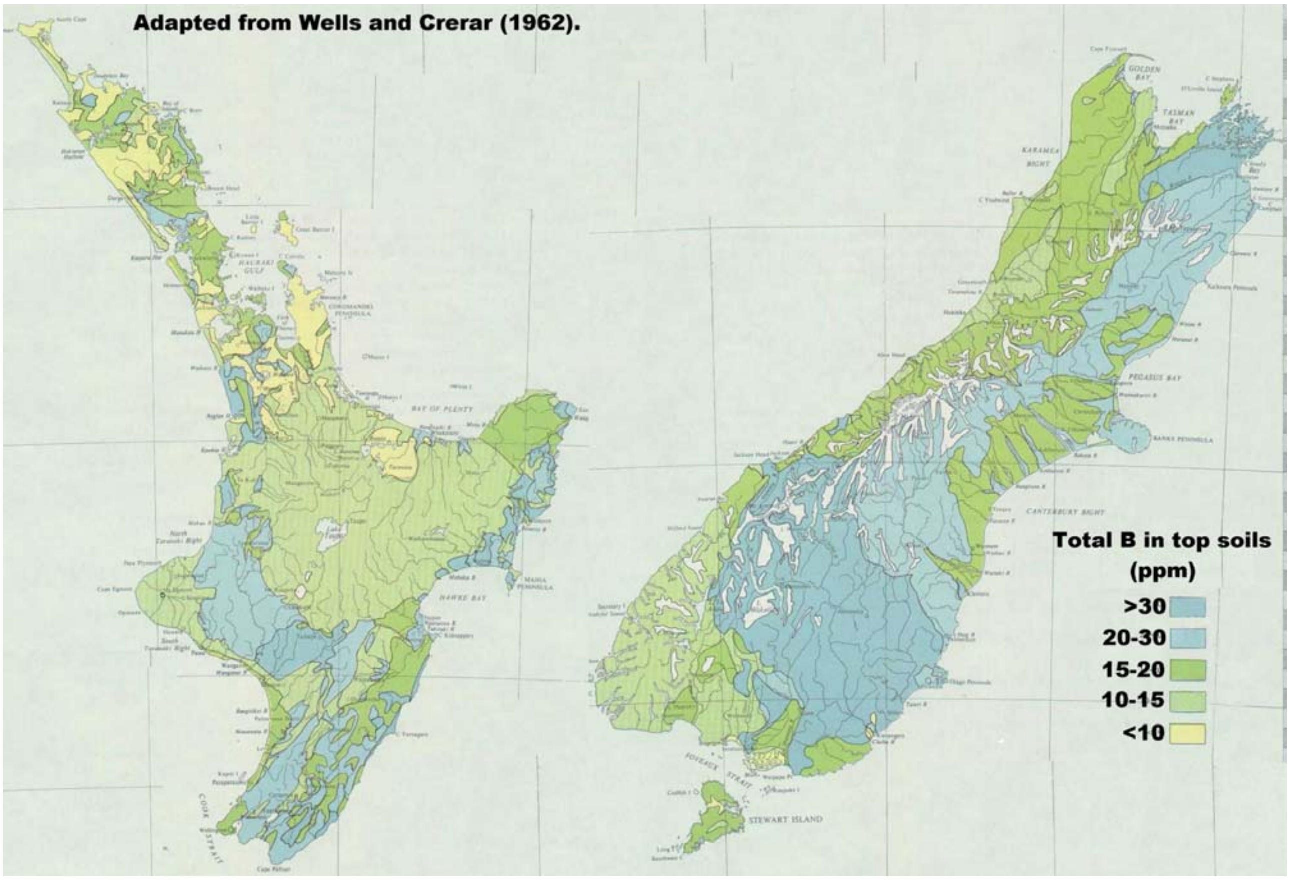
The FR 358 series of B trials, installed by the NZ Forest Site Management Cooperative, will offer an opportunity to study the effect of B on cellular structure and wood fibre properties in known genotypes of radiata grown with different rates of B addition. Biomass studies in two trials (FR358/1, Balmoral Forest in North Canterbury, and FR358/2 in Lake Taupo Forest) are scheduled for the winter of 2002.

FACT SHEET 4: SOIL BORON

and the role of rainfall/soil moisture in B availability

Total boron in NZ soils

A 'Total B in top soils' map for the North and South Islands was developed by Wells and Crerar (1962)[7] based on 100 samples representative of soil types nationwide:



However, total soil boron maps are not a guide to identifying areas where trees may suffer from boron deficiency. Boron deficiency is common in areas of high total boron in the South Island and unknown in areas of low total boron in the north of the North Island (Hunter *et al*. 1990).

The amount of total soil B varies across NZ and depends on many interacting factors such as:

Soil parent material

Kankama and Sahama (1950, cited by Lambert & Turner 1977) found that the boron concentration of igneous (volcanic) rocks was generally low (1-10 ppm) compared with those of marine sediments (20-300 ppm). This difference was replicated in soils derived from these parent materials and in the trees growing in the soils (Lambert & Turner 1977).

Climate (rainfall)

Highly leached soils (which occur in high rainfall environments) lose boron from the profile. The boron moves down with the drainage water and out of the rooting zone. These soils are therefore more prone to boron deficiency because the amount of available boron for plant uptake can be very small even thought there is no shortage of soil moisture.

Age of soils (amount of weathering)

Old soils have undergone prolonged weathering, which is closely related to leaching. Weathering of minerals produces constituents, such as basic cations and boron ions, which are leached from the soil. The loss of basic cations causes soil acidification, which enhances the weathering of the soil (McLaren and Cameron 1990). As weathering and leaching continue, the soil profile changes.

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[7] References are in Fact Sheet 11: Boron Bibliography.

Nearness to coast (inputs from sea spray/rain)

Sea water spray contains 4 to 5 ppm of boron (Reimerr Herrmann, pers. comm.). Blakemore (1953) suggested that boron deposition in New Zealand could range from 50 g/ha/yr in exposed coastal positions to 5 g/ha/yr or less in inland areas.

Management of soils

Soil disturbance

Soil disturbance at times of forest harvest and replanting can have a detrimental affect on the amount of boron in the soil. The loss of organic layers (e.g. Ballard and Will 1981) and the loss of the surface mineral soil (Ballard 1978) can reduce the amount of soil boron.

Addition of fertiliser not containing boron

The addition of macronutrients can induce boron deficiency symptoms by affecting the availability and uptake of boron from the soil and by dilution (i.e., foliage is significantly increased in size and boron concentration declines).

Pruning and thinning

This can be a positive impact, as the breakdown of slash returns nutrients to the soil. This may be a significant input in stands that have been previously fertilised with boron.

Soil properties that affect B

In the soil solution, boron is present in a non-ionic form $\{B(OH)_3\}$, and is not attracted to soil colloids. It is among the most mobile nutrients in the soil, and can be rapidly leached once released from soil minerals and organic matter. There are a number of soil properties that affect the availability and uptake of boron from in the soil.

Organic matter content

Soil organic matter is the major reserve of B in many soils. Boron is released as the soil organic matter decomposes. Soil disturbance, as mentioned above, can result in B because disturbance accelerates the breakdown of organic matter. Indirectly, organic matter is also involved in the retention of soil moisture and improvements in soil structure, which will affect boron uptake.

pH

The amount of plant available boron declines as soil pH increases above 6.5.

