FRI/INDUSTRY RESEARCH COOPERATIVES

MANAGEMENT OF EUCALYPTS COOPERATIVE

FOREST RESEARCH INSTITUTE
PRIVATE BAG
ROTORUA

EARLY RESULTS - THINNING X FERTILISER TRIAL - *EUCALYPTUS REGNANS*

P. KNIGHT AND P. ALLEN

REPORT 6 FEBRUARY 1990

Confidential to Participants of the Management of Eucalypts Cooperative

MANAGEMENT OF EUCALYPT COOPERATIVE

EARLY RESULTS - THINNING X FERTILISER TRIAL - *EUCALYPTUS REGNANS*

P. KNIGHT AND P. ALLEN

REPORT 6 FEBRUARY 1990

NOTE : Confidential to participants of the Management of Eucalypts Cooperative.
This material is unpublished and must not be cited as a literature reference.

FRI/INDUSTRY RESEARCH COOPERATIVES

EXECUTIVE SUMMARY

PRELIMINARY RESULTS FROM A THINNING X FERTILISER TRIAL (FR23) ESTABLISHED IN A 4-YEAR-OLD *EUCALYPTUS REGNANS* STAND IN KAINGAROA FOREST

SUMMARY

A factorial thinning x fertiliser trial was installed in a 4-year-old *Eucalyptus regnans* stand located in Cpt 59 Timberlands Kaingaroa Forest. Fertiliser nitrogen (N) was applied as urea at either 0, 250 or 500 kg/ha compound, and plots were either unthinned (ca. 1667 trees/ha), or thinned (to ca. spha) and form pruned. A supplementary treatment (t_1n_1p) consisted of 500 kg/ha partially acidulated phosphate rock ('Duraphos' PAPR), plus 250 kg/ha urea applied to a thinned/for pruned plot.

When measured 12 months from treatment date, crop trees in both thinned and unthinned plots showed a significant response to applied N in mean diameter. The diameter response to applied N in thinned plots was significantly greater than in unthinned plots. For crop trees, mean diameter gains to urea at the lower rate were 0.87 and 1.65 cm for unthinned and thinned plots respectively, with an additional 0.14 and 0.29 cm at the higher rate. The gain in mean basal area increment per crop tree was 16.2 cm^2 in unthinned plots, compared with 30.1 cm^2 in thinned/form pruned plots. When N rate was doubled the additional gain was 1.1 and 5.8 cm^2 respectively. Thinning slightly but significantly depressed mean height relative to unthinned treatments; applied nitrogen at either rate resulted in a small but significant increase in height relative to unfertilised trees. Thinning x N level interaction was not significant for mean height, but was highly significant for mean diameter response per tree.

Urea fertiliser at 250 kg/ha significantly increased foliar concentrations of N, P, S, Cu and Zn, but depressed levels of K and Mg in foliage samples collected a month after treatment. Thinning depressed foliar levels of Mg and Cl but did not significantly affect levels of other nutrients. The P inclusive treatment (t_1n_1p) significantly increased foliar concentrations of all macronutrients relative to the corresponding P omitted treatment (t_1n_1), but had no significant effect on micronutrient concentrations.

RESULTS FROM A THINNING X FERTILISER TRIAL - *EUCALYPTUS REGNANS*

P. KNIGHT AND P. ALLEN

INTRODUCTION

Following approval of an FRI work plan proposed by the Technical Committee of the Management of Eucalypts' Cooperative on 16.9.87, a fertiliser x thinning trial was established in a 4-year-old stand of *E. regnans* at a site in Cpt 59, off Waiora Rd, Timberlands, Kaingaroa Forest.

An earlier fertiliser x thinning trial with the same species was established in an older (7-year-old) stand at Waipapa in Tokoroa Forest (NZFP Ltd) by Dr M.G. Messina (a National Research Advisory Council post-doctoral fellow at the FRI). Urea (500 kg/ha)) applied in recently thinned plots (300 spha) elicited a strong response in both volume and basal area, but no height; in unthinned plots (1200 spha) there was no significant fertiliser response. Over the three year period following treatment, the volume[1] gain to N applied at 225 kg/ha in thinned plots amounted to 18 m^3/ha compared with a nil in the corresponding unthinned plots. The response to thinning and fertiliser were additive.

Another trial (AK1013) with IE. regnans at a site in Tairua Forest demonstrated a strong response in diameter but no height to DAP (500 kg/ha) applied in conjunction with thinning at stand age 2 (Knight, unpublished data). In this pilot trial no attempt was made to separate effects due to thinning and fertiliser.

On good sites, *E,. regnans* can attain a height of at least 8 m, by age 3 (Knight *et al.* 1989, unpublished). For a short rotation sawlog regime (<40 years) a heavy, early thinning in conjunction with fertilised can be used to capitalise on special features exhibited by this species. These features include: rapid growth, early assertion of dominance, good response of dominants to release, some capacity for 'self pruning', and minimal tendency to coppice. Furthermore, as crowns of eucalypts do not interlock even in older, fully-stocked forests, this genus is said to be "crown-shy". The growing tips on shoots are prone to abrasion when crowns touch during wind sway. Thus, for optimal growth it is desirable that rapidly growing young trees have enough room for their canopies to expand without undue restriction. The delicate, unprotected naked buds, which are a characteristic of eucalypts, make indeterminate, rapid growth possible whenever conditions are favourable. Excessive stocking tends to encourage height growth though intense competitive pressure for dominance; under such conditions height growth may be at the expense of diameter growth.

---

[1] Based on the TO38 tree volume equation (Hunter, 1968)

The present trial was designed to quantify growth responses to factorial combinations of 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.

The 3-year-old stand in Cpt 59, Kaingaroa Forest 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 was the high incidence e of double or multiple leader trees. In view of the prevalence of malformation, it was decided to make the silvicultural comparison one between unthinned/untended and thinned/form pruned crops.

Woolons (1985) has drawn attention to the problems associated with analyses of long term fertiliser x thinning experiments with particular reference to *Pinus*. He used data from a fertiliser trial established by H.D. Waring in NSW in 1944 to compare four different forms of covariance analysis; he concluded that the use of basal area per tree as a covariate and response variable is much to be preferred to use of initial basal area per hectare and stocking. In this study we have adopted his recommendation for using basal area per tree as covariate and have compared effects of treatments on marked crops selected 'from below'. Although not reported here, a record was also kept of basal area per plot based on measurements of all trees in the measurement plots made just prior to imposing treatments, and again one year later.

METHODS

SITE HISTORY

The site selected for the trial was located in Cpt 590, Kaingaroa Forest, off Waiora Road (Fig. 1). The 61 ha stand of *E. regnans* in this compartment was planted in August/September 1983 at about 3 x 2 m spacing (ca. 1667 stems per ha). Soon after planting, 60 g urea was applied in a spade slit by each tree. The eucalypt stand succeeded an earlier crop of *P. radiata* (planted in 1928) which was clearfelled and logged in 1982/83. The soil at the site is a disturbed yellow brown pumice sand. The deep pumice ash profile is shown in Fig. 10 (p 17). The area was windrowed by V-blade before being planted with *Eucalyptus* stock.

EXPERIMENT DESIGN AND TREATMENTS

The experimental design adopted was a randomised complete block with six blocks (Fig. 2). Treatments consisted of factorial combinations of two levels of thinning, *viz.* unthinned (ca.

