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Technical Note

Growth responses to boron fertilisation in *Pinus radiata*

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Summary: Boron (B) deficiency is the most widespread micro-nutrient deficiency of forests in New Zealand. Boron deficiency may cause death of terminal buds and shoots, especially in dry areas and/or periods of drought, and stem malformation. Where trees are susceptible to B deficiency, B fertiliser is commonly applied. A review of B response trials with *Pinus radiata* in New Zealand shows that significant stem growth responses, ranging from 8 to 150%, occurred in six of nine trials. Rainfall is a key determinant of growth response; at five sites where rainfall was less than about 800 mm and foliar B ranged from 6-14 mg/kg, growth responses averaged 49%; at three sites where rainfall exceeded 1100 mm and foliar B ranged from 7-16 mg/kg, growth responses averaged 5%. On drier sites, long term weed control may be necessary to achieve a response to B applied at establishment. Interactions between clones/families and B fertilisation indicate there is scope for selection of genetic material that is adapted to B deficient soils. Recent studies show that low rates of B application may stimulate soil microbial activity and ectomycorrhizal colonisation of roots but higher rates reduce activity and ectomycorrhizal colonisation. These effects will in turn influence plant nutrient and water uptake, and growth.

More work is needed to determine if growth responses to B occur in a wider range of environments than have been examined to date. Further study is particularly required to examine B responses in the intermediate rainfall (600-1100 mm) zone and in early-to-mid-rotation age stands. Study of the effect of B on soil microbial activity should be incorporated in new trials to provide information on fertiliser impacts on soil microbes in the field in different climatic, soil and stand-age-class environments.

Keywords: boron, fertilisation, Pinus, weed control, clones

Introduction

Boron (B) is the most widespread micro-nutrient deficiency of forests in New Zealand. Boron deficiency may cause the death of terminal buds and shoots, especially in dry areas and/or periods of drought (see Figure 1), reduced height growth and permanent stem malformation (Will, 1985). Boron deficiency is closely linked to soil moisture status: It appears in the driest part of the year, symptoms are worst in drought years, and trees on coarse-textured, sandy or gravelly soils seem to be more susceptible than those on soils with high clay content (Will, 1985, Hunter *et al.,* 1990). Other factors that may influence development of B deficiency include soil acidity (Will, 1985, McLaren & Cameron, 1996) and weed competition (Olykan *et al.,* 2008).

Where trees are susceptible to B deficiency, B fertiliser is commonly applied, either at planting, or in the first few years of crop growth, as an insurance to prevent bud and shoot death and development of stem malformation. Consequently, responses to B fertilisation have generally been considered in terms of alleviation of overt dieback symptoms, rather than as simple growth responses (Stone, 1990, Lehto *et al*., 2010). However, insufficient B supply retards root and shoot growth, even though visible symptoms do not appear (Stone, 1990) and, in overseas studies, growth

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responses to B fertilisation that are not associated with the prevention of leader dieback have been reported (Green & Carter, 1993, Brockley, 2003, White & Krause, 2001**,** Saarsalmi & Tamminen, 2005).

Since the initial work that described the occurrence and correction of B deficiency in New Zealand (Will *et al*., 1963, Will, 1985), a number of B fertiliser trials have been undertaken in different parts of the country to determine if deficiency is present, appropriate application rates, and to examine interactions between B fertilisation and management practices. We have reviewed these studies with the aim of improving our understanding of stem growth responses to B fertilisation.

Figure 1. Boron deficiency symptoms in *Pinus radiata.*

Results

Boron rate by clone/family by weed control trials

Trials investigating the interactions of B application rate by clone/family by weed control were established between 1998 and 2002 at two high rainfall sites in the North Island and two low rainfall sites in the South Island (Table 1). Four or five rates of B, from 0 to 32 kg/ha, were applied as ulexite (13.8% CaO and 7.6% Na_2O) as shown in Table 1. All trees in the trials received weed control by herbicide application at planting. Additional weed control was applied to provide longer term weed control at all sites except Tekapo, where only low-statured short tussock was present. Each plot was randomly planted with five clones and three families of *P. radiata*. No fertiliser was applied to control plots. Tree height, ground line diameter and diameter at breast height (DBH) of individual trees in all plots were measured periodically in all trials. For comparison, tree volume was calculated as 3.14 × $(DBH/2)^2$ × height/3. Early results (at age four) for two of these trials are given in Olykan et al (2008).