Soil moisture

Wetting and drying cycles increases B adsorption (fixation) in the soil. Large amounts of water moving through the soil profile will leach boron out of the plant available zone.

Soil texture

In sandy or gravelly soils the tree is more susceptible to boron deficiency than on soils with higher clay content. Clays retain boron against leaching but it may be their ability to raise a soil's moisture holding capacity that is the important factor (Hunter *et al.* 1990).

Detrimental interactions with other nutrients

Calcium

The effect of calcium on B is indirect as the soil pH higher, where lime has been added or in limestone soils, makes B less available.

Potassium

High levels of potassium can accentuate B deficiency symptoms (South *et al*. 2001).

Nitrogen

High levels of soil N, such as those in ex-pasture sites, have been associated with fast tree growth rates. In some instances this has been associated with an increase in the amount of growth deformities such as stem twisting and bending, multi-leaders etc. Boron, and other micronutrients, have been implicated. It is believed that the tree demand for B is greater then the soil's ability to supply and/or for the trees to take up.

The affect of N is probably indirect because of an imbalance in the availability of N compared to other nutrients such as Mg, Cu and B. High pastures often have high amounts of P and K in the soil and these macronutrients may also have a role in the development of growth deformities.

Role of soil B testing

Forest soil testing is not commonly carried out in New Zealand as forest nutrition is generally monitored by foliage sampling.

Why test the soil?

Soils may be sampled and tested for the following reasons.

<u>New site for forestry.</u>

The use of a soil test in this situation would depend on the development of a strong relationship between a soil B test and B uptake. This would indicate whether the site was susceptible to B deficiency. Such a relationship has not yet been satisfactorily developed and would depend on additional information about rainfall.

<u>Monitor B in the soil.</u>

This may become important for certification and sustainability reasons.

What 'portion' of soil B is routinely analysed?

At present soil samples can be analysed for:

- Hot-water soluble B (HWS B) which reflects the 'plant available' fraction of B in the soil.
- Total soil B.

A number of other methods have been developed but the relationship between B extracted by the soil test and plant uptake have been poor and site specific.

Using results from soil testing

What can we do with soil B data? In the future for a forest site it may be necessary to:

- Develop relationships between soil B & plant uptake of B for a forest site.
- Identify critical soil B values (i.e., when to add B)
- Monitor soil B over time to ensure levels are being sustained.
- Quantify the amount of added fertiliser B that has been retained in plant-available fractions in the soil.

How long does the fertiliser elevate soil B levels?

Climatic factors influencing B

Rainfall is the key climatic factor affecting B availability

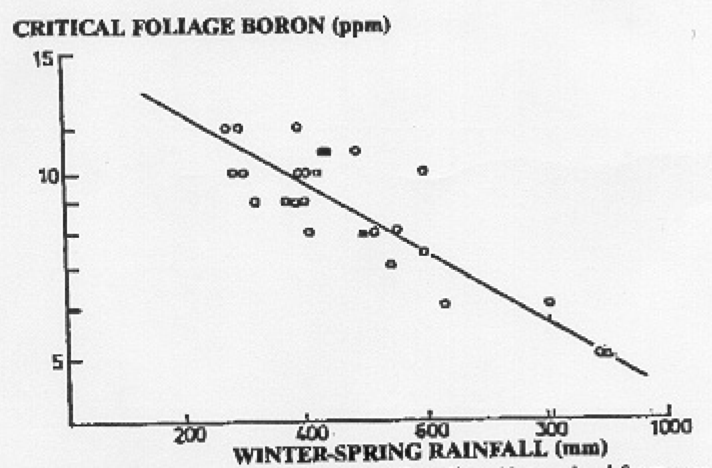
As noted by Hunter *et al.* (1990) boron deficiency symptoms appear in the driest part of the year and the majority of boron deficiency symptoms are in low rainfall districts. Symptoms are worst in drought years and are only recorded in the North Island in exceptionally low rainfall years.

Why is rainfall important?

- Rainfall influences soil moisture and therefore affects water (and B) uptake by trees.
- High rainfall can leach B through the soil profile.
- Rainfall near to the coast can include B from sea spray.

What are aspects of rainfall are important?

- summer droughts in some areas.
- growing season rainfall (winter/spring) may be reflected in foliar B (Feb/March) and potentially affect the critical foliar B concentration for an area as shown in the following graph from Lambert and Turner (1977):



Critical foliage boron concentration in *P. radiata* (determined from presence or absence of dieback) and winter plus spring rainfall. The open circles are from a wide range of sites in New South Wales, Australia.

- where rainfall distribution across the year is relatively even, there is no interruption in B supply to the trees.

Temperature

Temperature affects B availability indirectly through its influence on soil processes, such as organic matter breakdown, and evapotranspiration (i.e., water loss from the soil).

What are the high-risk areas for B deficiency?

- Soils with low total B (therefore low plant available B) e.g. leached, acidic soils; soils low in organic matter
- Soils with low moisture holding capacity e.g. light textured soils such as sandy soils, soils low in organic matter
- Areas with low rainfall
- Areas at risk from summer drought
- Calcareous or over-limed soils i.e. soils with high pH
- Soils containing high amounts of nitrogen (and possibly phosphorous and potassium).

FACT SHEET 5: MONITORING FOLIAR BORON

and variation in critical concentrations

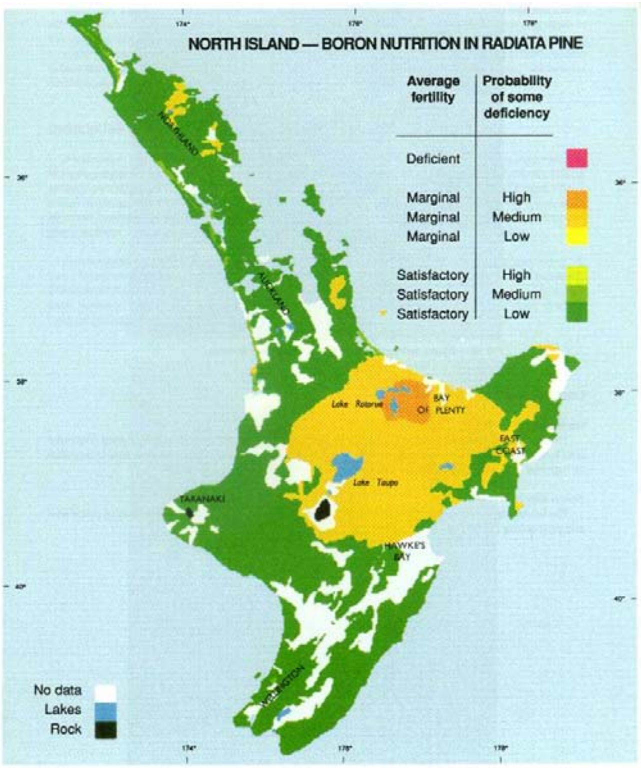
Some general facts about boron in forest trees

