RADIATA MANAGEMENT TECHNICAL NOTE
Site Productivity

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Tree Growth Response to Nitrogen Fertilisation

Summary

Nitrogen fertiliser application has the potential to increase productivity of radiata pine plantations in New Zealand, but may also result in leaching of nitrogen to waterways. A study is being undertaken to improve our understanding of both the growth response and the environmental consequences of applying nitrogen fertiliser to plantation pine forests. In this Technical Note the initial tree growth response to nitrogen application (200kgN/ha as urea) to plots at seventeen sites across the forest estate is described. The work is part of Scion's MSI funded Protecting and Enhancing the Environment through Forestry Programme, and falls under the FFR Radiata Management Theme focussing on site management and nutrition

Fertilisation increased mean foliar concentrations within four months of application. Nineteen months after application, stem volume increment on fertilised plots was 7.5% greater than on unfertilised plots, but this difference was not significant. As responses to nitrogen are often evident within one year, insufficient time for the response to occur is unlikely to be a key reason for the lack of a significant response to date. The results indicate that a response appears to be developing over time, with fertilised plots having nearly 10% greater volume increment in the second year, compared to 4.6% greater volume increment in the first year (measured seven months after application). Weed growth at some sites and nitrogen sufficiency at others, as indicated by foliar nitrogen concentrations, appear to be the main factors precluding the development of a significant response at this stage.

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Background

Nitrogen fertilisation has the potential to increase productivity of radiata pine plantations in New Zealand [4, 5, 6, 9]. Productivity increases can be quite large. For example stem volume responses of 20% were recorded in 13-14-year-old central North Island stands on pumice soils[9], while on pumice soils involving a number of sites with stands aged from four to twenty years, basal area responses up to 40% were identified[5]. Basal area responses of 16-23% were measured in a 7-year-old Canterbury plains forest[6].

Increased production from nitrogen fertilisation may, however, come at the cost of increased nitrate leaching to waterways. Although fertilisation effects on nitrate leaching are well documented from agriculture, there have been few studies of nitrate leaching following fertilisation of forests in New Zealand. As described in previous Technical Notes (RTN-009, and RSPTN 018 and 019), a study is being undertaken to improve our understanding of the environmental consequences of applying nitrogen fertiliser to forests. The previous Technical Notes have described the study and presented interim results of urea effects on soil water nitrate-N concentrations. In this Technical Note the tree growth response up to 19 months after fertiliser application is described.

Methods

The study uses 17 trial sites from the Long Term Site Productivity Series 2 trial. This trial series was selected because soil and climatic parameters for the sites were already well characterised. Existing 40 x 40 m permanent sampling plots at these sites represent the unfertilised control treatments of the new study. An additional plot was established at each site to match the existing plot in terms of soil, slope and aspect. Nitrogen was applied to these additional plots in November 2009 to determine the tree growth response to N application. The forest stands at the 17 sites were 7-9 years old at the time of N application. The trial sites are described in Table 1.

Foliage was sampled from control and fertilised plots in March 2010, four months after nitrogen application, and again one year later, for determination of foliage nutrient concentrations. Tree heights and diameters were measured prior to and on two occasions (winter 2009 and 2010) after N application. Leaf area index (LAI) was measured in spring 2009 and summer 2010-2011, and mean values were derived. The paired T-test was used to determine if there was a significant response to nitrogen application.

Table 1: Trial site physical characteristics. Altitude is of control plots. Mean annual temperatures are from site measurements (Mawhera & Otago Coast are from Bioclim [10]), and mean annual rainfall is from Bioclim.

	Latitude (°)	Altitude (m)	Rainfall (mm)	Temperature (°C)
Woodhill	36.777	55	1563	16.9
Riverhead	36.674	90	1520	16.5
Mahurangi	36.345	160	1739	16.0
Kaingaroa	38.268	450	1611	13.8
Ashley	43.150	270	851	14.4
Tikitere	38.058	345	1875	14.6
Waimarino	39.450	559	1707	12.9
Bulls	40.190	70	966	15.4
Hochstetter	42.544	291	3454	12.2
Mawhera	42.444	305	3718	10.8
Longwoods	46.163	368	1290	8.5
Catlins	46.420	256	1190	10.6
OtagoCoast	46.056	213	886	9.4
Karioi	39.470	690	1196	11.5
Eyrewell	43.430	150	776	11.5
Bottle Lake	43.459	15	640	11.9
Mamaku	38.083	570	2122	11.6

Results

Foliage Analyses

The main nutrients limiting tree growth in New Zealand are nitrogen, phosphorus, magnesium and boron. Analysis of foliage samples from control plots showed that 65% of the sites in the study contained foliar nitrogen concentrations that are considered sub-optimal for growth of radiata pine in New Zealand (Table 2, Fig. 1). Additionally three sites had inadequate concentrations of phosphorus and boron, and eight sites had inadequate concentrations of magnesium.