1667 stems/ha^{-1}) and thinned (ca. 600 stems ha^{-1}) and three levels of urea fertilisation, *viz.* 0, 250 and 500 kg urea kg^{-1}. The thinning treatments 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; and
t_0 and t_1 denote stocking (i.e. unthinned or thinned).

A supplementary treatment (t_1b_1p) testing the response of phosphorus applied as 'Duraphos' PAPR (500 kg ha^{-1}) in combination with thinning and 250 kg ha^{-1} urea was included in the trial.

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

Each whole plot (inner measurement plot plus surround) measured 30 x 30 m (0.09 ha). The surrounds which were treated in the same way as the inner plot 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 to avoid, as far as practicable, any uneveness in growth.

Thinning 'from below' was carried out from 13-14 January 1988. 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 prevent infection with pathogens such as *Stereum*.

DIARY OF EVENTS

Fertiliser treatments applied[1]	7-8 January 1988
Thinning treatment imposed	13-14 January 1988
Form pruning/fungicide treatment of stumps	19-22 January 1988
Tree measuring (diameters and heights)	12-15 January 1988
Foliage sampling	10 February 1988
Remeasurement of trees	2-3, 7 February 1989.

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

As plots nearer an adjoining old *P. radiata* stand had appreciable young pine regeneration, it was decided, during establishment of the trial, to slash 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 we--grown tutu throughout the plots.

MEASUREMENTS

Over the period 12-15 January 1988, diameter outside bark (D) at breast height (1.4 m) was recorded for all stems in the plots prior to thinning. At the same time 19 trees in each plot were selected on the basis of size, form and spacing as potential crop trees. Of these trees, which were tagged and numbered for identification, twelve were randomly selected and measured for height by means of height poles. The same twelve trees were remeasured for height one year later so that initial height could be used as a covariate.

Basal area[1] (BA) per tree was calculated as:

$$BA = \frac{\pi D^2}{4}$$

Volume function was calculated as:

$$VF\ (m^3) = (dbh\ (cm) \times Ht\ (m) / 10^4).$$

STATISTICAL METHODS

For the purposes of this report, the comparison of diameter responses in thinned and unthinned plots, except where mortalities have occurred, is based on 19 tagged and numbered trees in each plot. In unthinned plots, 19 trees were selected 'from below' prior to treatment in the same way as those selected as crop trees in plots to be thinned.

---

[1] Basal area at 1.4 m above ground.

