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RESPONSE TO THINNING AND NITROGEN FERTILISER IN YOUNG *EUCALYPTUS REGNANS* IN KAINGAROA FOREST

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EXECUTIVE SUMMARY

RESPONSE TO THINNING AND NITROGEN FERTILISER IN YOUNG *EUCALYPTUS REGNANS* IN KAINGAROA FOREST

A factorial thinning x fertiliser trial was installed in a 4.5-year-old *Eucalyptus regnans* stand located in Cpt 59 Timberlands Kaingaroa Forest. Fertiliser nitrogen (N) was applied as urea at either 0, 115 or 230 kg N/ha, and plots were either unthinned (ca. 1667 trees/ha), or thinned (to ca 600 spha) and form pruned. A supplementary treatment consisted of 75 kg P/ha in the form of partially acidulated phosphate rock ('Duraphos' PAPR), plus 115 kg/ha N applied as urea to a thinned/form pruned plot.

When measured 2 years after treatment crop trees in both thinned and unthinned areas had responded significantly to applied N in mean diameter, average height, basal area and volume. Crop tree diameters increased by 5.6 cm and 3.5 cm over 2 years at the low rate of applied N in thinned and unthinned treatments, respectively. Doubling the rate of N significantly increased diameter and mean tree basal area increments in the thinned treatments but not in unthinned areas. Thinning significantly increased mean crop tree volume increment but additional N did not. Height increment was not affected by additional N or by thinning. The N rate x thinning interaction was significant for diameter, mean tree basal area and volume increments but not for height.

On a stand basis the T_1N_1 treatment (thinned/115 kg N/ha) produced 80% of the basal area and volume increases of the corresponding unthinned (T_0N_1) treatment.

However this growth was concentrated on fewer stems resulting in larger trees than in the unthinned area.

The nutritional status of all treatments was very similar in 1990 and suggests that any advantage provided by the urea applications has now disappeared. On this basis growth rates of all treatments could be expected to parallel each other eventually without further nutritional input.

INTRODUCTION

Following approval of an FRI work plan proposal by the Technical Committee of the Management of Eucalypts' Cooperative on 16.9.87, a decision was made to investigate the effects of thinning and fertiliser on the growth of young *Eucalyptus regnans*. The rationale behind this decision has been outlined in Knight and Allen (1990). Evidence for growth responses to N fertiliser with thinning came from an earlier trial in 7-year-old *E. regnans* (Hunter 1986).

The present trial was designed to quantify growth responses to factorial combinations of thinning and fertilisation in a productive young *E. regnans* stand, at a stage when canopies of adjacent trees have run out of room to expand horizontally. In Kaingaroa Forest, stand age 4 is about the earliest stage when thinning will restore unrestricted growing conditions.

In summarising preliminary results Knight and Allen (1990) found that thinning (to 600 spha) and urea fertiliser treatments interacted to give a large diameter response in the first year after treatment. The lower urea rate (250 kg/ha) gave 85% of the diameter gain given by the higher rate (500 kg/ha) urea. The combination of thinning and urea fertiliser (250 or 500 kg/ha) increased mean diameter by 1.64 and 1.93 cm respectively. Urea fertiliser alone gave gains of 0.84 and 0.98 cm respectively, i.e. roughly half the gains from thinning plus fertiliser. Thinning alone did not significantly increase diameter.

Applying partially acidulated phosphate rock ('Duraphos') at 500 kg/ha together with urea in thinned plots had no additional effect on mean diameter. The P source significantly depressed mean height by a small margin.

The thinning x urea fertiliser combination stimulated diameter increment at the expense of height growth. Such an effect could be expected as thinning effectively reduces the competitive pressure on trees to gain dominance.

Standard foliage samples collected in February one month after treatment showed that urea fertiliser had significantly increased foliar levels of N, P, S, Cu and Zn, but had depressed levels of K and Mg; levels of other nutrients were not significantly affected by urea fertilisation. Thinning significantly decreased levels of Mg and Cl in the foliage, but did not significantly affect levels of other nutrients determined. Thinning x N level interaction was only significant for P, and K. The P-inclusive treatment significantly increased foliar concentrations of macro- but not micronutrients relative to those for the corresponding thinning/urea only treatment.

A final measurement and foliar analysis was done in 1990, 2 years after treatment, and are reported here.