Fertiliser application in November 2009 rapidly increased foliar nitrogen concentrations. In samples collected four months after application, the average foliar nitrogen concentration in fertilised plots (1.50%) significantly (P < 0.01) exceeded that in control plots (1.36%). This difference was maintained in samples collected one year later (March 2011; 1.49% and 1.38% in fertilised and unfertilised plots respectively, P < 0.01). Foliage nitrogen increased at all except one site (Bottle Lake) with inadequate nitrogen concentrations in control plots for optimum growth (Fig. 1).

Table 2: Foliar nutrient concentrations in unfertilised plots in samples collected in March 2010. Adequate levels for optimum growth are 1.45%, 0.14%, 0.10% and 12mg/kg for N, P, Mg and B respectively. Values where levels are considered to be below adequate for growth are highlighted.

	N (%)	P (%)	Mg (%)	B (mg/kg)
Woodhill	1.24	0.14	0.17	21
Riverhead	1.27	0.15	0.11	18
Mahurangi	1.50	0.13	0.10	21
Kaingaroa	1.36	0.16	0.13	8
Ashley	1.52	0.09	0.09	11
Tikitere	1.62	0.22	0.10	16
Waimarino	1.50	0.16	0.09	23
Bulls	1.26	0.13	0.12	29
Hochstetter	1.26	0.12	0.06	21
Mawhera	1.12	0.14	0.08	11
Longwoods	1.43	0.20	0.07	16
Catlins	1.30	0.23	0.08	16
OtagoCoast	1.30	0.16	0.12	14
Karioi	1.56	0.16	0.09	18
Eyrewell	1.22	0.16	0.11	21
Bottle Lake	1.21	0.14	0.12	17
Mamaku	1.49	0.11	0.06	14

The failure of fertiliser to increase foliar nitrogen at Bottle Lake may have been due to high rainfall in the month following urea application (225 mm), causing leaching of the fertiliser. The Bottle Lake soil is a porous coastal sand bare of understory vegetation cover (Table 4) which would be prone to leaching of nitrogen if high rainfall followed fertiliser application. Two other sites in the study were also developed in coastal sands (Woodhill and Bulls), but rainfall at these sites in the month following fertilisation was only half that at Bottle Lake (110 and 100 mm respectively).

Tree Growth Response to Nitrogen Fertiliser

Mean stem volume increment of the 17 sites over the nineteen-month period since fertiliser application was 7.5% greater in the fertilised plots than in unfertilised plots (Table 3). This difference was not significant. Owing to the diversity of sites, a number of factors may have contributed to the lack of a significant growth response to nitrogen including; insufficient time for the response to develop, nitrogen may not have been limiting at some sites, severe deficiency of another nutrient, insufficient space to grow the canopy (closed canopy sites), drought, or the presence of weed competition.

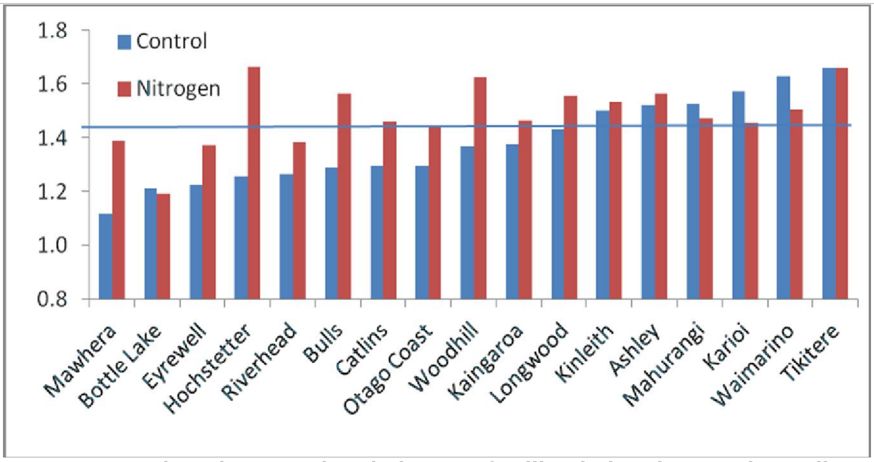

Figure 1: Foliar nitrogen concentrations in control and nitrogen fertilised plots in samples collected in March 2011. Values below the horizontal line are inadequate for optimum growth.

Table 3: Mean stem volume increment in fertilised and unfertilised plots for the first 19 months following nitrogen application.

Year	Control	Fertilised	Response (%)	P^1
1	27.6	28.8	4.6	0.49 ns
2	33.0	36.3	9.8	0.23 ns
1+2	60.6	65.1	7.5	0.29 ns

[1] *P* value from paired t-test.

