HERBICIDES INCREASE GROWTH RESPONSES TO FERTILISER IN A 5-YEAR-OLD *EUCALYPTUS REGNANS* PLANTATION*

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(Received for publication 17 July 1989; revision 16 December 1989)

ABSTRACT

A 5-year-old *Eucalyptus regnans* F. Muell. plantation in the Napier district of the North Island of New Zealand was treated with 200 kg diammonium phosphate (DAP) + 250 kg urea/ha or 200 kg DAP + 500 kg urea/ha, and with a 2% solution of glyphosate applied at a rate of approximately 3 *l* a.i./ha, in an incomplete factorial design. Reduction of herbaceous/shrubby competition significantly ($p = 0.05$) increased 20-month diameter-at-breast-height and volume increments but did not affect height increment. Fertiliser significantly influenced height increment, but did not affect diameter and volume increment over the 20-month study period. Neither herbicide nor fertiliser treatment significantly influenced foliar nutrient concentrations. The study showed that weed control can be as important as fertiliser in enhancing eucalypt growth.

Keywords: competition; herbicides; nitrogen fertiliser; phosphorus fertiliser; nutrition; *Eucalyptus regnans*.

INTRODUCTION

Several eucalypt species are currently planted in New Zealand for a variety of products ranging from fine-quality paper to furniture. Normal establishment practice involves planting nursery-grown seedlings on prepared cutover or old-field sites. Research has demonstrated the need for proper site selection and preparation, and post-planting treatment in eucalypt plantations in New Zealand (Dale 1982; Revell & van Dorsser 1980; Revell 1981; Forest Research Institute 1982; Fry 1983) and elsewhere (Schonau *et al.* 1981; Schonau & Stubbings 1983; Cremer *et al.* 1984; Schonau 1984). Growing characteristics of eucalypts are such that most species demand intensive early culture for successful plantation establishment. This intensive input to eucalypt plantations usually includes fertiliser treatment with 60 g urea/seedling at planting followed by an aerial application of 250 kg urea/ha at 12 months. Consideration has been given to further fertiliser application at crown closure. Most forest managers are aware of eucalypt species' strong demand for nutrients

* Technical Article No. 24820 of the Texas Agricultural Experiment Station, College Station, Texas.

and of the gains that may be realised through treatment of plantations with fertiliser. However, the lack of tolerance eucalypts have for weed competition is sometimes ignored in young plantations, and herbaceous/shrubby vegetation management is often neglected in favour of fertiliser treatment as a means of increasing stand productivity.

The detrimental effects of herbaceous/shrubby weed competition on the successful establishment and early growth of eucalypts are well documented (Schonau *et al.* 1981; Forest Research Institute 1982; Schonau & Stubbings 1983; Schonau 1984). One of the negative effects of weed competition concerns reduced fertiliser efficiency, defined here as the amount of applied fertiliser that is utilised by the target species. Experience with *Eucalyptus grandis* Maiden in South Africa has shown that soil should be weed free for maximum fertiliser efficiency and that fertiliser will normally increase the necessity for weeding (Schonau *et al.* 1981; Schonau & Stubbings 1983; Schonau 1984). These results apply mostly to young plantations that have not closed canopy. It is normally assumed that after stands have attained canopy closure, or the trees are at least of sufficient size to overtop competing herbaceous/shrubby vegetation, the need for weed control to maximise fertiliser efficiency declines. In fact, the point of diminishing returns from herbaceous weed control has been designated by declining herbaceous biomass (Tiarks & Haywood 1986). However, one of the causes of low fertiliser efficiencies in forest stands is uptake of fertiliser elements by competing secondary vegetation, even in older stands (Ballard 1980). Fertiliser recovery by secondary vegetation has been measured as great as or greater than recovery by the major overstorey tree species (Bjorkham *et al.* 1967; Baker *et al.* 1974).

Greater fertiliser responses may be realised in New Zealand eucalypt plantations if herbaceous competition is controlled, especially in very young stands (Forest Research Institute 1982). However, there is currently a lack of information concerning the effect of herbaceous/shrubby competition on fertiliser response in stands beyond the establishment stage, or the early period during which the trees are recovering from planting shock and adjusting to the site. The objective of this study was to determine the interaction of nitrogen (N) plus phosphorus (P) fertiliser and herbaceous/shrubby weed control in a 5-year-old *E. regnans* plantation.