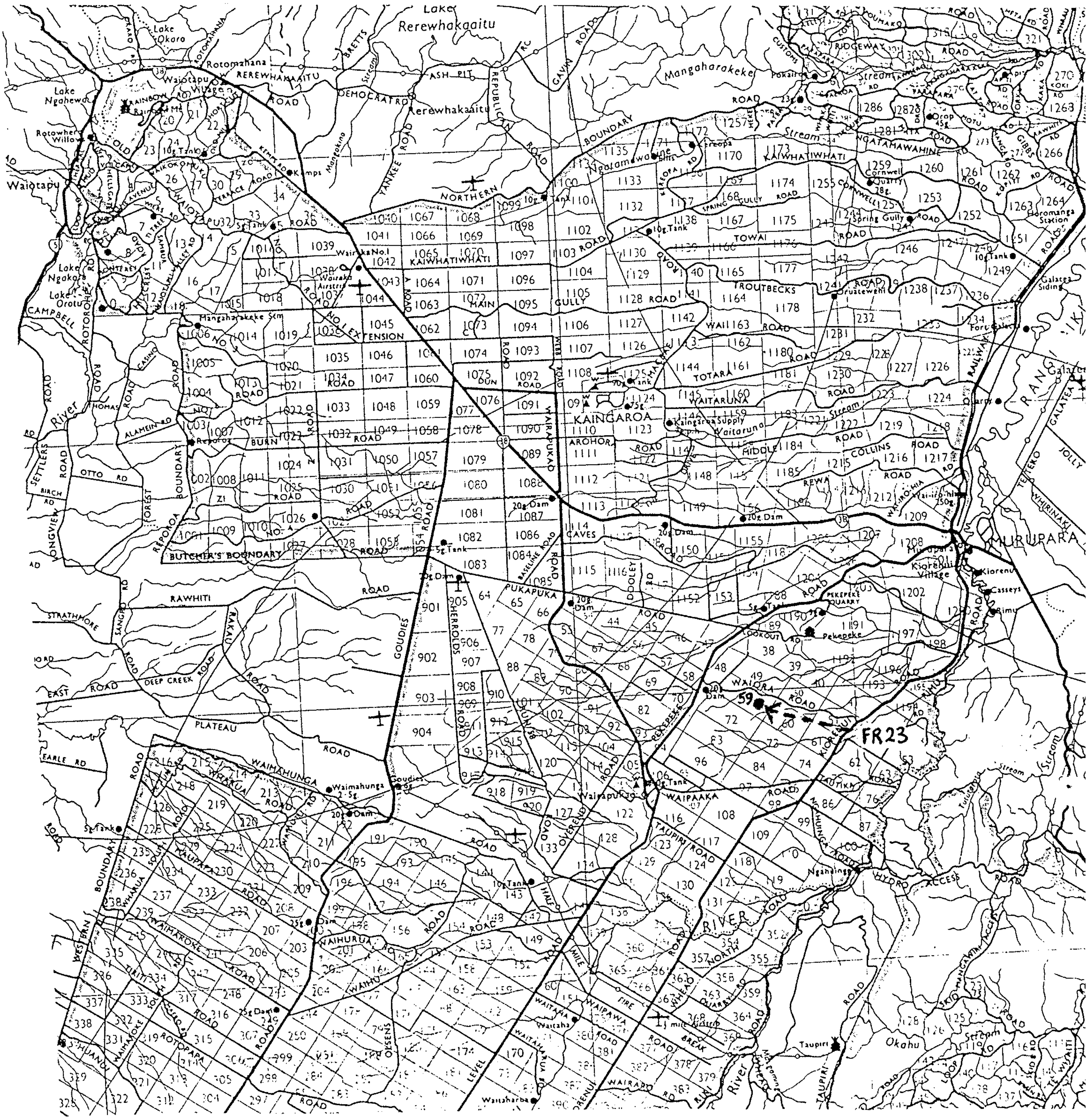

Figure 1 : Location of Cpt 59 in Timberlands, Kaingaroa Forest

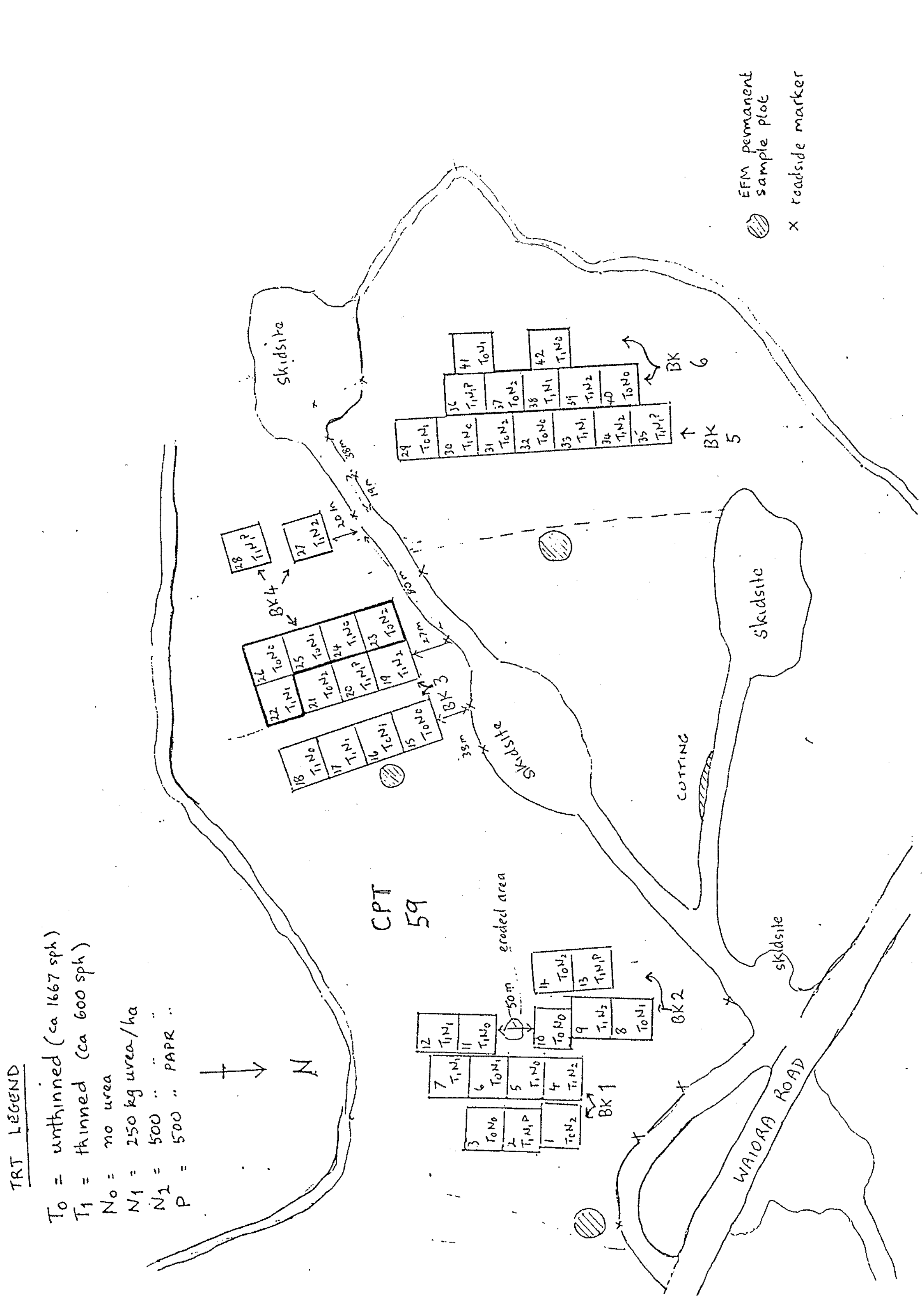

Figure 2 : Sketch plan showing layout of trial in Cpt 59, Timberlands, Kaingaroa Forest

The comparison of height response is generally based on 12 trees[1] in each plot. However where tops were subsequently lost, as a consequence of wind damage from Hurricane (March 1988), height data for affected trees were excluded from analysis.

As recommended by Woolons (1985) we have used basal area per tree as a covariate and response variable. Two-way analyses of covariance (thinning x N rate) were carried out for dbh OB (D), height (Ht), basal area/tree and a volume function (Ht x D). The covariates used were the initial values of dbh, Ht, basal area or volume function. The Least Significant Difference (LSD) test was used to separate means.

Other response variables examined by two-way analyses of variance (thinning x N rate) were foliar concentrations of each of 13 elements (N , P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn, Al and Cl) determined in samples collected one month after treatment.

Comparison of individual nutrient levels in standard foliage samples from the t_1n_1 treatments respectively was by means of one-way analysis of variance (for all seven treatments) and LSD $_{0.05}$ test.

FOLIAGE SAMPLING AND CHEMICAL ANALYSIS

Foliage samples were collected from the upper third of sunlit crown and were fully expanded leaves of the current season. Three blocks (1, 3 and 5) were sampled for each of the seven treatments on 10 February 1988, i.e. ca. one month after imposition of fertiliser treatment.

The samples were oven dried to constant weight and were finely ground in a stainless steel Wiley mill. Thirteen elements were determined in the samples viz. N, P, K, C a, Mg, S, B , Cu, Fe, Mn, Zn, Al and Cl. Nitrogen was determined in a micro-Kjeldahl digest using indophenol blue. Boron was determined colorimetrically by a modified curcumin method after dry ashing. Other elements were determined by X-ray fluorescence spectroscopy. Details of the procedures can be found in Nicholson 91984).

---

[1] The number of trees for height measurement was restricted to 12 to keep costs to an acceptable level.

RESULTS AND DISCUSSION.

Densities in the trial plots prior to thinning are listed in Appendix Table 1.

Although a hot dry period followed imposition of treatments, an isolated, heavy rain shower occurred on the day following application of fertilisers. This washed the urea into the soil and should have effectively prevented any serious risk of volatilisation.

As the incidence of multileadering was high in the trial area (Appendix Table 6) it was decided to combine form pruning with the thinning operation. Any trees which were multileadered from below breast height (1.4 m) were pruned at time of thinning, leaving only the best single leader. In this trial, therefore the effects of form pruning and thinning are confounded.

Although no record was kept of canopy depth, it was very obvious to the eye when measuring trees one year later, that urea fertilised trees in thinned plots had appreciably greater depth of crown than in unfertilised thinned plots. When recording diameters it was also apparent that for individual trees, diameter increment was generally related to the initial diameter. Subsequent statistical analysis showed that initial diameter and height were highly significant as covariates for diameter and height measured on year later. Similar treatment effects, i.e. accelerated canopy development (increase in foliage mass) and a tendency for larger diameter trees to grow faster in diameter, have been reported by Mead *et al.* (1984) from a thinning x nitrogen fertiliser trial in a young *Pinus radiata* stand.

When measured 12 months from the date of imposition of treatments, the average diameter[1] gains to N_1 (urea 250 kg/ha^{-1}) on crop trees were 0.87 and 1.64 cm in unthinned and thinned/form pruned plots respectively (Table 1). These are equivalent to mean basal area increments per tree (at 1.4 m) of 16.2 and 30.1 cm^2 respectively. When the N rate was doubled (N_2:500 kg urea ha^{-1}), diameter gain over the N_1 level was significantly increased in thinned, but not in unthinned plots. However the additional gains amounted to average increases of only 0.14 and 0.29 cm in diameter, i.e. 1.1 and 5.8 cm^{23}/m basal areas per tree respectively.