METHODS

SITE HISTORY

The site selected for the trial was located in Cpt 59 Kaingaroa Forest, off Waiora Road in a 61 ha stand of *E. regnans* planted in August/September 1983 at about 3 x 2 m spacing (ca. 1667 stems per ha). The area had been windrowed by V-blade following the logging of the original *P. radiata* crop in 1982/83. Soon after planting the eucalypts, 60 g urea was applied in a spade slit by each tree. The soil at the site is a disturbed yellow brown pumice sand.

This 4.5-year-old stand was selected because of its proximity to the FRI and because the site was reasonably even in terms of growth, topography and cover. One disadvantage of this site which was largely overcome by the silvicultural design of the trial was the high incidence of double or multiple leader trees.

EXPERIMENTAL DESIGN AND TREATMENTS

The experimental design adopted was a randomised complete block with six blocks and factorial combinations of two levels of thinning, *viz.* unthinned (ca. 1667 stems/ha) and thinned (ca. 600 stems/ha), and three levels of urea fertilisation, *viz.* 0, 115 and 230 kg N/ha. The thinning treatment included form pruning. In subsequent tables of data the factorial treatments are shown as follows:

T_0N_0	T_0N_1	T_0N_2
T_1N_0	T_1N_1	T_1N_2

where N_0, N_1 and N_2 denote the rate of urea applied i.e. 0, 115, and 230 kg N/ha respectively and
T_0 and T_1 denote stocking (i.e. unthinned or thinned).

A supplementary treatment (T_1N_1P) testing the response of phosphorus applied as 'Duraphos' PAPR (75 kg P/ha) in combination with thinning and 115 kg/ha of N urea was included in the trial.

For ease of access and uniformity, fertilisers were applied just prior to thinning, and were hand-broadcast over plots and surrounds.

Each whole plot (inner measurement plot plus surround) measured 30 x 30 m (0.09 ha). The surrounds measured 5 m along rows and 6 m across rows leaving a measurement plot of 18 x 20 m. The plots were interposed between windrows. As plots nearer an adjoining old *P. radiata* stand had appreciable young pine regeneration, it was decided, during establishment of the trial, to fell the pines to make all plots more consistent in this respect. Also, large tutu plants (*Coriaria* sp.) were present in many plots and had to be slashed to allow clear lines of sight for establishing plot boundaries and ready access for uniform fertilisation. Again for consistency it was decided to cut back all well- grown tutu throughout the plots. In view of the prevalence of forked trees, it was decided to make the silvicultural comparison one between unthinned/untended and thinned/form pruned crops.

Thinning was "from below" having regard to good spacing but generally leaving trees with the greatest potential to produce ideal crop trees. At the same time, trees remaining in the thinned plots were form pruned by chainsaw to a single leader. Any stumps or wounds were painted with 'Captafol' fungicide to inhibit infection with pathogens such as *Chondrostereum purpureum*.

DIARY OF EVENTS

Fertiliser treatments applied[1]	7-8 January 1988
Trees measured (diameters and heights)	12 -15 January 1988
Thinning treatment imposed	13-14 January 1988
Form pruning/fungicide treatment of stumps	19-22 January 1988
Foliage sampling	10 February 1988
Remeasurement of trees	2-3, 7 February 1989
Remeasurement of trees	19 Feb – 9 March 1990
Foliage sampling	15-16 March 1990

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1 A heavy rain shower fell over the area the following day dissolving and washing the urea into the topsoil.

MEASUREMENTS

At trial establishment and the subsequent two assessments, diameter outside bark at breast height (DBH) was recorded for all stems in all plots. At the same time 19 trees (equivalent to 528 stems/ha) in both thinned and unthinned plots were selected on the basis of size, form and spacing as potential crop trees. Of these trees, twelve were randomly selected and measured for height at each measurement date.

STATISTICAL METHODS

In each plot mean basal area (BA) per tree was calculated as :

$$BA = \frac{\pi}{4}\frac{\sum DBH^2}{n}$$

and mean volume inside bark (IB) per tree was calculated by inserting mean DBH and average height in the following equation:

Vol.(IB)[1] = $0.02984.DBH^2.Ht$	where	DBH	=	cm
		Ht	=	m
		BA	=	cm^2
		Vol.	=	dm^3
		n	=	no. of stems

For the purposes of this report, the analysis of variance (ANOVA) of diameter and volume responses in thinned and unthinned plots, except where mortalities have occurred, was based on 19 selected crop trees in each plot. Statistical comparison of treatments based on all stems per plot was not valid because of the thinning effect.