According to the foliar diagnostic criteria of Will (1985), foliar B concentrations in control plots were satisfactory (>12 mg/kg) at Tungrove, marginal (8-12 mg/kg) at Taupo and Balmoral, and marginal to deficient (<8 mg/kg) at Tekapo (Table 1). Significant stem growth responses, either to B alone or in interaction with additional weed control, occurred at all sites. The strongest response was recorded at Tekapo – the site with the lowest rainfall and the most B-deficient – where stem volume responses to B rates of 8 and 16 kg/ha of more than 50% occurred at age 6. Responses were more subdued (8-13%) at the remaining sites.

Additional weed control was important in determining whether a response occurred at the low rainfall Balmoral site. A stem volume response of 13% to B at 4 kg/ha was recorded at age 10, but only where additional weed control was applied; smaller responses of 8-10% were observed at higher application rates. In the absence of weed control, a significant response was only evident at the highest rate of B application.

At the moister Taupo and Tungrove sites, there were no significant interactions between B application and weed control for stem volume. At Taupo, B rates between 4 and 16 kg/ha increased stem volume, the greatest increase (8.5%) occurring at 4 kg/ha. There was a different response at Tungrove, where B at 8 kg/ha increased DBH in the absence of weed control, but there was no significant effect of B on stem volume.

There appears to be scope for selection of genetic material that is well adapted to B deficient soils. Strong clone/family by B interactions occurred at Tekapo, where they were highly significant (P <0.001) for height, diameter and volume at age six. Significant clone/family by B interactions also occurred at Tungrove at year four, but these were lost by year six. No significant interactions occurred at Taupo or Balmoral. At Tekapo, the clones and families varied in the size of the growth response to B, the application rate at which peak growth occurred, as well as the size of the growth reduction caused by the high B application rate, as shown in Figure 2.

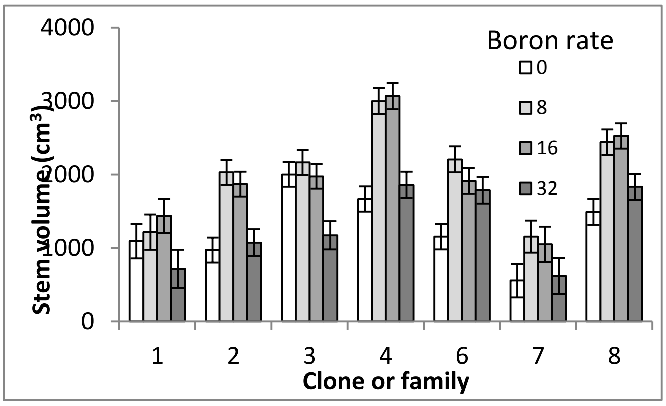

Figure 2. Response to boron fertilisation by eight clones or families of *Pinus radiata* at Tekapo. Bars show standard errors.

Table 1. Details of boron fertilisation field trials with *Pinus radiata*. All trials were fertilised with ulexite, except for the trial at Harakeke, Nelson, where borax (sodium tetraborate) was used.

	Soil texture and pH	Annual Rainfall (mm)	Age at fertil-isation	Age at measure-ment (years)	Foliar B in control (mg/kg)	Boron application rates (kg/ha)	Stem response measure	Maximum Response (%)	Reference
Boron rates by clone/family by weed control trials									
Taupo CNI[2]	Waipahihi sand, pH 5.7	1616	At planting	10	9-10	4,8,16,32	Volume	+8* (4)	Xue *et al* unpublished
Balmoral Canterbury[2]	Balmoral stony sandy loam, pH 5.6	597	At planting	10	11-14	4,8,16,32	Volume	+13* (4)	Xue *et al* unpublished
Tungrove Northland[2]	Awarua clay, pH 4.5	1263	At planting	6	14-15	4,8,16,32	DBH	+(8)* (8)	Xue unpublished
Tekapo Canterbury[2]	Pukaki silt loam, pH 5.5	600	3 months	6	6-8	4,8,16,32	Volume	+59* (8)	Xue unpublished
Single boron rate trials									
Harakeke Nelson	Mapua sandy loam, pH 4.8	1131	4 years	9	16	22	Volume	-5.7^{ns}	Knight *et al*. (1983)
Mamaku CNI	Sand pH not given	2000	7 years	12	7-9	8	Volume	0	Skinner *et al*. (2002)
Ashley Canterbury	Makerikeri stony silt loam, pH 5.0	808	3 years	4	11	7.4	Biomass	+150*	Olykan *et al*. (1995)
Tekapo[2] Canterbury	Fork sandy loam, pH 5.5	600	1 year	6	8	3.25	Height	+18*	Davis *et al.* (2001)
Tekapo[2] Canterbury	Pukaki stony sandy loam, pH 5.5	600	1 year	6	9	3.25	Height	+4^{ns}	Davis *et al*. (2001)