---

[1] At breast height (1.4 m)

TABLE 1 - Means Separation by LSD test (for factorial 2-way anocovars)
(a) Diameter at breast height; (b) Height' (c) Basal area per tree; (d) Vol. function per tree

(a) Diameter at breast height (cm)

	MEAN DIAMETER/TREE			
	N_0	N_1	N_2	Mean
t_0 (unthinned)	10.69^a	11.53^b	11.67^b	11.30^b
t_1 (thinned)	10.77^a	12.41^a	12.70^a	11.96^a
Mean	10.73	11.97	12.18	11.63

	TEST	
Source	$LSD_{0.05}$	Pr.F Sig.
Thinning	0.154	<.001**
N level	0.182	<.001**
Interaction	0.257	<.001**

(b) Height (m)

	MEAN HEIGHT			
	N_0	N_1	N_2	Mean
t_0 (unthinned)	10.52	10.74	10.84	10.70^a
t_1 (thinned)	10.14	10.66	10.36	10.39^b
Mean	10.33	10.70	10.60	10.54

	TEST	
Source	$LSD_{0.05}$	Pr.F Sig.
Thinning	0.150	<.001**
N level	0.190	<.002**
Interaction	0.273	0.110ns

(c) Basal area per tree (cm^2)

	MEAN BA/TREE			
	N_0	N_1	N_2	Mean
t_0 (unthinned)	93.1^a	109.3^b	110.4^b	104.3^b
t_1 (thinned)	95.2^a	125.3^b	131.1^a	117.2
Mean	94.2	117.3	120.8	110.7

	TEST	
Source	$LSD_{0.05}$	Pr.F Sig.
Thinning	2.97	<.001**
N level	3.46	<.001**
Interaction	4.89	<.001**

(d) Volume function per tree (cm^2)

	MEAN VOLUME FUNCTION/TREE			
	N_0	N_1	N_2	Mean
t_0 (unthinned)	0.138^a	0.168^b	0.169^b	0.158^b
t_1 (thinned)	0.138^a	0.191^a	0.196^a	0.175^a
Mean	0.138	0.180	0.182	0.166

	TEST	
Source	$LSD_{0.05}$	Pr.F Sig.
Thinning	0.0065	<.001**
N level	0.0079	<.001**
Interaction	0.0111	0.003**

There was no significant interaction between thinning and N level for mean height. Thinning significantly depressed height growth but only, on average, by 0.31 m (less than 3% of total height). Such an effect is not unusual in thinning trials as thinning tends to reduce the competitive pressure for individual trees to gain dominance. The nitrogen effect on height was positive with a small but significant increase up to the N_1 level. Doubling the N rate did not result in any further increase.

Thinning and N fertiliser effects on mean volume function per tree show a significant interaction. Thinning by itself did not affect volume function. Urea at 250 kg/ha, with or without thinning significantly increased volume function, but doubling the rate of urea did not result in any further significant increase. The gain in volume function to urea alone was 0.030 m^3/tree, compared with 0.053 m^3/tree to thinning-plus-urea.

Treatment t_1n_1p, which combined P (as partially acidulated phosphate rock (PAPR) at 500 kg/ha) with thinning and urea (250 kg/ha), did not increase mean dbh ba/tree or vol. function/tree relative to the corresponding thinning and urea only (t_1n_1) treatment, but did depress mean height by a significant small margin.

TABLE 2 - Growth response to applied P " Comparison of T_1N_1 and T_1N_1P treatments (from one-way anocovars with means separation by $LSD_{0.05}$ test)

Treatment	VARIATE			
	Mean height (m)	Mean dbh (cm)	Mean BA/tree (cm^2)	Mean vol/tree (m^3)
t_1n_1	10.65^a	12.40^a	125.2^a	0.1987^a
$t_1b_1p_1$	10.37^b	12.41^a	124.6^a	0.1808^a
$LSD_{0.05}$	0.26	0.24	4.5	104

The results of two-way analyses (thinning x N level) of variance for individual elements in standard foliage samples collected one month after the imposition of treatments are presented in Appendix Table 4. The results show that foliar N, P, S, Cu and Zn were significantly elevated by urea fertilisation, but that doubling the urea rate did not result in a further significant increase.

By contrast, foliar K and Mg concentrations were significantly depressed by urea application at the higher rate. Thinning significantly decreased foliar Cl and Mg concentration. Significant interaction effects of thinning x N level were recorded for P and K only.

The effect of including a P source with the thinning/urea (250 kg/ha) combination on individual foliar levels can be seen in Appendix Table 5. Including a P source significantly raised levels of the macronutrients, but had no effects on levels of micronutrients.

Fig.1:Treatment effects on mean dbh '89
(with mean dbh 1988 as covariate)

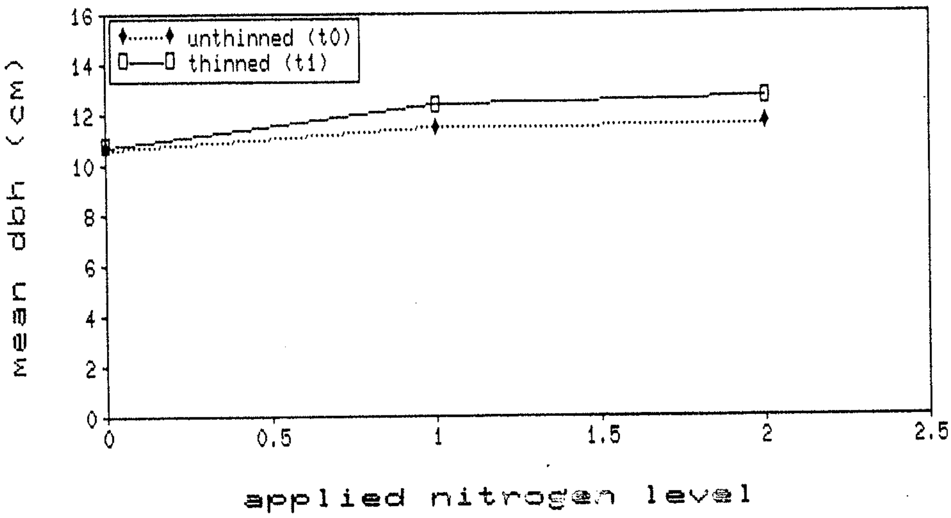

Fig.2:Treatment effects on mean BA/tree
1989 (with mean ba/tree '88 as covar.)

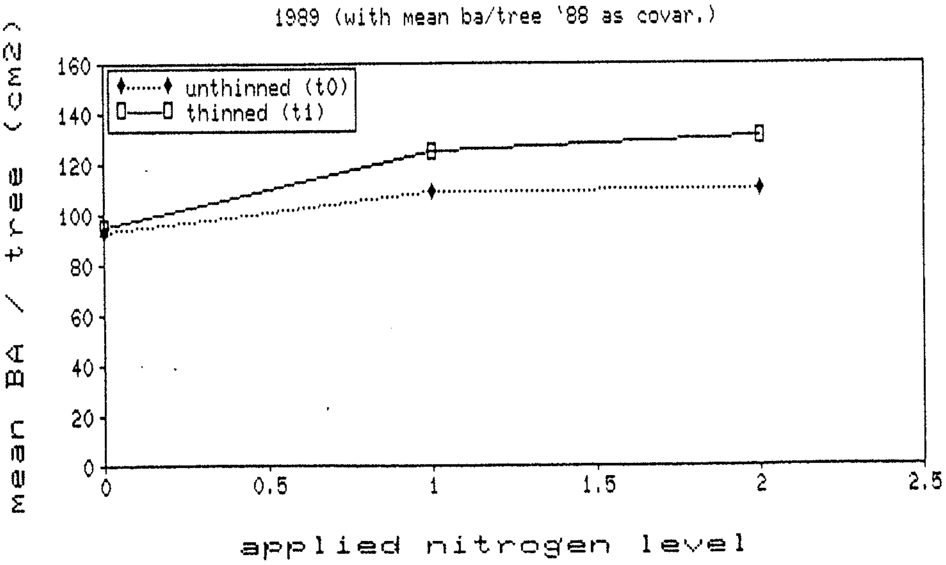

Fig.3:Treatment effects on mean ht 1989

(with mean ht '88 as covar.)