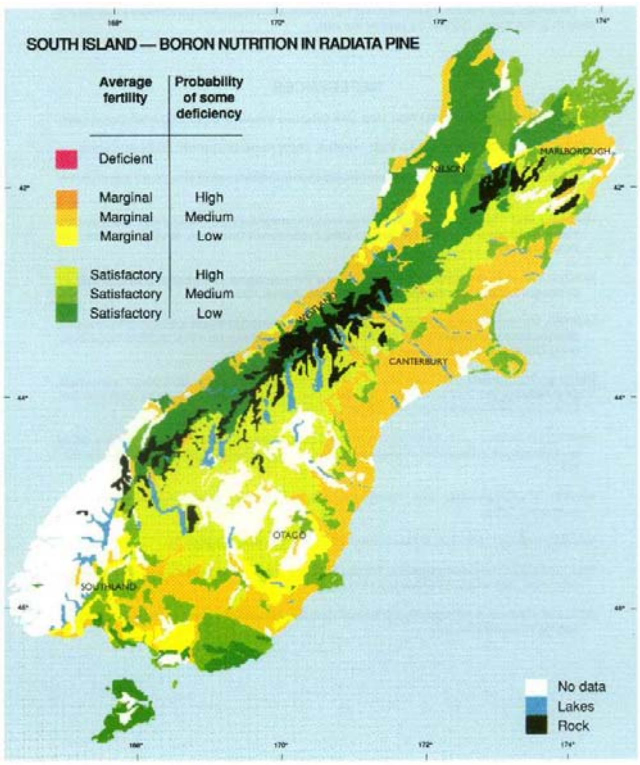
- Average accumulation of B in radiata biomass over a 30 year rotation is between 30 and 50 g/ha/yr (Madgwick *et al*. 1988[8]).
- The proportion of B immobilised in the wood is about 2-3 ppm (Madgwick *et al*. 1988) and this concentration is equivalent to about 1/5 of that in the foliage (Stone 1990). This proportion of B is removed at harvesting.
- Ballard and Will (1981) found that B was the first nutrient to be depleted to near deficiency in a whole-tree-harvest/litter-rake study.

Boron nutrition across New Zealand

The nutrient atlas (Hunter *et al*. 1991) highlighted the following generalisations about foliar B in radiata in New Zealand:

- Areas where there was good total rainfall (probably >800 mm) tended to have satisfactory foliar B concentrations with a low probability of deficiency (e.g. Northland, West Coast regions).
- Areas with low total rainfall (<800 mm) which were prone to summer droughts had marginal foliar B and a medium probability of deficiency (e.g. the East Coast of the South Island such as Marlborough, Canterbury and Otago).
- Some areas have low amounts of boron in the soil (regardless of rainfall) and marginal to low foliar B with a medium to high probability of deficiency (e.g. the central North Island plateau, Pakihi soils on the South Island West Coast). These soils may have developed from a parent material low in B or may be subject to a high rainfall regime that has leached the B from the soil.
- Light, textured sandy soils or stony soils, which are very freely draining and have a low soil moisture holding capacity, have also been prone marginal foliar B (e.g. Moutere gravel soils in Nelson, dredge tailings on the West Coast).





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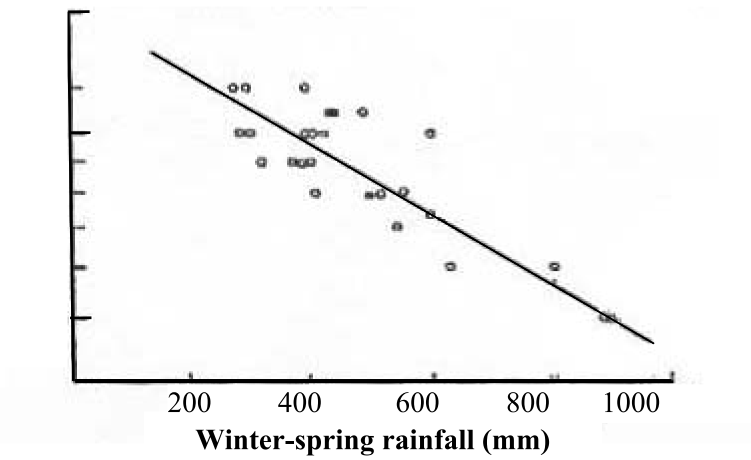
8 References are in Fact Sheet 11: Boron Bibliography.

In New Zealand, average foliar B concentrations are a reflection of rainfall in combination with the amount of plant available B in the soil.

Critical concentrations of foliar boron

Will (1985) described the critical levels of foliar B as 8 to 12 ppm. Below 8 ppm, B nutrition was 'low' or deficient, within the 8 to 12 ppm range B nutrition was 'marginal', and above 12 ppm B was satisfactory. The confidence rating associated with these critical levels was '**' meaning that there was good prediction of responsive sites in the low range but not in the marginal range. These critical concentrations for foliar B were aimed at the prevention of tip dieback.

Within a stand, foliar B concentrations can fluctuate from year to year. One explanation is the amount of rainfall as shown in the graph below from Lambert and Turner (1977):



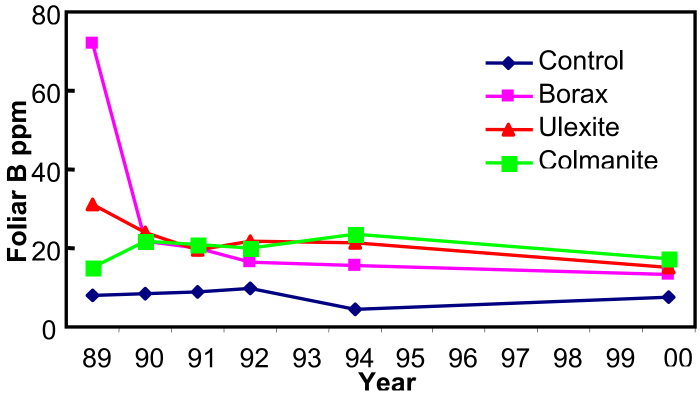
Critical foliage B concentration in P. radiata (determined from presence or absence of dieback) and winter plus spring rainfall. The open circles are from a wide range sites in NSW, Australia.

In making management decisions about B addition, rainfall clearly has an important role to play. This is already recognised for those forests in areas of high risk for summer drought which are routinely fertilised with B at a young age and foliar B concentrations monitored over time to ensure they remain adequate. In other areas, foliage sampling is periodically used to assess foliar B before decisions are made about B fertiliser addition.

Influence of fertiliser B on foliar B

The addition of B fertiliser can have a large and long-lasting affect on foliar B. The intial impact and the longevity of the effect depends on both the type (solubility) of the fertiliser and the rate of addition (Skinner *et al.* 2000).

Other studies have shown that the addition of B fertiliser elevates B concentrations throughtout the tree (Olykan *et al.* 1995).



Maintenance of adequate foliar boron

Ongoing, periodic foliage sampling to monitor foliar B concentrations should be used to assess the impact of B fertiliser addition on foliar B, the longevity of the response and determine if the reapplication of B is necessary. The relationship between foliar B and time after fertiliser addition may vary from forest to forest and seasonally.

Refining critical thresholds for foliar boron

When considering the management of B, there are a number of questions that need to be answered in relation to the end-product required from the forest, the level of silvicultural management and the risk associated with summer drought.