The comparison of height response was based on the average height of 12 trees in each plot. However where tops were subsequently lost, as a consequence of wind damage from Cyclone Bola (March 1988), new height trees were selected.

The Least Significant Difference (LSD) test was used to compare treatment means.

[1] Equation based on Hayward (1987).

Other response variables examined by analyses of variance (thinning x N rate) were foliar concentrations of each of 6 elements (N, P, K, Ca, Mg, and B) determined in samples collected 2 years after treatment.

FOLIAGE SAMPLING AND CHEMICAL ANALYSIS

In blocks 1, 3 and 5 foliage samples of fully expanded leaves of the current season's growth were collected by shotgun from the upper third of sunlit crowns of 6 dominant trees per plot. Samples were bulked to give 1 composite per plot, oven dried to constant weight and ground to pass a 1 mm screen in a stainless steel Wiley mill. Subsamples were digested in sulphuric acid and hydrogen peroxide in the presence of lithium sulphate and selenium. Nitrogen (N) and phosphorus (P) were determined colorimetrically by indophenol blue and vanado-molybdate methods respectively. Potassium (K), calcium (Ca) and magnesium (Mg) were determined by atomic absorption. Boron (B) was determined colorimetrically by a modified curcumin method after dry ashing (Nicholson 1984).

RESULTS

CROP TREE GROWTH AT AGE 6.5 YEARS

ANOVA on crop tree mean diameter, mean basal area per tree and mean volume per tree showed a highly significant ($P<0.001$) treatment effect being highest in the thinned plus fertilised treatments in 1990 (at age 6.5 years) (Table 1, Table 2). Average height was not affected by treatment. However, because significant differences also existed prior to treatment in 1988 (Appendix 1 and 2) analysis of 1990 growth data should be viewed with some caution. For this reason 2-year growth increments between 1988 and 1990 were the main focus of this report.

TABLE 1 – Mean crop tree diameter and basal area at age 6.5 years (2 years after treatment)

<table>
<tr><th>Treatment</th><th>DBH (cm)</th><th>Basal area (cm^2/tree)</th><th colspan="4">LSD test</th></tr>
<tr><td>T_1N_2</td><td>15.6</td><td>191.1</td><td>|</td><td></td><td></td><td></td></tr>
<tr><td>T_1N_1</td><td>15.0</td><td>177.9</td><td>|</td><td></td><td></td><td></td></tr>
<tr><td>T_1N_1P</td><td>14.9</td><td>175.2</td><td>|</td><td></td><td></td><td></td></tr>
<tr><td>T_1N_0</td><td>13.1</td><td>134.9</td><td></td><td>|</td><td></td><td></td></tr>
<tr><td>T_0N_2</td><td>12.6</td><td>125.2</td><td></td><td>|</td><td>|</td><td></td></tr>
<tr><td>T_0N_1</td><td>11.9</td><td>112.1</td><td></td><td></td><td>|</td><td>|</td></tr>
<tr><td>T_0N_0</td><td>11.1</td><td>97.5</td><td></td><td></td><td></td><td>|</td></tr>
</table>

Note: Means with same bar in each column are not significantly different at $P < 0.05$. (LSD test).

TABLE 2 – Mean crop tree volume (inside bark) at age 6.5 years (2 years after treatment)

<table>
<tr><th>Treatment</th><th>Vol. (IB) (dm^3/tree)</th><th colspan="3">LSD test</th></tr>
<tr><td>T_1N_2</td><td>91.2</td><td>|</td><td></td><td></td></tr>
<tr><td>T_1N_1</td><td>87.3</td><td>|</td><td></td><td></td></tr>
<tr><td>T_1N_1P</td><td>84.2</td><td>|</td><td></td><td></td></tr>
<tr><td>T_1N_0</td><td>61.5</td><td></td><td>|</td><td></td></tr>
<tr><td>T_0N_2</td><td>60.8</td><td></td><td>|</td><td></td></tr>
<tr><td>T_0N_1</td><td>53.1</td><td></td><td>|</td><td>|</td></tr>
<tr><td>T_0N_0</td><td>46.4</td><td></td><td></td><td>|</td></tr>
</table>

Note: Means with same bar in each column are not significantly different at $P < 0.05$. (LSD test).