* significant at $P < 0.05$; ns, not significant.
[1]In brackets - the boron rate (kg/ha) at which maximum response was seen.
[2]The response value for *P. radiata* is the mean of 5-8 clones and families.

The growth response to B at Taupo and Balmoral was not associated with reduced leader dieback (Olykan *et al*., 2008). This is also likely to have been the case at Tungrove, where foliar B concentrations exceeded 12 mg/kg, the level above which dieback symptoms do not normally occur (Will, 1985). However, at Tekapo, where foliar B concentrations were marginal to deficient, the growth response is likely to have been at least partly associated with reduced shoot dieback. An earlier study close to the present trial site showed B application significantly improved the form of *P. radiata* (Davis *et al*., 2001). These results suggest that the minimum B concentrations for optimum growth may be above those required to prevent B deficiency symptoms occurring, as was recently suggested was the case for *Pseudotsuga menziesii* (Davis *et al*., 2012).

Single rate boron trials

Five trials have been conducted with *P. radiata* where B has been added or not added, all but one located in the South Island. These are also summarised in Table 1.

At Harakeke Forest in the Nelson region, a moderate rainfall (1130 mm) site, no significant response to B was observed. The foliar B concentration in the control plots was adequate at Harakeke (16 mg/kg). The high B application rate (22 kg/ha) may have been sufficient to cause some toxicity, as it caused a small, though not significant, growth reduction (Knight *et al*., 1983).

Mamaku Forest in central North Island is a high rainfall (2000 mm) region. In contrast to Harakeke, the foliar B concentration in unfertilised plots was limiting at Mamaku (8 mg/kg). However, no significant response to B was observed. An on-going weed control treatment was included at Mamaku but no interaction between B and weed control was recorded over the five years of the trial.

At Ashley Forest, Canterbury, with mean annual rainfall of 808 mm, Olykan *et al*., (1995) reported a large response to B. They applied B at a rate of 7.4 kg/ha as ulexite to three-year-old *P. radiata* trees on a Makerikeri soil. The foliar B concentration in control plots was marginal at 11 mg/kg in current needles and 8 mg/kg in one-year-old needles. The stand management did not include weed control, and scrub, grass weeds and wilding conifers were present. The trial trees did not show overt symptoms of B deficiency. The response, measured in dry weight of harvested trees, amounted to approximately 150% for stem biomass and 130% for whole shoot biomass.

Boron deficiency is apparent on drier soils in some high country regions in some years. The effect of B on the growth of *P. radiata* was compared on Fork and Pukaki soils in a dry (annual rainfall 600 mm) environment in the Mackenzie Basin (Davis *et al*., 2001). Both soils overlie gravels, and the Fork soil is stonier and has less water storage capacity than the Pukaki soil. Foliar B concentrations in control plots were marginal for *P. radiata*, being 8-9 mg/kg in the breed 'GF17' (Table 1). Boron was applied as ulexite around trees one year after planting at a rate of 1.3 g tree^{-1} (3.25 kg/ha). Weed control was carried out at planting. At age seven, B application on Fork soil improved the height growth of all *P. radiata* breeds, the increase ranging from 10 to 26% (mean = 18%). However, B application did not significantly improve height growth on Pukaki soil despite the low foliar B concentration, a result that contrasted with the results seen in the later boron rate by clone/family by weed control trial located nearby also on Pukaki soil (see above). Boron application improved mean tree form on both soils.