End-product required from the forest

Crop purpose

- Pulp: minimise B nutrition? (i.e., less energy required to breakdown cell walls).
- Framing: maximise B nutrition?

Wood and wood fibre properties

- Minimum and maximum levels of foliar B will be determined.
- B by genotype interactions examined (sugar alcohols).

Both the final crop purpose and the future development of relationships between boron nutrition and wood fibre properties may indicate that different foliar B thresholds are required compared to the management of B nutrition to prevent tip dieback.

Managing B in the forest

There are two growth phases in the rotation that need to be considered:

Pre-crown closure

- Choice of B fertiliser type – soluble versus insoluble – may depend on intended level of silviculture.
- Ensuring adequate P nutrition.
- Maintaining adequate weed control at establishment (critical in areas with low rainfall and/or a high risk of summer drought).

Later in the rotation

- Litter and slash from silvicultural operations returns B to the soil (B mineralisation).
- B retranslocation (internal source of B within the tree). Influence of genotype? This is the subject of current research.

Risk scenarios - current and future

Tip dieback/malformation expressed through:

- Drought: the lower the risk of summer drought the lower the foliar B intervention level.
- Nutrient interactions: ex-pasture sites and malformation (this area has yet to be adequately researched).
- Frost: high growth rates and out of season frosting. Has been identified as a problem but not examined in detail in New Zealand.

Future foliar boron thresholds

The following are some suggested rules for managing B nutrition using foliar B concentrations.

Foliar threshold level for visual symptoms of boron deficiency

- Where foliar B >15 ppm, deficiency unlikely
- If rainfall is low, site is drought-prone and foliar B is 8-10 ppm, apply B
- If area is not prone to drought (Southland and Northland) and foliar B is low (4-8 ppm) deficiency symptoms will not be expressed
- B fertilising as INSURANCE against dieback – essential in low rainfall areas with a high risk of summer drought.

Foliar threshold level for crop purpose or wood fibre properties

These have yet to be determined.

Research directions

To manage foliar B with more certainty it will be necessary to understand the effect of climate (e.g. seasonal rainfall and the impact on soil moisture) and B fertiliser rates on long term foliar B and develop tools within a B DSS to develop relations for individual forests.

FACT SHEET 6: BORON IN ALTERNATIVE SPECIES AND FOREST TREE GENOTYPES

Boron in Alternative species

Boron deficiency symptoms in tree species

Eucalypts and pines are among the species most sensitive to B deficiency & responsive to B application. The following outlines B deficiency symptoms for a range of forest tree species.

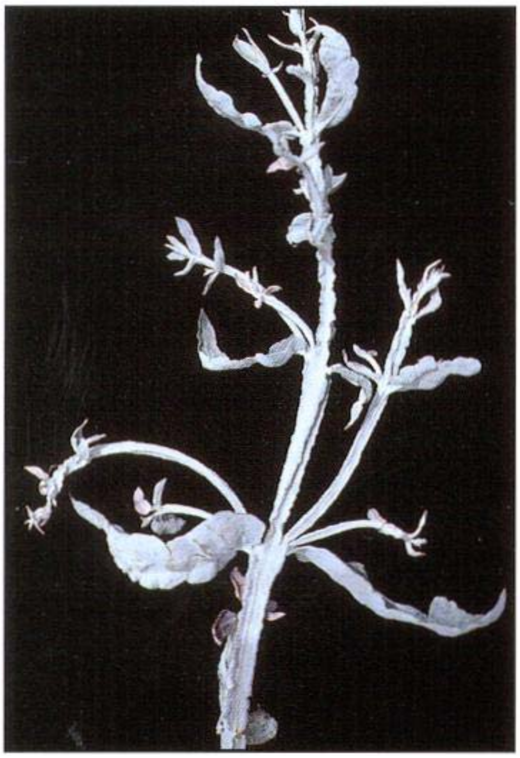
Pines: Bud, tip and shoot die-back, usually of main leader first, followed by shoots on upper branches. Stem 'crooking'. Pith brown.

Douglas fir: Bud, tip or shoot die-back. Distorted leaders. Brown pith. Stem swelling.

Eucalypts: Die-back of young shoots on top of crown. Old leaves may abscise prematurely. Bark may show bleeding.

Cypress: Die-back and cessation of vertical growth. Trees may become bushy.

Blackwood: Die-back of main shoot and subsequently laterals near apex. Stem distortion. Trees may become bushy.



🡐 Stem distortion in 1 year-old *Eucalyptus globulus* grown in a pot trial without B. (Photo:

Breakdown of stem apices in boron deficient *Eucalyptus camaldulensis.* (Photo:)➔

'Deficient' and 'adequate' Foliar B levels

Across a range of forest tree species, the critical foliar B concentration recognised as deficient can vary greatly. Examples in the following table show a 'deficient' range from 6 ppm in *Pinus pinaster* to 20 ppm for Black walnut. ➔

SPECIES	DEFICIENT	ADEQUATE
Blackwood	12	
E. delegatensis		14
E. fastigiata		14
E. globulus	10	15
E. nitens		10
E. regnans		19
E. saligna		25
Black walnut	20	50
Pinus contorta		15
P. nigra		20
P. pinaster	6	16
P. radiata	8	12
Douglas-fir	12	15

Foliar B levels in Douglas-fir.

The table below highlights the variation, of foliar B in Douglas fir stands, with age and location in the South Island. Foliar B concentrations were deficient/marginal on the Mesopotamia and Tekoa and marginal to adequate on the Tekapo, Makerikeri and Kaikoura/Tekoa soils. 🡻

Boron and forest tree genotypes

Location	Soil	Stand age (years)	Foliar B (ppm)	Rating
Ribbonwood	Kaikoura/Tekoa	11	21	Adequate
Coleridge	Tekapo	62	13-20	Marg-Adeq
Glen Lyon	Mesopotamia	52	9	Deficient
Bridge Hill	Tekoa	10	5	Deficient
Trig E	Tekoa	15	10	Deficient
Trig E	Tekoa	29	13	Marginal
Ashley Forest	Makerikeri	19	29	Adequate
Ashley Forest	Makerikeri	44	16	Adequate

What is a forest tree genotype?

Within a forest tree species there are different provenances, breeds, families and clones within a forest tree species can represent a forest tree genotype.

The potential role of forest tree genotypes

There are examples in the literature of forest tree genotypes varying in their ability to absorb, transport, use, store, and retranslocate nutrients. This offers the opportunity to identify genotypes that are efficient at absorbing or using specific nutrients under conditions where those nutrients may be limiting. Future research within the Sustainable Management of Forest Ecosystems programme will focus on the diversity of nutrient-use characteristics in forest tree genotypes of radiata pine, Douglas fir and cypress.

Specifically, for B nutrition, there are questions around water-use efficiency and B uptake and the ability of genotypes to retranslocate, or move B around inside the tree, as a mechanism to reduce the impact of summer drought on B availability. These issues will be studied in the FR358 B trials where the genetic material is known and replicated across the three existing trials.