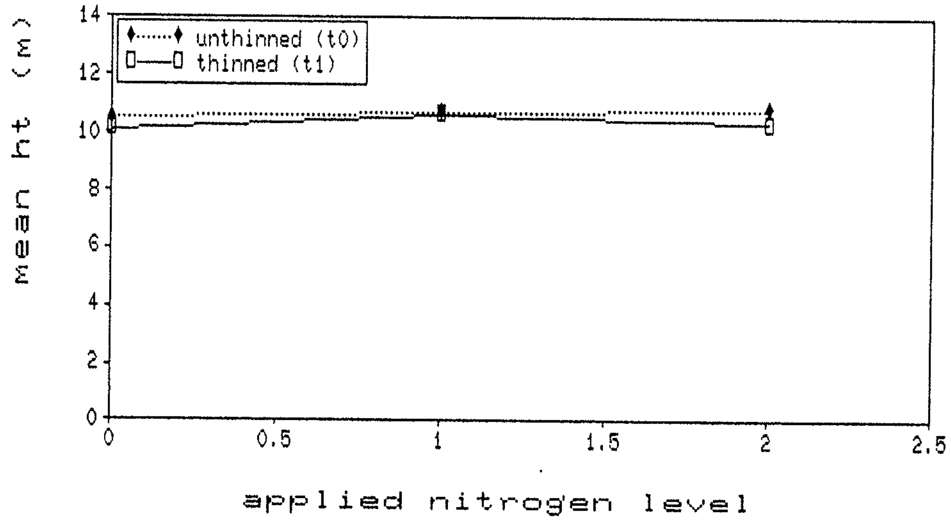

Fig.4:Treatment effects on mean vol/tree

1989 (with mean vol/tree '88 as covar.)

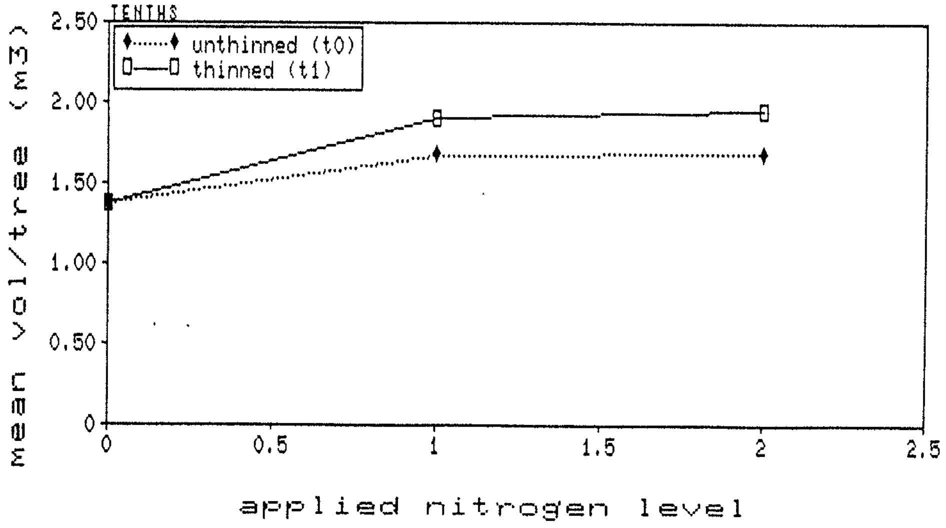

Fig.5:Effect of applied P on growth
variates (1989 with 1988 as covar.)