Boron effect on soil fungi and bacteria

Khan *et al*. (2012) investigated the B response of *P. radiata* in two pot trials on Waipahihi sand soil, similar to that in the Taupo field trial described above. B addition was seen to affect soil microbial activity and ectomycorrhizal fungal colonisation of roots (Khan, 2012, Khan *et al*., 2012). In both trials, high rates (≥16 kg/ha) reduced bulk soil activity of the enzyme dehydrogenase, an index of soil microbial activity, indicating high B rates are toxic to some soil microorganisms. In the second trial, low B rates (2-8 kg/ha) enhanced dehydrogenase activity in rhizosphere soil (but not bulk soil) by about 20%. The activity of β-glucosaminidase, an enzyme that plays a major role in nitrogen mineralisation in soils, has also been shown to be enhanced by a low application rate of B to soils (Ekenler & Tabatabai, 2002).

Ectomycorrhizal colonization of roots was strongly affected by B application. Colonisation was more than doubled in the first trial when B was applied at 4 kg/ha and more than trebled when B was applied at 8 kg/ha. Higher B application rates reduced colonization to a level found in the control. The second trial indicated an application rate of 2 kg/ha was sufficient to stimulate ectomycorrhizal colonization. However, in contrast to the first trial, colonization was reduced at the rate of 8 kg/ha. These results suggest that ectomycorrhizal fungi may be more sensitive to B toxicity than soil bacteria. The results of these studies are consistent with those of studies undertaken elsewhere with other species (Mitchell *et al*., 1987, Lehto, 1994, Möttönen *et al*., 2001).

Conclusions

Growth responses to boron are common.

- Six of nine field trials have shown significant positive growth responses to rates of B application between 4 and 8 kg/ha. The responses, measured between one and ten years after B application, have ranged from 8 to 150%. In one of the three trials that did not result in a response to B, the rate of application (22 kg/ha) may have been sufficient to cause B toxicity.

Rainfall is a key determinant of growth response.

- At five sites where rainfall was less than about 800 mm and foliar B ranged from 6-14 mg/kg, growth responses averaged 49%; at three sites where rainfall exceeded 1100mm and foliar B ranged from 7-16 mg/kg, growth responses averaged 5%.

- While most responses occurred on free draining soils in low rainfall environments, responses have also been observed on (high pH) clay soils and in high rainfall environments, and where foliar concentrations are considered adequate.

Weed control is important.

- In areas where low soil moisture availability limits tree growth, longer term weed control over and above that normally applied at planting may be necessary to achieve a response to B application when B is applied at establishment. In moister areas the initial requirement for B may be met by weed control reducing the competition for the soil B resource. With stand development, changes in weed competition and soil moisture availability occur which may in turn influence response to B fertilisation.

Selection for tolerance of B deficient soils is possible.

- The occurrence of an interaction between clone/family and B application on B deficient soils indicates that there is scope for selection of genetic material adapted to such soils.

Critical foliar B concentrations for growth response and overt deficiency symptoms may differ.

- Limited data for *P. radiata* indicate that foliar concentrations that are adequate to prevent overt symptoms of B deficiency such as shoot tip and leader dieback may be lower than required for optimum growth. Further study is needed to confirm this.

The growth response to B may be at least partly due to the effect of B on soil microbes.

- Low rates of B may stimulate soil microbial activity and especially ectomycorrhizal colonisation of roots but higher rates reduce activity and mycorrhizal colonisation. These effects will in turn influence plant nutrient and water uptake processes.

Recommendations

Further experimentation is needed to determine if growth responses to B occur in a wider range of environments than have been examined to date. The field trials undertaken so far have been concentrated in the very low (600 mm) rainfall zone, or in areas where rainfall exceeds 1100 mm; new trials are particularly required in the intermediate rainfall zone. Further, most trials have examined B responses at the establishment phase and additional trials are needed to examine potential responses in early-to-mid rotation age stands. These new trials could be of simple design and examine the effects of two rates of B (nil and + B) and two rates of additional weed control (nil and + additional weed control) on *P. radiata*. Study of the effect of B on soil microbial activity should be incorporated in these trials to provide new information on the impacts of fertiliser on soil microbes in the field in different climatic, soil sand stand-age-class environments.

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