The effect of B on forest trees genotypes

Davis *et al.* (2001): Boron response in pine species and breeds

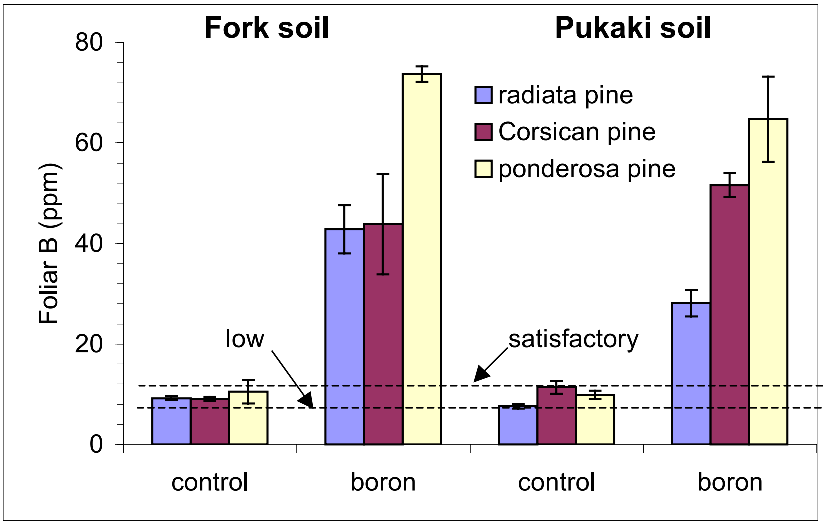
Background

This paper summarised a number of trials conducted in the South Island High Country with breeds of radiata pine, ponderosa pine (*Pinus ponderosa*) and Corsican pine (*Pinus nigra*) on a number of different soil types. The object was to identify fertiliser requirements (N, P, S and B) for the establishment of pines and Douglas fir in the High Country.

NB: Some of the following graphs were not published in Davis et al. (2001) but were presented by Murray Davis in the Boron workshops in 2000 and/or in a handout to the NZFFA meeting (14th April 2002) titled "Dryland Forestry, Balmoral Station, Lake Tekapo".

Results

Three years after application, B fertiliser (10g ulexite/tree) had increased foliar B levels significantly compared to the controls (**Figure 1, top graph**). Where B was applied, the foliar B response differed between the pines (Ponderosa pine was the most responsive) and there appeared to be a soil (or site) factor involved affecting the radiata pine response to B addition.



Seven years after B application, the foliar B levels had dropped substantially although they remained higher than the controls (**Figure 1, bottom graph**). Corsican pine had the highest foliar B levels where B had been applied. This contrasted with the results from age 3 where Ponderosa pine had the highest foliar B.

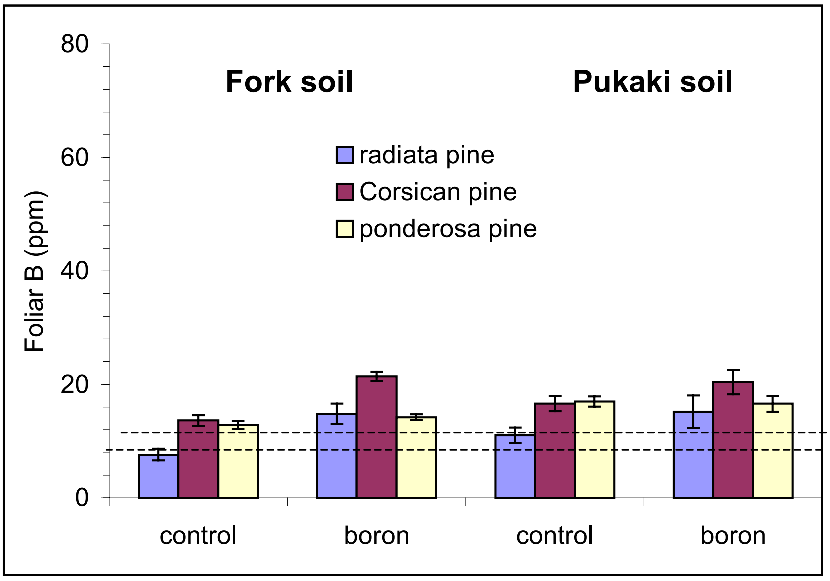


Figure 1: Effect of B fertiliser (10 g ulexite/tree) on foliar B concentrations at age 3 (top) and age 8 (bottom) on two soils. Foliage was sampled 2 and 7 years after application. The radiata breed is GF17.
(Vertical bars show standard errors).

On the Fork soil, some radiata breeds (GF25, GF28 and Guadalupe) showed a significant height response to the addition of B at age 7 (6 years after B addition, **Figure 2**). The smaller heights of *P. nigra* and *P. ponderosa* reflected their slower growth rates compared to the radiata breeds.

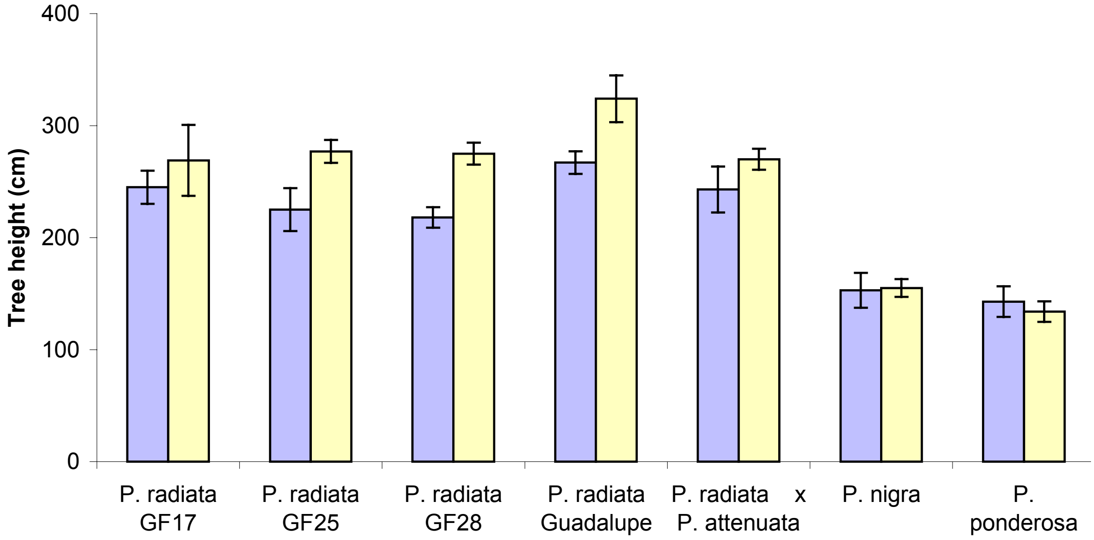


Figure 2: Height responses by radiata pine breeds, Corsican and Ponderosa pines to B application at age 7. Values are means of the Fork and Pukaki soils.

On the Fork soil, boron affected tree form at age 7 (**Figure 3**). Within the radiata breeds, B addition significantly improved the form of GF28, Guadalupe and *P. radiata* x *P. attenuata*. Radiata GF 28 had the poorest form without B addition. The better form of *P. nigra* and *P. ponderosa* may be a result of their slower growth rates compared to the radiata breeds.