Nitrogen responses generally peak at 2-4 years after application[1], but responses are often evident within one year, so insufficient time is unlikely to be a key reason for the lack of a significant response to date. The results shown in Table 3 indicate that a response appears to be developing over time, with fertilised plots having nearly 10% greater volume increment in the second year, compared to 4.6% at the first measurement seven months after fertiliser application. This response difference may be a reflection of the period of growth available over the two measurement periods (7 months and 12 months in the first and second years respectively), and further measurement is required to clarify this.

Foliar concentrations in control plots indicate nitrogen may not have been limiting tree growth at some sites. Foliar nitrogen concentrations were not determined in fertilised plots prior to urea application, but there was a positive linear relationship (r = 0.64, P<0.01) between foliar nitrogen concentrations in fertilised and unfertilised plots, so values in unfertilised plots were used as a surrogate for concentrations in fertilised plots. Six sites in the study had foliar nitrogen concentrations in unfertilised plots in excess of 1.45%, the value considered adequate for optimum growth of radiata pine (Table 2). Removal of these six sites from the comparison showed the mean response for the eighteen month period to increase from 7.5% to 13.4%, supporting the suggestion that nitrogen may not have been limiting at those sites. However this greater response remained non-significant (P = 0.23).

Overstocking, which restricts the opportunity for crown expansion, may also limit response to nitrogen application[1]. Ballard and Lea[in1] found peak response to nitrogen fertiliser in pole stage loblolly pine plantations occurred at basal areas of 25-35m^2/ha, with only a small decline in response at 40 m^2/ha. Basal areas measured in nitrogen plots prior to fertilisation in the present study ranged from 3.4 to 41.8 m^2/ha (Table 4), indicating that nitrogen response was unlikely to have been limited by overstocking. Mean LAI values ranged from 0.7-5.5 (Table 4), but the maximum values recorded during the study remained below canopy closure[2], which would limit a response to nitrogen fertiliser.

Phosphorus, magnesium and boron concentrations were below that required for optimum growth at a number of sites (Table 2). There was only one instance, however, where a deficiency may be considered sufficiently severe to strongly limit a response to nitrogen. This was at Ashley Forest where the concentration of phosphorus (0.09%) was in the deficient zone for radiata pine [3, 8].

Weed cover at several sites may have been sufficient to limit fertiliser response to nitrogen because of competition for moisture, light or nutrients, including the nitrogen added in the fertiliser. Sites with high weed cover (Table 4) included Tikitere where the main weed cover was blackberry, Bulls (grass and gorse), Mawhera (bracken and gorse), Longwoods

(bracken and native woody species) and Catlins (bracken and blackberry). Removal of the five sites with high (80% or more) weed cover from the analysis of nitrogen response, along with the Ashley Forest site because of P limitation, increased the response over 19 months from 7.5% to 16% (P = 0.06), indicating that weeds were an important factor in limiting the response.

On both control and fertilised plots, growth increment over the 19-month period was positively correlated with ground slope (P < 0.05), and soil total P (P < 0.05) exchangeable Ca (P < 0.01) and exchangeable K (P < 0.05). Growth increment in both control and fertilised plots was also positively related to canopy LAI in their respective plots.

The response to nitrogen was positively correlated with soil mineralisable nitrogen (P < 0.05) in the first year, but not in the second year or over the total 19-month period. Nitrogen response was not correlated with any other soil or climatic variable measured.

The growth increment in control plots over the 19-month period was positively correlated with nitrogen and potassium on control plots (all P < 0.01). The growth increment of fertilised plots was not correlated with any foliar characteristic, nor was the response to nitrogen.

Table 4: Initial basal area, leaf area index (LAI) and weed cover in nitrogen-fertilised plots. Both LAI and weed cover were estimated after fertilisation.

Site	Basal area (m^2/ha)	Mean LAI	Weed cover (%)
Woodhill	25.0	4.2	5
Riverhead	15.6	2.9	65
Mahurangi	41.8	4.3	55
Kaingaroa	10.2	1.5	32
Ashley	27.4	2.7	60
Tikitere	21.1	4.5	100
Waimarino	35.2	4.0	7
Bulls	20.3	3.8	85
Hochstetter	15.7	0.7	15
Mawhera	5.9	1.7	95
Longwoods	13.4	2.5	95
Catlins	20.2	5.1	95
OtagoCoast	15.3	5.5	30
Karioi	18.0	3.8	40
Eyrewell	3.4	0.9	15
Bottle Lake	14.8	3.9	0
Mamaku	7.8	2.1	25

Conclusions

A significant response to nitrogen has not yet been recorded in this study, but a response appears to be developing over time. A high weed cover at some sites and nitrogen sufficiency at other sites may be the main factors precluding the development of a significant overall response.

Tree growth will continue to be measured for the next two years, and possibly beyond then to follow development of the nitrogen response and how it relates to environmental variables. It is expected that a further Technical Note and an article for journal publication will be prepared in 2013 to document the nitrogen response up to that time.

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