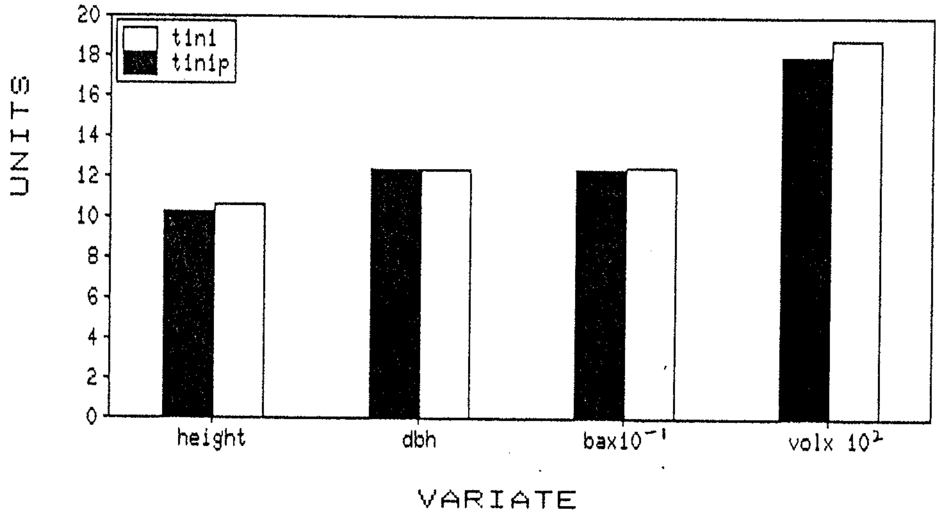

Fig.6 :Effect of N rate on foliar N
concentration in March 1989 samples

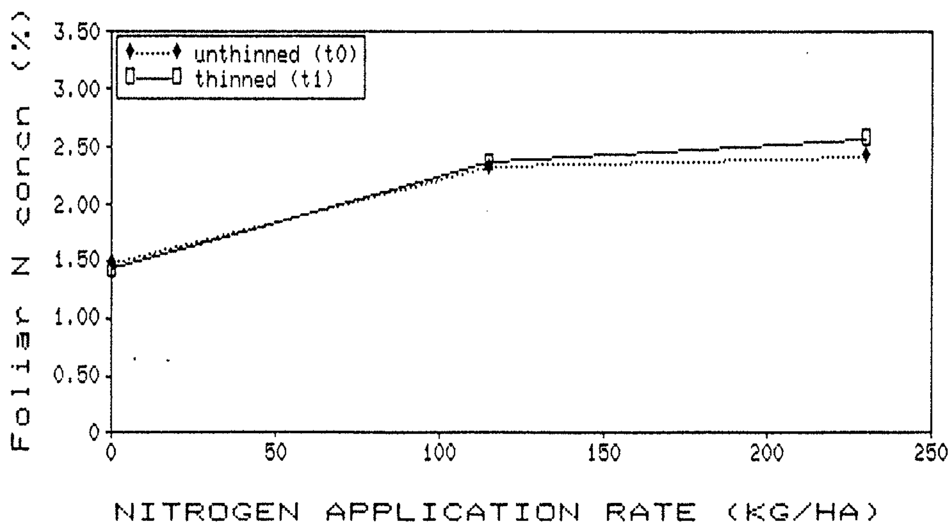

Fig.7 :Effect of N rate on foliar P concentration in March 1989 samples

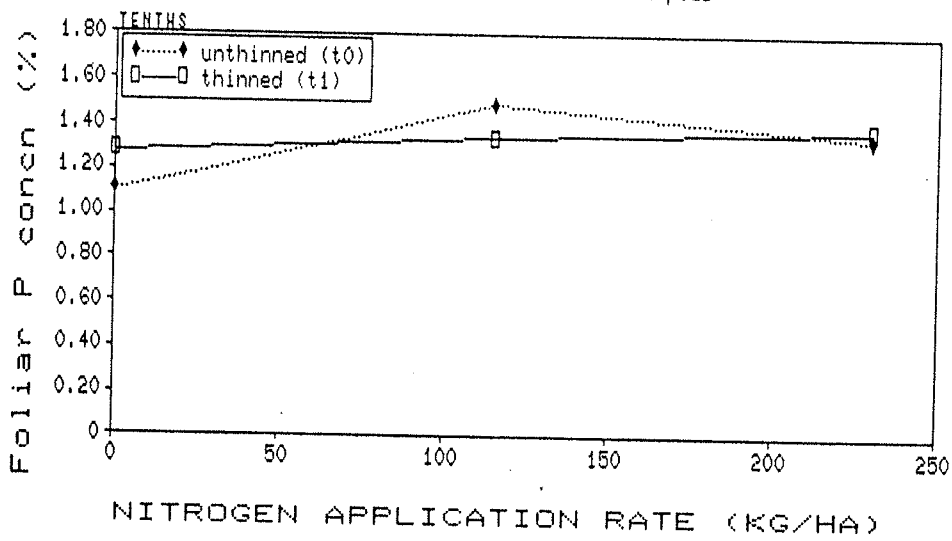

Fig. 8 : Relationship between foliar N and rate of applied nitrogen

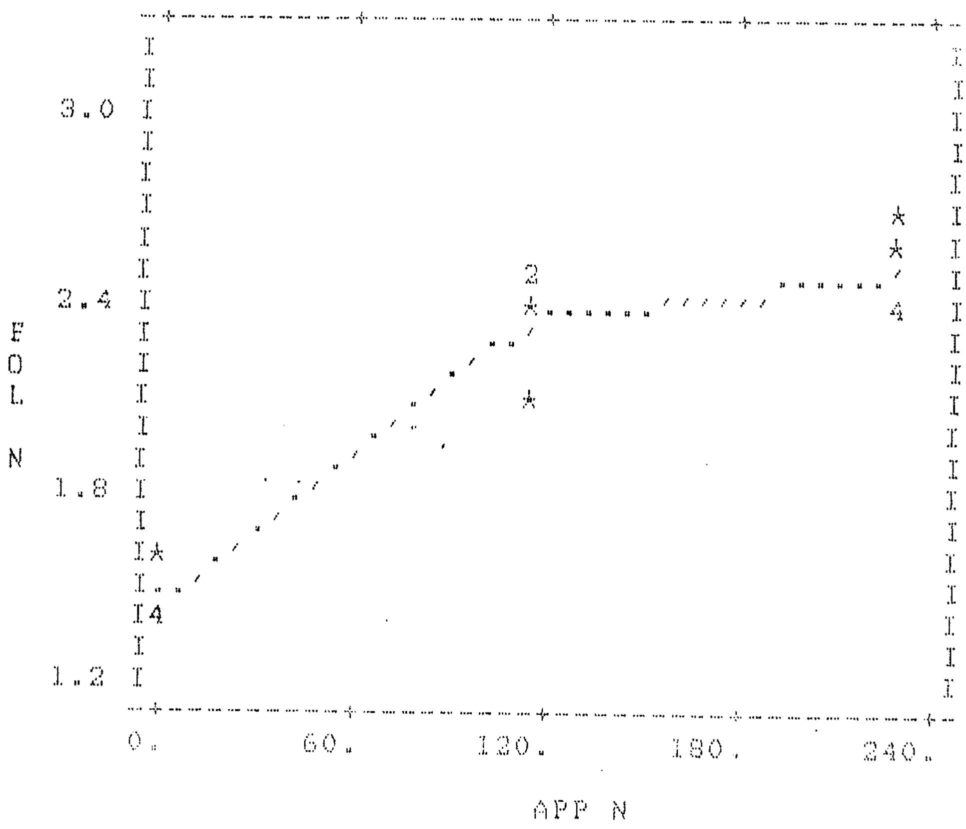

Figure 9 : View of the 4-year-old *Eucalyptus regnans* stand in Cpt 59, Kaingaroa Forest

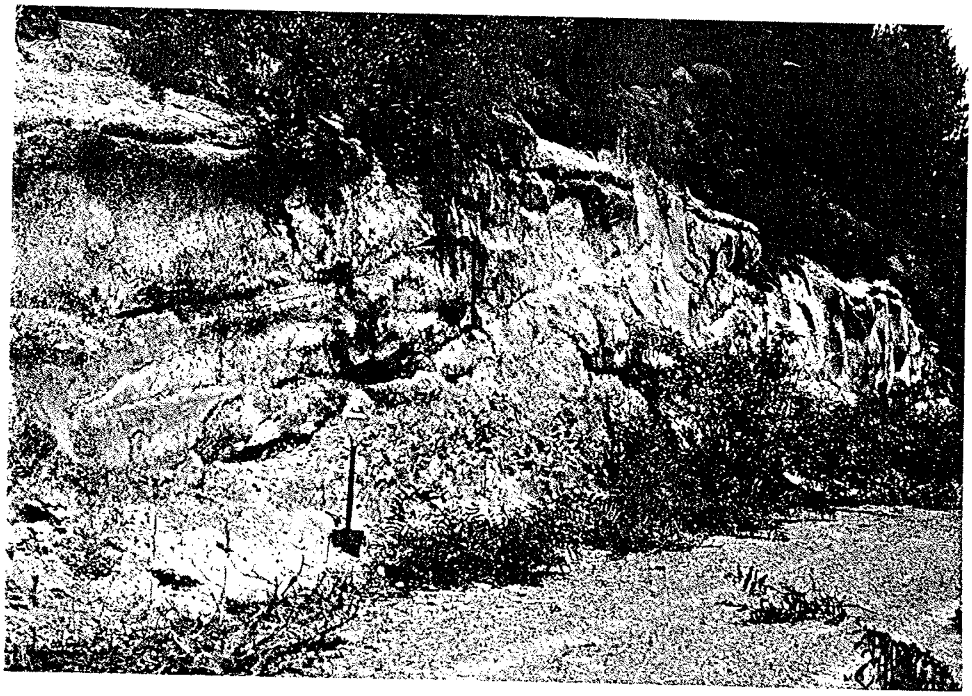

Figure 10 : Soil profile exposed in a road cutting in Cpt 59, Kaingaroa Forest

Figure 11 : View inside an unthinned trial plot

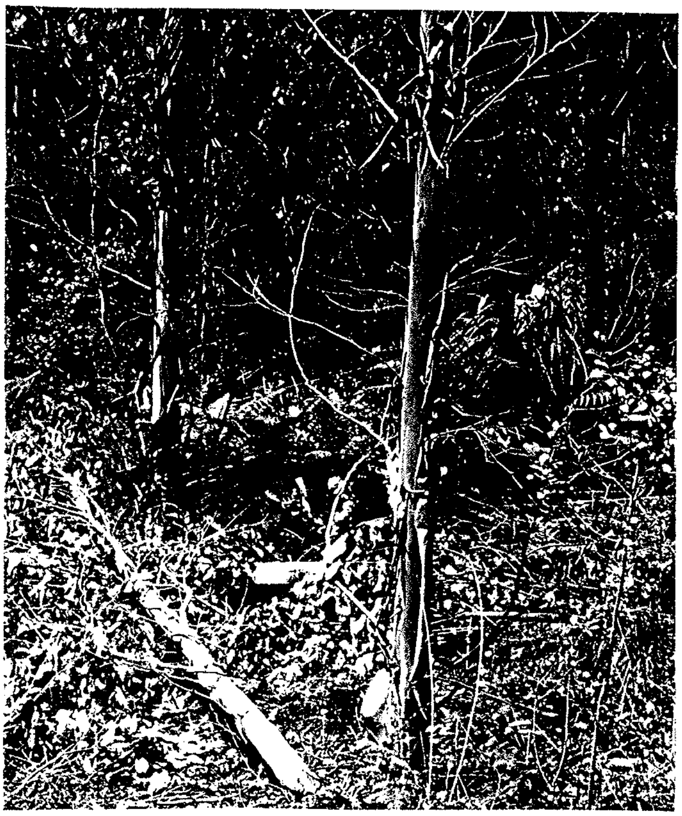

Figure 12 : Form pruning trees in a thinned plot

CONCLUSIONS

In a productive young (4-year-old) *E. regnans* stand growing on a yellow-brown pumice soil, 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.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance received from Dr S.O. Hong (FRI Biometrics) in the statistical analyses of the trial data.