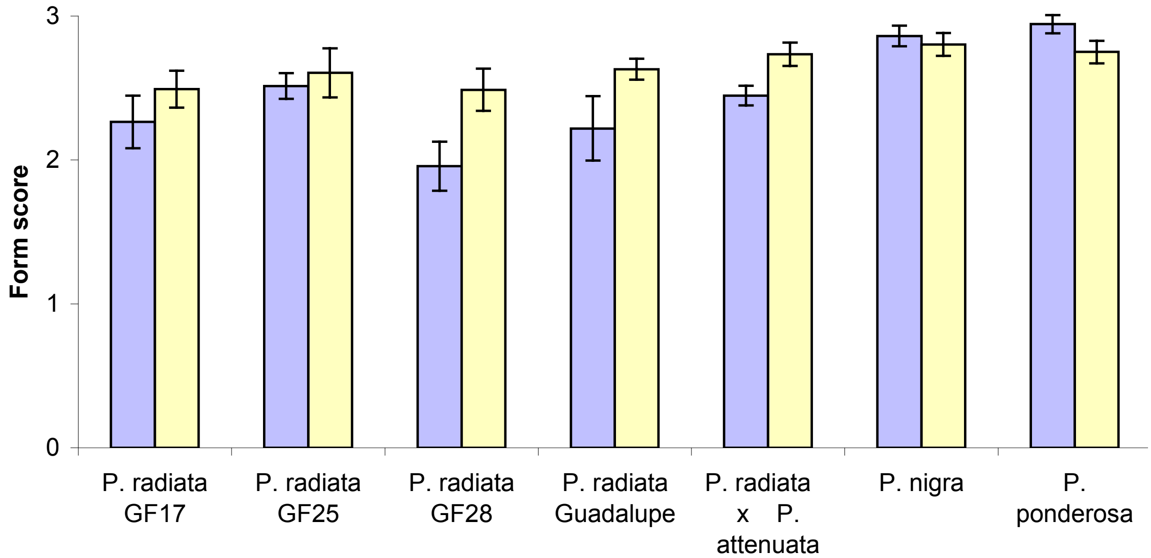


Figure 3: Form responses by radiata pine breeds, Corsican and Ponderosa pines to B application at age 7 on the Fork soil.

Radiata pine genotypes in the FR358 B trials

Results to date indicate that, while the affect of genotype was highly significant for growth at Balmoral and Lake Taupo Forests, there has been no interaction between genotype and rate of boron addition.

Routine foliage sampling has been carried out on a per plot basis so there is no information about the affect of genotype on foliar B response to rates of B fertiliser addition.

Current and future research

Research into radiata genotypes, which are efficient at taking up and utilising nutrients such as boron, is being developed. At this stage it is not known if boron uptake and use varies significantly between genotypes or if the development of 'boron-efficient' genotypes will be feasible compared to the many other nutrient-use traits that may have wider use (e.g. N or P efficiency). In the meantime, an increasing forest estate requires B fertiliser inputs to maintain foliar B concentrations. Forest sites also need B inputs to sustain soil B levels for future forest production.

The focus of current genotype research is on the influence of nutrition (and other site factors) on growth and wood properties.

FACT SHEET 7: TYPES OF BORON FERTILISER

Background

In the 1960's, boron deficiency was recognised in New Zealand (Will 1985[9]) and borax fertiliser was used to overcome the deficiency. Most of this work was with pines at time-of-planting, and the borax was applied (usually in a carrier fertiliser) either in a slit about 10 cm from the base of the seedling, and at a depth of about 10 cm, or as a broadcast fertiliser. This action was sufficient to raise foliar B concentrations to well above deficiency, but it was noticed that foliar B levels declined rapidly. This was a cause for concern. At this time the work was not monitored over the longer term.

In the mid-1980's, a comparison was made between borax and the less soluble B minerals colemanite and ulexite. Early results (first 3 years) showed that foliar B rose rapidly with borax fertiliser and then declined (still above critical level) whereas with the insoluble B minerals foliar B rose more slowly (to above critical levels) and appeared to stabilize (see Olykan *et al*. 2002). As a result of this work there was general consensus that the boron minerals were preferable to the soluble borax.

However, recent analyses from the older trial work with borax and boron minerals, and more recent work with the same fertilisers, has revealed another story. Over the long-term (10+ years) foliar B levels are almost comparable between the soluble and insoluble forms of B. These more recent long-term results can be explained by the release of B from slash (thinnings and prunings).

The contrast between B fertiliser types therefore is between ensuring the longevity of B in the soil (use of B minerals), and rapid movement of soluble fertiliser borax "above ground" for re-cycling. It could be argued that the latter approach with borax would therefore potentially minimise B leaching losses and maximize potential uptake (in the longer-term) by the crop.

In summary, both soluble and insoluble forms of B have their place in the nutrition of pines. The dominance of the mineral form in the current market place may be to some extent an artifact of the application of short-term research results to the needs of pine crops in the longer-term.

Chemistry of B fertilisers

Soluble B fertilisers, such as Borax, are sodium borates. Once applied, the mineral dissolves quickly when subjected to rainfall. Insoluble fertilisers are calcium borates. Between these two extremes there are minerals that both Na and Ca borates. The higher the Ca content the less soluble the fertiliser. The length of time that the mineral will remain on the soil surface will depend on factors such as granule size (or 'fineness'), rainfall, and temperature.

Boron fertilisers, such as those based on the ulexite mineral, can have a range of sodium:calcium ratios. Generally the Na:Ca ratio is about 1:2 to 1:3. Some products have been calcined (injected CaO or CaSO4) during granulation to slow down the release of B.

Boron minerals and fertilisers

Boron minerals

The following is a list of common boron minerals:

- Ulexite: $NaCa[B_5O_6(OH)_6].5H_2O$
- Borax: $Na_2[B_4O_5(OH)_4].8H_2O$
- Colemanite: $Ca_2[B_3O_4(OH)_3].2H_2O$
- Kenite: $Na_2[B_4O_5(OH)_4].2H_2O$

Boron fertilisers

The following are some of the boron fertilisers available in New Zealand.

[9] References are in Fact Sheet 11: Boron Bibliography.

Borax

Borax is sodium borate and contains 11% B. It is a fine crystalline product for dry application by hand to the soil, or application in solution to the soil or foliage.

- Fertiliser borax (also known as Fertiliser Borate) contains about 14.8% B as it contains less water i.e., $Na_2B_4O_7.5H_2O$.
- Borate Granular (14.3 % B) is a granulated fertilizer, making it more suitable for dry application by machine than Borax to the soil, on its own or in blends with other fertilizers.

Boronat

Chemical formula: $NaCaB_5O_9.8H_2O$. This is a proprietary formulation of ulexite (see below) containing about 10% B or 32% B_2O_3. The ratio of Ca to Na is not less than 1.6. Boronat is a granular product that has been developed for helicopter application in forestry.

Colemanite

Colemanite is a calcium borate mineral and has been used in New Zealand in historical fertiliser trials to represent a relatively insoluble form of B fertiliser. This mineral does not appear to be commercially available as a fertiliser.

Solubor

Chemical formula: $Na_2B_8O_{13}.4H_2O$. This fertiliser contains 20.5% B in a water-soluble form and can be applied as a dust or a spray. Solubor is more soluble than Borax, especially in cold water, and is the recommended choice for application in solution.