CROP TREE 2-YEAR GROWTH INCREMENTS

Diameter, basal area and volume increments per mean tree (Figs 1 and 2) were significantly (LSD $_{0.05}$) increased by fertiliser and by thinning with best growth occurring in treatment T_1N_2, i.e., thinned plus 230 kg N/ha. Crop tree DBH, basal area and volume in the T_1N_1 treatment increased by 5.6 cm, 107.2 cm^2/tree and 63.9 dm^3/tree respectively over 2 years compared to 3.5 cm, 56.7 cm^2/tree and 45.7 dm^3/tree in the corresponding unthinned treatment T_0N_1. In both the thinned and unthinned treatments doubling the rate of nitrogen applied (i.e., from 115 to 230 kg N/ha) resulted in a slight but insignificant increase in volume increment. However doubling the rate of applied N significantly (LSD $_{0.05}$) increased DBH and basal area increments in thinned treatments but not in unthinned areas.

Average height increment (Fig. 1) increased significantly (LSD $_{0.05}$) due to N fertiliser at the low rate but was not affected by additional N or by thinning. The interaction of fertiliser x thinning was significant ($P < 0.009$) for DBH, basal area and volume increments but not for height and can readily be seen in Figures 1 and 2.

EFFECTS OF PHOSPHATE FERTILISER ON CROP TREE GROWTH

The addition of 75 kg P/ha in the form of PAPR to 115 kg N/ha as urea in combination with thinning (T_1N_1P treatment) resulted in no significant differences in mean DBH, average height, basal area or volume at age 6.5 years (Table 1 and 2) or in 2-year growth increments (Appendix 1 and 2), when compared to treatment T_1N_1.

STAND GROWTH

Stand characteristics of each treatment, based on all trees at age 6.5 years (2-years after treatment) are shown in Table 3. The unthinned treatment combined with 230 kg N/ha as urea (Treatment T_0N_2) achieved the greatest basal area and volume (15.8 m2/ha and 70.6 m^3/ha respectively). However this was at the expense of mean diameter which was highest (15.6 cm) in the equivalent thinned treatment (T_1N_2). Mean height was greatest in the thinned plus fertilised treatments at about 12.5 m. Mean top height was similar across all treatments (average 13.7 m).

TABLE 3 – Stand characteristics of each treatment based on all stems at age 6.5 years (2 years after treatment)

Treatment	Stocking stems/ha	DBH (cm)	Mean height (m)	Mean top height (m)	Basal area (m^2/ha)	Volume (inside bark) (m^3/ha)
T_1N_2	509	15.6	12.4	13.8	9.7	46.8
T_1N_1	519	15.0	12.7	13.9	9.2	45.2
T_1N_1P	523	14.9	12.5	13.8	9.2	44.2
T_1N_0	528	13.1	11.9	13.1	7.1	32.7
T_0N_2	1662	11.0	11.6	13.7	15.8	70.6
T_0N_1	1667	10.5	11.5	13.8	14.5	63.6
T_0N_0	1796	9.9	11.5	13.6	13.8	59.0

FOLIAR NUTRIENTS 2 YEARS AFTER TREATMENT

There was no significant difference between treatments for concentrations of 5 macro-nutrients and B (Table 4) 2 years after treatment except for Ca which was highest in the control (T_0N_0) treatment and lowest in the T_1N_2 treatment.

TABLE 4– Mean concentrations of foliar elements 2 years after treatment

Treatment	Concentration (OD basis)						
	N	P	K	Ca	Mg	B	N/P
	%					ppm	
T_1N_2	1.90	0.118	0.77	0.44^{a}	0.192	10.3	16.1
T_1N_1	1.78	0.115	0.76	0.48^{ab}	0.211	13.3	15.5
T_1N_1P	1.81	0.128	0.71	0.52^{b}	0.209	12.0	14.2
T_1N_0	1.80	0.128	0.77	0.52^{b}	0.195	13.3	14.1
T_0N_2	1.88	0.122	0.78	0.51^{b}	0.218	10.7	15.5
T_0N_1	1.72	0.117	0.78	0.52^{b}	0.215	11.3	14.8
T_0N_0	1.84	0.129	0.77	0.62^{c}	0.215	13.3	14.3

Note: Ca concentrations with same superscripts do not differ at $P < 0.05$ (LSD test). No significant difference between treatments for other elements.