Thanks are also due to Mrs Jean Prince who carried out the foliage analyses, and to other FRI staff, too numerous to mention, who assisted from time to time, e.g. in selecting trees, applying fertiliser, and measuring the trees.

REFERENCES

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., Hong, S.O. and Allen, P.J. 1989: Application of the diagnostic recommendation integrated system (DRIS) to young plantation eucalypts in New Zealand - A preliminary evaluation based on provisional norms. FRI Project Record (in press; unpublished).

Mead, D.J., Draper, D. and Madgwick, H.A.I. 1984: Dry matter production of a young stand of *Pinus radiata* : some effects of nitrogen fertiliser and thinning. *New Zealand Journal of Forestry Science* 14(1): 97-108.

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

Woolons, R.C. 1985: Problems associated with analyses of long term *Pinus* fertiliser x thinning experiments. *Australian Forest Research* 15: 495-507.

APPENDIX

CONTENTS

APPENDIX TABLE 1

STOCKING AT TIME OF THINNING

Treatment	Block (trees per plot)					
	1	2	3	4	5	6
	(Trees per plot)					
(1) $t_0\,n_0$	46	41	44	48	45	47
(2) $t_0\,n_1$	36	40	46	51	50	48
(3) $t_0\,n_2$	44	52	45	45	48	44
(4) $t_1\,n_0$	43	46	45	51	44	50
(5) $t_1\,n_1$	42	47	47	48	47	48
(6) $t_1\,n_2$	38	49	48	47	46	49
(7) $t_1\,n_1\,p$	52	46	50	44	46	51

APPENDIX 2

SUMMARY OF HEIGHT (HT) AND DIAMETER (DBH) MEANS BY BLOCK AND TREATMENT FOR :
(A) 1988 (PRETREATMENT)
(B) 1989 (12 MONTHS LATER)

(a) 1988 Means

	DBH (cm)					
Block	**1**	**2**	**3**	**4**	**5**	**6**
Treatment						
$t_0 n_0$	10.953	10.379	9.258	9.674	10.053	9.295
$t_0 n_1$	9.489	9.147	9.337	8.826	9.653	9.358
$t_0 n_2$	10.379	9.958	9.200	8.468	9.679	10.205
$t_1 n_0$	9.016	9.026	9.974	9.484	9.174	10.116
$t_1 n_1$	10.089	9.589	8.795	9.121	9.821	8.642
$t_1 n_2$	9.005	8.379	8.747	8.953	9.505	9.537
$t_1 n_1 p$	9.468	7.863	10.184	8.547	9.695	10.147

	Ht (m)					
Block	**1**	**2**	**3**	**4**	**5**	**6**
Treatment						
$t_0 n_0$	9.125	9.258	8.108	8.425	8.758	8.700
$t_0 n_1$	8.767	7.483	8.425	8.408	8.550	7.850
$t_0 n_2$	8.850	8.917	8.300	7.517	8.650	8.100
$t_1 n_0$	8.283	8.150	9.233	8.108	8.192	8.408
$t_1 n_1$	9.142	8.583	8.650	9.008	8.858	7.717
$t_1 n_2$	8.408	8.300	8.433	8.175	8.608	8.958
$t_1 n_1 p$	8.550	8.333	9.233	8.058	8.542	7.950

(b) 1989 Means

	DBH (cm)					
Block	**1**	**2**	**3**	**4**	**5**	**6**
Treatment						
$t_0\ n_0$	12.24	11.52	10.35	10.94	11.42	10.22
$t_0\ n_1$	11.86	11.45	11.39	10.89	11.48	11.29
$t_0\ n_2$	12.62	12.27	11.46	11.00	11.67	12.05
$t_1\ n_0$	10.27	10.71	11.21	10.76	10.34	11.38
$t_1\ n_1$	13.07	12.50	11.50	12.09	12.92	11.79
$t_1\ n_2$	13.02	11.73	11.64	12.31	12.62	12.59
$t_1\ n_1\ p$	12.49	10.87	13.13	11.62	12.81	12.87

	Ht (m)					
Block	**1**	**2**	**3**	**4**	**5**	**6**
Treatment						
$t_0\ n_0$	10.95	11.20	10.03	10.59	11.03	10.77
$t_0\ n_1$	11.08	9.66	10.68	10.34	10.83	10.47
$t_0\ n_2$	11.44	11.24	10.57	9.76	11.13	10.37
$t_1\ n_0$	9.53	10.05	10.94	9.63	9.92	10.26
$t_1\ n_1$	11.08	1.081	10.87	11.15	11.27	9.82
$t_1\ n_2$	10.29	10.51	10.08	10.43	10.44	10.42
$t_1\ n_1\ p$	10.19	10.27	11.47	9.74	10.37	9.98

APPENDIX 3

SUMMARY OF BASAL AREA PER TREE AND VOLUME FUNCTION PER TREE BY BLOCK AND TREATMENT FOR :
(A) 1988 (PRETREATMENT)
(B) 1989 (12 MONTHS LATER)

(a) 1988 Means

	BA/Tree (cm^2)					
Block	**1**	**2**	**3**	**4**	**5**	**6**
Treatment						
$t_0\ n_0$	98.95	90.10	71.78	76.98	81.89	69.70
$t_0\ n_1$	74.28	73.48	70.80	63.58	76.52	71.72
$t_0\ n_2$	86.78	80.33	68.94	58.93	75.47	84.58
$t_1\ n_0$	67.37	68.52	80.75	72.42	67.55	83.37
$t_1\ n_1$	81.69	73.87	63.67	68.10	76.84	59.80
$t_1\ n_2$	69.18	56.99	62.53	64.90	73.59	73.41
$t_1\ n_1\ p$	73.09	50.26	84.02	59.74	76.73	83.32

	[1]Volume Function/Tree					
Block	**1**	**2**	**3**	**4**	**5**	**6**
Treatment						
$t_0\ n_0$	1291	1293	944	888	1009	829
$t_0\ n_1$	1037	829	820	764	866	816
$t_0\ n_2$	1137	1071	785	545	918	871
$t_1\ n_0$	764	811	1083	848	749	1016
$t_1\ n_1$	1088	888	827	867	898	642
$t_1\ n_2$	940	699	791	724	752	928
$t_1\ n_1\ p$	892	631	1078	673	860	907

(b) 1989 Means

	BA/tree(cm^3)					
Block	**1**	**2**	**3**	**4**	**5**	**6**
Treatment						
$t_0\, n_0$	123.8	109.7	89.8	98.8	106.1	84.1
$t_0\, n_1$	116.8	113.3	104.7	96.5	108.8	105.4
$t_0\, n_2$	127.4	121.3	106.3	98.1	108.9	117.0
$t_1\, n_0$	87.0	94.6	102.8	94.5	86.3	106.1
$t_1\, n_1$	136.7	125.9	108.4	118.1	134.1	111.3
$t_1\, n_2$	140.1	112.3	110.9	121.6	130.1	128.9
$t_1\, n_1\, p$	126.3	95.7	139.0	108.9	132.2	132.5