Ulexite

This fertiliser contains about 10% B. This fertilizer contains boron in soluble (sodium borate) and insoluble (calcium borate) forms in a ratio of approximately 1:3 ratio. Ulexite is used in forestry and other perennial crops on acid soils where boron is applied infrequently and long-term responses are required.

The following table can be found on the website:

Boron chemicals and fertilisers currently available in New Zealand:

Company name	Fertiliser name	Chemical formula	% elemental B content	% other key nutrients (e.g. N, P, K, Mg)	Type of chemical or fertiliser	Particle size (mm)	Price per tonne ($NZ)	Comments[1]
Example	*Borax*	$Na_2B_4O_7.10H_2O$	*11*	-	*Soluble*	*Fine*	*X*	*Highly soluble, 50g dissolves in 1 litre of water. Apply by hand to soil or spray.*

[1] Comments (e.g. special features of fertiliser, Na:Ca ratio, where produced and by which company, suitable for helicopter application, arsenic content etc).

FACT SHEET 8: UNDERSTOREY VEGETATION

competing for soil water and boron

Introduction

There is information showing the impact of weed control on tree growth already available within the NZFSMC[10]. In terms of B nutrition, the impact of weeds could be two-fold:

- competition for moisture that would reduce amount available for tree uptake and would therefore impact B uptake.
- competition for soil B. On a site where moisture supply id snot an issue, the uptake of B by an understorey may be significant if soil B supplies are low.

These impacts are likely to be most important during the early phases of the rotation prior to canopy closure. It is expected that after canopy closure, the understorey would be suppressed and the B it contained would be returned to the soil and become available for tree uptake. In some circumstances (e.g. for sites with a high rainfall), understorey could play a valuable role retaining added B for future use.

To assess the impact of the understorey, the following factors need to be investigated:

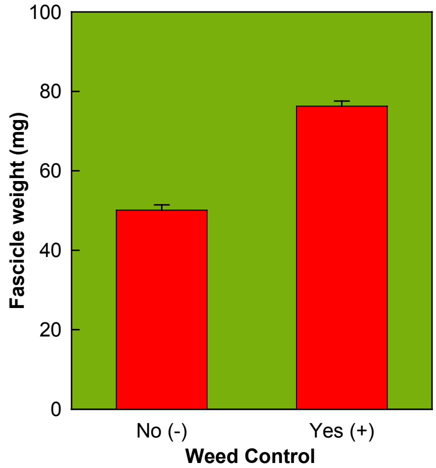
- differences between the major weed types (broom, grass, gorse, bracken etc)
- key limiting factor(s) for a site: soil moisture versus soil B availability.

More research is required to understand the impact of the understorey vegetation across New Zealand and the interaction with soil moisture and soil B.

Balmoral results (FR358/1)[11]

Nutrition

Weed control had a significant affect on fascicle weight. Weed control increased fascicle weight from 50 to 76 mg. Because of this, there was a significant increase in the amounts of nutrients/fascicle in the weed-free plots.



The effect of weed control on foliar nutrient concentrations varied. The concentration of N and B were increased while the concentration of P and Mg were slightly decreased. As a result of the decline in foliar Mg, the K:Mg ratio increased from 8.4 to 9.4.

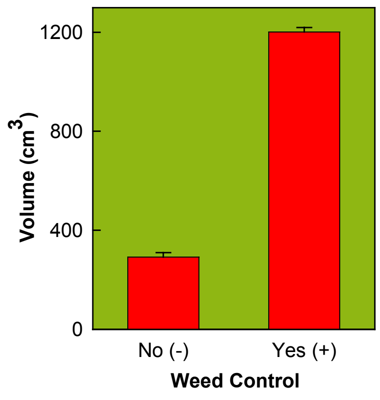
		Weed control treatment				
	Significance	No (-)		Yes (+)		Duncans
Variable	P	Mean	Std Err	Mean	Std Err	LSD
N (%)	0.0001	**1.22**	0.015	**1.32**	0.015	b a
P (%)	0.0234	**0.182**	0.0039	**0.169**	0.0037	a b
Mg (%)	0.0273	**0.107**	0.0022	**0.100**	0.0021	a b
B (µg/g)	0.0398	**38.4**	2.15	**44.9**	2.07	b a
K:Mg	0.0036	**8.4**	0.23	**9.4**	0.22	b a

[10] Peter Clinton's "Forest Weeds" DSS chart.
Brian Richardson et al. 2001 "Radiata growth responses to weed control at Tokoiti Forest – results after six years" NZ Forest Site Management Cooperative Report No. 115.

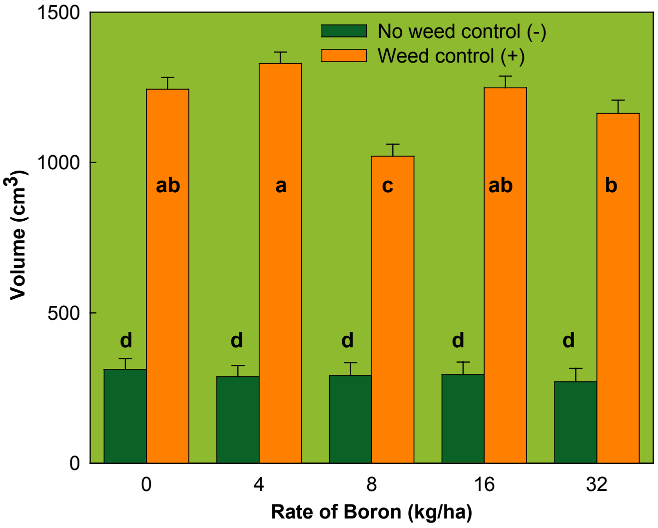
[11] These results are from "Balmoral FR358/1, Update sheet 2 (2002): Results from foliage sampling (March 2001), winter measurement (2001) and soil sampling (2001)".

Tree growth

Weed control had a huge impact (*p*<0.001) on tree growth. Height was increased by 50% (113 to 169 cm) and root collar diameter by 67% (29 to 49 mm). This resulted in a 312% increase in volume (292 to 1201 cm^3).



A further investigation of this results found that the interaction between Boron and weed control was highly significant for tree height (*p*<0.001) and volume growth (*p*=0.003). With no weed control, B16 reduced height growth compared to B0 (110 versus 118 cm). Where the weeds were controlled, B4and B16 had a positive affect on height (176 and 174 cm versus 167 in B0). Rates of B did not affect volume when there was no weed control, but with weed control the volume was significantly less in B8 than B0 (1021 versus 1244 cm^3).



Balmoral Forest has a low annual rainfall and a high risk for summer drought. The potential impact of weeds, especially for soil moisture, is high. On higher rainfall sites, the impact of weeds would be less on soil moisture. The potential to affect B uptake may depend on soil B availability.

Taupo results (FR358/1)[12]

Weed control had no affect on nutrition in 2001. There was a weal affect on tree height growth where trees in the weed control plots were slightly shorter than those with no weed control (2.08 versus 2.13 m).

[12] These results are from "Taupo FR358/2, Update sheet 2 (2002): Results from foliage sampling (March 2001), winter measurement (2000) and soil sampling (2001)".