DISCUSSION

EFFECT OF FERTILISER AND THINNING ON GROWTH

The 2 year gain in crop tree mean volume of the thinning alone treatment (T_1N_0) and the fertiliser alone at 115 kg N/ha (T_0N_1 treatment), over the control (T_0N_0), was 11.1 and 8.8 dm^3/tree, respectively (Appendix 1 and 2). However, a synergic effect resulted from combining thinning and fertiliser, i.e., the gain in crop tree volume increment of the T_1N_1 treatment over the control (T_0N_0 treatment) was 37.0 dm^3/tree, equivalent to an extra 19.5 m^3/ha on crop trees over the 2 year period since treatment. This meant that the thinning plus fertiliser combination produced a better response than the additive effects of either treatment alone would suggest. In terms of volume there was no significant advantage in doubling the amount of nitrogen applied to 230 kg N/ha or adding a phosphate source.

The main difference between the growth effects after 2 years and the results found 1 year after treatment (Knight and Allen, 1990) was that thinning alone (treatment T_1N_0), produced a significant response in diameter, basal area and volume increments over and above the control (T_0N_0) treatment which was not evident at 1 year. Also, the significant negative effect on height due to thinning noted at 1 year had disappeared after another 12 months.

The site is not particularly good compared to other *E. regnans* sites for which the Management of Eucalypt Cooperative has collected data. Basal area and height in *E. regnans* PSP plots adjacent to this trial were overpredicted by the NZFP Forests growth model (McKenzie 1990) showing that Cpt 59 was at the poorer end of the range studied. Severe out-of-season frosts caused substantial defoliation at age 2 years such that the trees in the stand appeared killed. They recovered, but this indicated the site was marginal for *E. regnans*. (H. McKenzie pers. comm.). The initial topsoil total nitrogen level of 0.2% (Table 5) in the fertiliser x thinning trial confirm that this site is relatively N poor compared to soils under an *E. regnans* age series near Tokoroa (Frederick *et al.* 1985). This was possibly related to the degree of topsoil removal by windrowing.

TABLE 5 - Soil characteristics of Cpt 59 trial site under 4.5-year-old *E. regnans*

Soil depth (cm)	pH	Total N (%)	Bray P (sequential)	ppm		Bray-2	me %		Organic matter (%)
0-10	4.9	0.20	33.6	22.8	15.3	0.24	1.59	0.43	11.1
10-20	5.3	0.12	21.0	30.0	12.2	0.22	1.18	0.29	7.5

EFFECTS OF P FERTILISER ON GROWTH

The lack of a growth response, 2 years after treatment, to the addition of a P source was in agreement with results after 1 year (Knight and Allen, 1990) and is consistent with the top soil Bray-P levels of 15-34 ppm (Table 5).

FOLIAR NUTRITIONAL STATUS

The absence of significant differences in macro-nutrient concentrations between treatments in 1990 is in contrast to results 1 month after treatment (Knight and Allen, 1990) when, of the 5 elements reanalysed in 1990 Ca was the only element not affected by treatment. Foliar B levels 2 years after treatment were on average about 3 ppm lower than when sampled earlier. In the treatments which received nitrogen fertiliser, foliar N and P levels after 2 years were considerably lower than the initial analyses (Knight and Allen, 1990). However in the N_0 treatments foliar N levels increased from a low of 1.4% to around 1.8% in 1990. P levels in N_0 treatments remained quite stable over this same period. In general foliar N and P levels in 1990 appear to be slightly lower than the optimum for vigorous growth in young eucalypts (Will, 1985) and the foliar N/P ratio (Table 4) of about 15 is slightly higher than the figure suggested as satisfactory for young *E. fastigata* (Knight, 1988).

The significant difference in macro-nutrient levels between treatments T_1N_1 and T_1N_1P 1 month after treatment (Knight and Allen, 1990) due to the inclusion of a P source (75 kg P/ha) had disappeared after 2 years (Table 4) although the foliar P level in treatment T_1N_1P was still amongst the highest (0.128%) which also occurred in both N_0 treatments.

IMPLICATIONS FOR MANAGEMENT

The relative increase in stand growth in each treatment is shown in Table 6. The T_1N_1 treatment achieved 80% of the basal area and volume increases of the corresponding unthinned T_0N_1 treatment but the number of stems was only 1/3 that of the unthinned area. This raises the question of how long the fertilised and thinned treatments will keep up their superior growth rate, e.g., 274% volume increase in T_1N_1 treatment (Table 6) compared to 108% increase in the unthinned unfertilised control (T_0N_0) over 2 years. The nutritional status of all treatments was very similar in 1990 and suggests that any advantage provided by the urea applications has now disappeared. On this basis growth rates of all treatments could be expected to parallel each other eventually without further nutritional input.