MATERIALS AND METHODS

The study was established on a volcanically derived, moderately well-drained, Taupo sandy silt soil (yellow-brown pumice; Vitrandept) in the Napier district of the North Island of New Zealand. Prior to the 1979 planting with *E. regnans*, the site was rotary slashed to remove existing vegetation, predominantly of manuka (*Leptospermum scoparium* J.R. et G.Forst) and bracken fern (*Pteridium esculentum* (Forst.f.) Kuhn.), and then disced to a depth of 30 cm. Each eucalypt seedling had 30 g diammonium phosphate (DAP) applied shortly after planting. No weed control was performed after stand establishment.

The plantation was established at a spacing of 5 m inter-row × 2 m intra-row, and so crown closure between rows had not occurred by the time of study initiation. Recommended spacing for eucalypt plantations varies with location and agency in New Zealand; however, response to fertiliser and weed control should not vary greatly with stocking level, except at extreme crowding wherein competition is too great to permit trees to respond to silvicultural inputs until stocking is reduced. Management plans for *Eucalyptus* spp. in New Zealand

recommend a second fertiliser application at about the time of normal crown closure. Therefore, this stand was scheduled for fertiliser soon but had considerable weed competition (blackberry (*Rubus fruticosus* agg.), manuka, bracken fern, and grasses). The study site was chain-flail slashed after plot layout on 12 September 1984 in preparation for fertiliser application.

The experiment was designed as a herbicide × fertiliser factorial replicated five times in a completely randomised design. Plots measuring 15 × 22 m were installed, each containing two measurement rows and two border rows. Border rows were shared by adjacent plots but border trees at row ends were not. There was an average of seven trees per plot but this number varied from three to 11 owing to variable survival, the source of which was unknown.

Two herbicide and three fertiliser rates were used. However, the design was unbalanced as a herbicide-without-fertiliser treatment was not installed. The herbicide concentration used was a 2% solution of glyphosate applied at a rate of approximately 3 *l* a.i /ha. Herbicide was applied first as a weed-wiping with a tractor-mounted wick on 30 November 1984. Results were unacceptable and so a second application on 27 February 1985 was broadcast with a tractor-mounted directed-spray system at the same rate. Herbaceous biomass was not quantitatively assessed, but the visual results were very satisfactory and control was effective for the remainder of the study.

Fertiliser treatments were 0, 200 kg DAP + 250 kg urea/ha, and 200 kg DAP + 500 kg urea/ha. The fertiliser was broadcast by hand in two stages: the DAP was applied on 16 October 1984 and the urea on 13 December 1984. Applications were staggered to increase fertiliser efficiency by avoiding a large single-dose application. These treatments are designated as follows throughout the remainder of the paper:

H0F0: no herbicide, no fertiliser
H0F1: no herbicide with 200 kg DAP + 250 kg urea
H0F2: no herbicide with 200 kg DAP + 500 kg urea
H1F1: herbicide with 200 kg DAP + 250 kg urea
H1F2: herbicide with 200 kg DAP + 500 kg urea

Total tree height and diameter at breast height (dbh) were measured at study establishment and at 10 and 20 months after the DAP was applied. Foliage samples were collected on 27 February 1985, which was 4 months and 2 months after application of DAP and urea, respectively. Foliage was collected with a pole pruner from the upper one-third of the crown and only fully expanded leaves were analysed. Samples were dried to constant weight in a forced-air oven at 60°C. Ground samples were digested using sulphuric acid and hydrogen peroxide in the presence of lithium sulphate and selenium in block digesters (Parkinson & Allen 1975). Nitrogen was determined by the indophenol-blue method and phosphorus by the vanadomolybdate method; potassium (K), calcium (Ca), and magnesium (Mg) were determined by atomic absorption spectrophotometry (Nicholson 1984).

Complex volume equations covering the range of smaller tree measurements did not exist; therefore, all stem volumes were calculated with the equation for the volume of a cone:

$$\text{stem volume} = \frac{\pi r^2}{3} \times \text{total tree height}$$

Although a volume equation produced by more complete stem analysis involving measures of diameter at intervals along the length of the stem would be superior, the above equation should provide a satisfactory representation of total stem volume for the purpose of

comparing treatment effects (Husch *et al.* 1972). A volume expression derived from more detailed measurements may have assisted in explaining some of the results.