FACT SHEET 9: THE FR358 BORON TRIAL SERIES

The New Zealand Forest Site Management Cooperative has funded and installed the FR358 B trial series. This project is called ‘Effect of Boron on Wood Quality’.

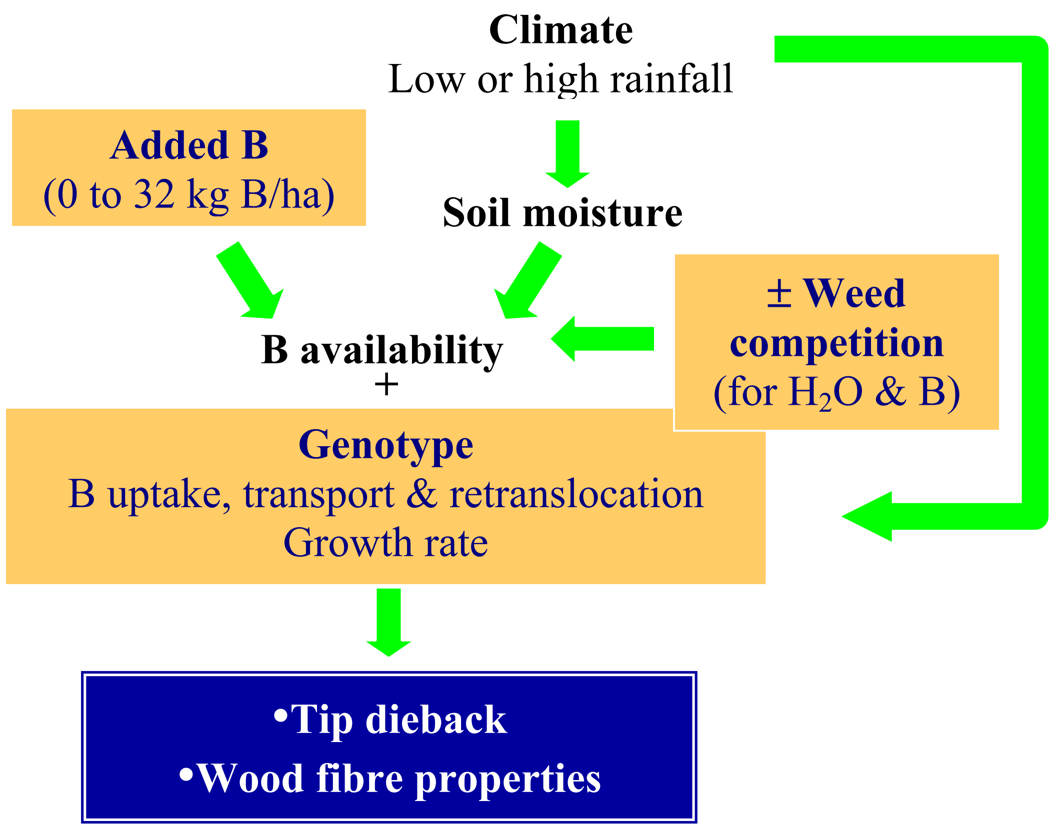
Objectives

The B trial series has the following objectives:

- To determine if the control of weeds improves B availability to trees by increasing soil moisture availability and decreasing competition for B.
- To measure and tabulate the spring and summer rainfall prior to foliage sampling in March as an aid in the diagnosis of foliar B concentrations.
- To determine if, and how long, the soil can act as a ‘reservoir’ for the added B.
- To study internal retranslocation of B and the effect this has on efficiency of B use and the longevity of response to added B.
- To document changes in wood cell characteristics and wood physical properties after B has been added to growing trees.

Trial design

The basic trial design is based on rates of boron (0, 4, 8,16 or 32 kg B/ha) by +/- weed control. An additional ‘optimum’ treatment (Nitrophoska + 16 kg B/ha and +weed control) was also included. These 11 treatments were replicated 4 times in blocks. The radiata pine material planted at each site is based on 8 specific genotypes: 5 clones Fletcher Challenge Forests and 3 families supplied by Carter Holt Harvey Forests. The genotype of each individual tree in the inner plots of the trial was mapped.



Specific background information and the installation details for FR358/1 and /2 have been described by Olykan *et al.* (2000) and Olykan *et al.* (2001) respectively. These details have been summarised in the following Update sheets:

- Balmoral FR358/1, Update sheet 1 (1998, revised 2002): Site details, trial design and plot layout.
- Taupo FR358/2, Update sheet 1 (2001): Site details, trial design and plot layout.

Location of trials

Site selection is based on a number of factors including rainfall (total annual), risk of summer drought, measurements of soil B and growth rates.

The series currently has 3 trials:
/1 Balmoral Forest, North Canterbury. Established in 1998.
/2 Lake Taupo Forest, central North Island. Established in 1998.
/3 Tekapo, McKenzie High Country. Established in 2000.

Results to date (2002)

Results to date have come from the Balmoral and Lake Taupo trials. These were based on winter growth measurements, foliage sampling and soil sampling. The results have been described in the following Update sheets:

- Balmoral FR358/1, Update sheet 2 (2002): Results from foliage sampling (March 2001), winter measurement (2001) and soil sampling (2001).
- Taupo FR358/2, Update sheet 2 (2002): Results from foliage sampling (March 2001), winter measurement (2000) and soil sampling (2001).

FACT SHEET 10: SUMMARY OF HISTORICAL BORON TRIALS

containing soluble (and other) B fertilisers

The following is a summary of major boron trials, or trials with a boron treatment, with forest tree species that have been carried out in New Zealand and overseas. The emphasis is on radiata but trials with other forest tree species, particularly those that have been conducted in the High Country, have also been included. Trial details are summarised in **Table 1**.

This Fact Sheet is still being developed. As information is collated from the archives or published, a summary or a copy of the paper will be provided on the website.

Results from historical B trials

FR24/1, Mariri (or Harakeke) Forest (Nelson)

CY 581, Ashley Forest

CY 451 McLeans Island

High Country trials

The results from these trials have been published by Davis *et al*. (2001) and are summarised in **Fact Sheet 6**.

NxB trial, Ashley Forest trial

Results from this trial can be found in Olykan 1993 and Olykan *et al*. 1995. A summary of the effect of B on growth has been included in **Fact sheet 2**.

Effect of Borax on tree form and growth (Australia)

- Results published by Hopmans and Clerehan (1991).
- Effects of B on growth and form reported in **Fact Sheet 2**.

Current boron trials:

Rerewhakaituu: FR24/2

- See NZFSMC Report 113
- B DSS report summary

NZFSMC FR358 series

A summary of these trials is provided in **Fact Sheet 9** and a range of other outputs (see the website)

High country Douglas fir trials

FR90

- FR90 is a multi-nutrient weed control trial with radiata and has plots with +/-B with and without weed control.

Details of major New Zealand forestry trials with boron as the main treatment:

Trial no.	**Forest**	**Location**	**Species**	**B fertilisers**	**Status**	**Outputs/papers**
FR24/1	Mariri/ Harakeke	Nelson	Radiata	Borax & others	Terminated	Graph of early results only
FR24/2	Rerewhakaituu	Rerewhakaituu	Radiata	Borax & others	Current	NZFSMC Report 113