TABLE 6 – Two year stand basal area and volume response for each treatment (based on all stems)

Treatment	1990 stocking (stems/ha)	Basal area (m^2/ha) 1988	Increment 88-90	Increment %	Volume (m^3/ha) 1988	Increment 88-90	Increment %
T_1N_2	509	3.5	6.2	177	11.4	35.4	319
T_1N_1	519	3.7	5.5	149	12.1	33.1	274
T_1N_1P	523	3.7	5.5	149	12.1	32.1	265
T_1N_0	528	3.8	3.3	87	12.3	20.4	166
T_0N_2	1662	8.2	7.6	93	23.5	47.1	200
T_0N_1	1667	7.9	6.6	84	22.4	41.2	184
T_0N_0	1796	9.4	4.4	47	28.4	30.6	108

CONCLUSIONS

* Thinning in combination with urea N fertiliser resulted in significant diameter, height, basal area and volume increases 2 years after treatment, in a young *E. regnans* stand in Kaingaroa Forest.

* Best crop tree growth increments occurred in the thinned/high N rate (T_1N_2) treatment.

* Two year crop tree DBH, height, basal area and volume increments in the T_1N_1 treatment were 5.6 cm, 4.2 m, 107.2 cm^2/tree, and 63.9 dm^3/tree respectively compared to 3.5 cm, 4.2 m, 56.7 cm^2/tree and 35.7 dm^3/tree in the corresponding unthinned treatment (T_0N_1).

* Doubling the rate of applied N significantly increased crop tree DBH and basal area increments (to 6.3 cm and 123.9 cm^2/tree respectively) in thinned areas but not in unthinned areas.

* Doubling the rate of N gave no significant increase in crop tree volume increment in either unthinned or thinned areas.

* Average height was not significantly affected by additional N or by thinning.

* Fertiliser x thinning interaction was significant for DBH, basal area and volume increments but not significant for height.

* There was no treatment effect on foliar N, P, K, Mg and B levels but foliar Ca was affected 2 years after treatment.

* Inclusion of a P source (treatment T_1N_1 P) did not affect growth increments or foliar nutrient levels compared to treatment T_1N_1 two years after treatment.

* The foliar nutritional status of all treatments in 1990 was below the values associated with optimum growth of vigorous young eucalypts.

ACKNOWLEDGEMENTS

This trial was established in 1988 and remeasured in 1989 by Peter Knight and Phil Allen with assistance from FRI technical staff. Ham Gifford and Errol Hay helped remeasure trees and collect foliage samples in 1990. Jean Prince and Gillian Nicholson analysed the foliage and soil samples. The authors wish to thank all these people for their contributions.

REFERENCES

Frederick, D.J., Madgwick, H.A.I., Jurgensen, M.F., Oliver, G.R. 1985: Dry matter and nutrient distribution in an age series of *Eucalyptus regnans* plantations in New Zealand. New Zealand Journal of Forestry Science 15(2): 158-79.

Hayward, W.J. 1987: Volume and taper of *Eucalyptus regnans* grown in the central North Island of New Zealand. *New Zealand Journal of Forestry Science 17(1)*: 109-120.

Hunter, I.R. 1986: Growth response in an N fertiliser and thinning trial in *Eucalyptus regnans*. FRI Project Record No. 1399 (unpublished).

Knight, P.J. 1988: Seasonal fluctuations in foliar nutrient concentrations in a young nitrogen-deficient stand of *Eucalyptus fastigata* with and without applied nitrogen. *New Zealand Journal of Forestry Science 18(1)*: 15-32.

Knight, P.J. and Allen, P. 1990: Early results – thinning x fertiliser trial – *Eucalyptus regnans*. Management of Eucalypts Cooperative. Report No. 6. (Unpublished).