	[1]Volume Function/Tree					
Block	**1**	**2**	**3**	**4**	**5**	**6**
Treatment						
$t_0\, n_0$	1988	1860	1442	1441	1643	1223
$t_0\, n_1$	2069	1591	1527	1434	1555	1623
$t_0\, n_2$	2117	2019	1582	1171	1658	1559
$t_1\, n_0$	1135	1337	1622	1363	1129	1597
$t_1\, n_1$	2175	1877	1750	1892	2055	1500
$t_1\, n_2$	2243	1782	1676	1758	1665	1891
$t_1\, n_1\, p$	1827	1466	2189	1469	1804	1709

1. $m^3 = \frac{\text{vol function}}{10^4}$

APPENDIX TABLE 4

MEAN CONCENTRATIONS OF 13 ELEMENTS IN FOLIAGE SAMPLES COLLECTED IN TRIAL PLOTS 1 MONTH AFTER IMPOSITION OF TREATMENTS, TOGETHER WITH RESULTS OF 2-WAY ANALYSES OF VARIANCE (THINNING X N LEVEL) AND LEAST SIGNIFICANT DIFFERENCES

TREATMENT	Foliar N (% OD wt)			
	N_0	N_1	N_2	Mean
t_0 (unthinned)	1.48	2.32	2.42	2.07
t_1 (thinned)	1.43	2.37	2.58	2.13
Mean	1.45	2.35	2.50	2.10

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	0.13	0.380 ns
N level	0.16	<0.001 **
Interaction	0.23	0.400 ns

TREATMENT	Foliar P (% OD wt)			
	N_0	N_1	N_2	Mean
t_0 (unthinned)	0.110 [a]	0.149 [a]	0.134 [a]	0.131
t_1 (thinned)	0.128 [a]	0.134 [a]	0.152 [a]	0.138
Mean	0.119	0.142	0.143	0.134

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	0.011	0.100 ns
N level	0.014	0.005 **
Interaction	0.020	0.035 *

TREATMENT	Foliar K (% OD wt)			
	N_0	N_1	N_2	Mean
t_0 (unthinned)	0.79	0.77	0.64	0.73
t_1 (thinned)	0.86	0.63	0.70	0.73
Mean	0.82	0.70	0.67	0.73

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	0.059	0.846 ns
N level	0.073	0.002 **
Interaction	0.103	0.014 *

TREATMENT	Foliar Ca (% OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	0.580	0.558	0.598	0.579
t_1 (thinned)	0.548	0.570	0.491	0.536
Mean	0.564	0.564	0.545	0.558

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	0.071	0.210 ns
N level	0.086	0.850 ns
Interaction	0.122	0.339 ns

TREATMENT	Foliar Mg (% OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	0.231	0.221	0.221	0.224 [a]
t_1 (thinned)	0.224	0.204	0.193	0.207 [b]
Mean	0.224	0.212	0.207	0.216

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	0.012	0.011 *
N level	0.015	0.034 *
Interaction	0.021	0.341 ns

TREATMENT	Foliar S (% OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	0.099	0.117	0.112	0.109
t_1 (thinned)	0.101	0.116	0.129	0.115
Mean	0.100	0.117	0.120	0.112

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	0.009	0.187 ns
N level	0.012	0.006 **
Interaction	0.016	0.226 ns

TREATMENT	Foliar Al (ppm OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	77	57	80	71
t_1 (thinned)	57	77	70	68
Mean	67	67	75	69

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	19.0	0.705 ns
N level	23.3	0.665 ns
Interaction	33.0	0.189 ns

TREATMENT	Foliar Cl (% OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	0.392	0.382	0.355	0.376 [a]
t_1 (thinned)	0.356	0.305	0.345	0.335 [b]
Mean	0.374	0.344	0.350	0.356

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	0.035	0.029 *
N level	0.044	0.308 ns
Interaction	0.062	0.281 ns

TREATMENT	Foliar B (ppm OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	15.3	15.3	14.3	15.0
t_1 (thinned)	17.0	15.7	15.3	16.0
Mean	16.2	15.5	14.8	15.5

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	1.29	0.114 ns
N level	1.58	0.218 ns
Interaction	2.23	0.658 ns

TREATMENT	Foliar Cu (ppm OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	3.6	4.9	4.7	4.4
t_1 (thinned)	3.6	4.9	5.1	4.5
Mean	3.6	49	4.9	4.5

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	0.72	0.715 ns
N level	0.88	0.012 *
Interaction	1.25	0.796 ns

TREATMENT	Foliar Fe (ppm OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	52	57	66	58
t_1 (thinned)	42	65	70	59
Mean	47	61	68	59

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	15.9	0.903 ns
N level	19.5	0.101 ns
Interaction	27.5	0.567 ns

TREATMENT	Foliar Mn (ppm OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	1299	1236	1557	1364
t_1 (thinned)	1339	1333	1249	1307
Mean	1319	1285	1403	1336

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	244	0.614 ns
N level	299	0.673 ns
Interaction	422	0.304 ns

TREATMENT	Foliar Zn (ppm OD wt)			
	N_0	N_1	N_2	Mean
t_o (unthinned)	17.0	18.7	18.0	17.9
t_1 (thinned)	15.7	17.7	19.0	17.4
Mean	16.3	182	18.5	17.7

SOURCE OF VARIATION	TEST	
	LSD 0.05	Pr. F Sig
Thinning	1.23	0.439 ns
N level	1.50	0.020 *
Interaction	2.13	0.223 ns

APPENDIX TABLE 5

COMPARISON OF MEAN CONCENTRATIONS OF 13 ELEMENTS IN FOLIAGE SAMPLES FROM THINNED PLOTS WITH (A) UREA AND PARTIALLY ACIDULATED ROCK PHOSPHATE APPLIED; AND (B) UREA ONLY APPLIED; SAMPLES WERE TAKEN 1 MONTH AFTER TREATMENT

Treatment	%						ppm						%
	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Al	Cl
t_1n_1	2.372^{b}	0.134^{b}	0.63	0.57^{b}	0.204^{b}	0.116^{b}	15.7	4.9	65	1333	17.7	77	0.305
t_1n_1p	2.654^{a}	0.187^{a}	0.71	0.69^{a}	0.227^{a}	0.159^{a}	15.7	4.6	69	1378	18.3	73	0.336
LSD $_{0.,05}$	0.224	0.022	0.12	0.11	0.023	0.016	2.0	1.1	25	413	2.0	30	0.074

Note : values in the same column with different superscript letters differ significantly at the 5% level (LSD test)

APPENDIX TABLE 6

PERCENTAGE OF MULTIPLE OR DOUBLE LEADERED TREES BY TREATMENT AND BLOCK

Treatment	BLOCK 1	2	3	4	5	6	Treatment Mean Untransformed	After Angular Transformation
	%							
t_0n_0	35	39	45	52	36	38	41.0	39.8
t_0n_1	28	43	33	31	46	40	36.7	37.2
$t_0 n_2$	33	46	44	43	31	27	37.6	37.7
$t_1 n_0$	28	30	36	33	36	29	32.1	34.5
$t_1 n_1$	26	34	26	60	26	38	34.9	36.0
$t_1 n_2$	21	46	40	30	43	31	35.1	36.1
$t_1 n_1 p$	21	54	54	52	26	35	40.5	39.3

NOTE : Means bracketed by vertical lines do not differ significantly at the 5% level