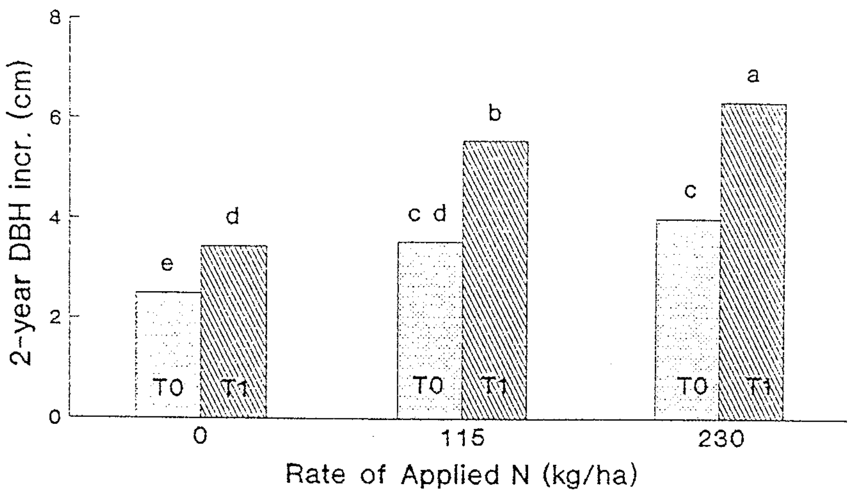
McKenzie, H. 1990: Validation of the NZFP Forests *Eucalyptus regnans* growth model. Management of Eucalypts Cooperative Report No. 7 (unpublished).

Nicholson, G. 1984: Methods of soil, plant and water analysis. FRI Bulletin No. 70.

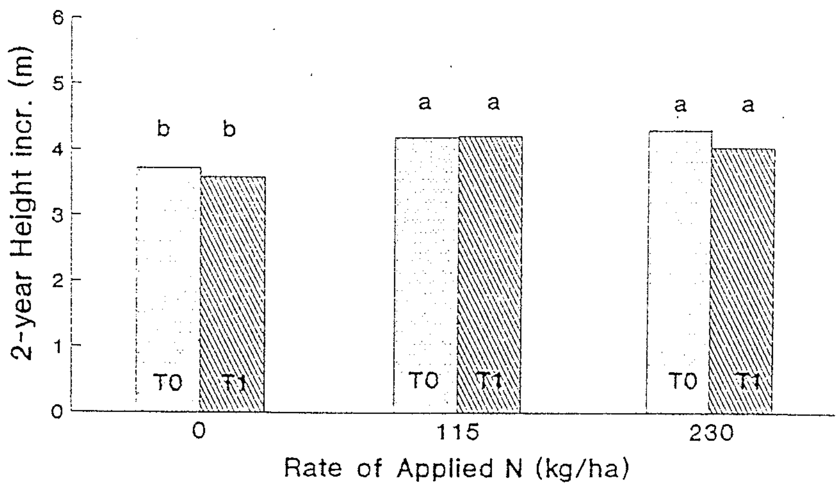
Will, G. 1985: Nutrient deficiencies and fertiliser use in New Zealand exotic forests. FRI Bulletin No. 97.

Effect of Thinning and N Fertiliser on
Crop Tree Growth between 4.5 and 6.5 Years

DBH Increment



Height Increment

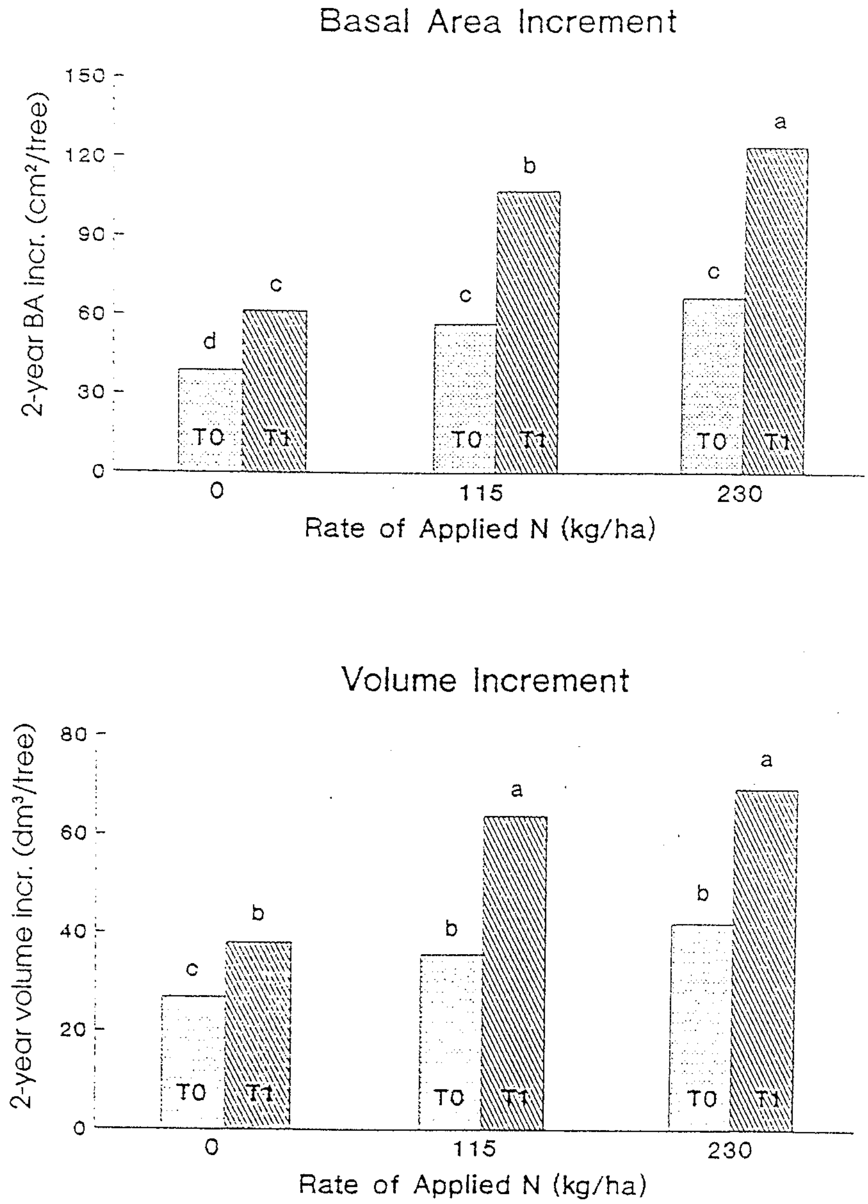


Note : T0 = Unthinned T1 = Thinned
Values with same letters do not differ significantly at $p < 0.05$ (LSD test)

FIGURE 1

Effect of Thinning and N Fertiliser on

Crop Tree Growth between 4.5 and 6.5 Years



Note : T0 = Unthinned T1 = Thinned
Values with same letters do not differ significantly at $p < 0.05$ (LSD test)

FIGURE 2

APPENDIX 1

Mean DBH and average height of crop trees in 1988 and 1990 and 2 year increments

Treatment	DBH (cm)		Incr.	Height (m)		Incr.
	1988	1990	88-90	1988	1990	88-90
T_1N_2	9.2^{ab}	15.6^{a}	6.3^{a}	8.5	12.5	4.0^{abc}
T_1N_1	9.5^{a}	15.0^{a}	5.6^{b}	8.7	12.9	4.2^{a}
T_1N_1P	9.5^{a}	14.9^{a}	5.4^{b}	8.4	12.6	4.2^{ab}
T_1N_0	9.7^{a}	13.1^{b}	3.4^{d}	8.4	12.0	3.6^{c}
T_0N_2	8.6^{bc}	12.6^{bc}	4.0^{c}	8.4	12.7	4.3^{a}
T_0N_1	8.4^{c}	11.9^{cd}	3.5^{cd}	8.3	12.5	4.2^{ab}
T_0N_0	8.6^{bc}	11.1^{d}	2.5^{e}	8.7	12.5	3.7^{bc}

Note: Any means in one column with different superscripts differ significantly at $P < 0.05$ (LSD test).

APPENDIX 2

Mean basal area (BA) and volume (inside bark) of crop trees
in 1988 and 1990 and 2 year increments

Treatment	BA (cm^2/tree)		Incr.	Vol. (dm^3/tree)		Incr.
	1988	1990	88-90	1988	1990	88-90
T_1N_2	67.2^{ab}	191.1^{a}	123.9^{a}	21.7^{ab}	91.1^{a}	69.4^{a}
T_1N_1	70.7^{a}	177.9^{a}	107.2^{b}	23.4^{a}	87.3^{a}	63.9^{a}
T_1N_1P	71.0^{a}	175.2^{a}	104.2^{b}	22.8^{a}	84.2^{a}	61.4^{a}
T_1N_0	73.3^{a}	134.9^{b}	61.5^{c}	23.4^{a}	61.5^{b}	38.0^{b}
T_0N_2	58.5^{bc}	125.2^{bc}	66.7^{c}	18.7^{bc}	60.7^{b}	42.0^{b}
T_0N_1	55.3^{c}	112.0^{cd}	56.7^{c}	17.4^{c}	53.1^{bc}	35.7^{bc}
T_0N_0	58.5^{bc}	97.5^{d}	39.0^{d}	19.5^{abc}	46.4^{c}	26.9^{c}

Note: Any means in one column with different superscripts differ significantly at $P < 0.05$ (LSD test).