Nutrient concentration and mensurational data were analysed by the Statistical Analysis System software (SAS Institute Inc. 1987) using analysis of variance ($p = 0.05$). Initial tree diameters and heights were variable within and among plots (Table 1) and so covariance analysis was used with initial diameter, height, and volume serving as covariates. Statistical analyses were performed for response over each measurement period, i.e., 0 to 10 months, 10 to 20 months, and 0 to 20 months after treatment. Covariance analysis will adjust treatment means to values they would have had with no differences in initial values, will reduce experimental error, and will increase the precision for comparing treatment means (Gomez & Gomez 1984).

TABLE 1–Mean dbh, total height, and volume by treatment at study initiation.

Treatment	dbh (cm)	Total height (m)	Stem volume (dm^3)	No. trees per treatment
H0F0	8.4	6.5	14.3	30
H0F1	9.1	7.0	18.5	36
H0F2	8.3	6.5	14.9	34
H1F1	8.9	7.1	15.9	38
H1F2	9.7	7.7	21.7	40

RESULTS AND DISCUSSION

Although initial conditions (Table 1) varied somewhat among treatments, none of these differences was significant ($p = 0.05$). The coefficients of variation (CV) among plot means for the initial conditions were 19% for dbh, 14% for height, and 49% for volume. The CV for volume is larger than that for dbh and height as volume was calculated from dbh and height and therefore incorporates the variations of both dbh and height measurements.

The effect of fertiliser on amount and colour of herbaceous growth in the non-herbicide plots was easily discernible within 1 month of application. The herbaceous material, particularly the grasses, responded almost immediately to the fertiliser with greater growth and darker green colour making those plots easily distinguishable. However, study objectives and available technical assistance precluded measurement of herbaceous biomass for quantifying fertiliser effects on this stratum and so comparisons are limited to general observation.

Treatment effects on dbh, height, and volume increments from zero to 20 months are shown in Table 2. All statistical significances referred to in the following sections are at the $p = 0.05$ level. Herbicide application significantly affected diameter increment during the first and second 10-month measurement periods and therefore over the entire course of the 20-month study. However, herbicide application affected height and volume growth differently. Height growth responded to herbicide application significantly only during the second measurement period, but volume growth responded significantly during the second period and over the entire 20-month measurement period.

TABLE 2–Increase in mean dbh, total height, and volume by treatment after 20 months

Treatment	dbh (cm)	Total height (m)	Stem volume (dm^3)
Individual treatment effects			
H0F0	7.2 a*	4.8 a	64.9 a
H0F1	7.8 a	5.5 b	81.7 ab
H0F2	7.5 a	5.2 ab	71.4 a
H1F1	8.8 b	5.6 b	88.0 ab
H1F2	8.8 b	5.4 b	101.6 b
Overall means	8.0	5.3	81.5
Herbicide effects			
H0 (no fert)	7.2 a	4.8 a	64.9 a
H0 (with fert)	7.6 a	5.4 a	76.6 a
H1	8.8 b	5.5 a	94.7 b
Fertiliser effects			
F0	7.2 a	4.8 a	64.9 a
F1	8.3 a	5.6 b	84.9 a
F2	8.2 a	5.3 b	86.5 a

* Numbers in columns within groups followed by the same letter do not differ significantly ($p = 0.5$).

Fertiliser did not significantly alter diameter increment in any period, even though the data in Table 2 show a trend of increasing diameter growth due to fertiliser. Volume growth was significantly affected only during the first period. Fertiliser significantly affected height growth during the second period and over the entire course of the study although there was no significant difference between the two application rates. There was no herbicide × fertiliser interaction in any period for any parameter.

Covariance analysis showed that initial tree size was sometimes a significant contributing factor to growth rates during the measurement periods. Even though initial dbh was not extremely variable (CV 19% among plot means), it significantly affected dbh growth over the first measurement period and over the entire study period. Moreover, the effect of initial dbh on final dbh was quadratic over the 20-month period, indicating that trees of larger initial dbh grew at a somewhat slower rate than did trees of smaller initial dbh. However, this did not eliminate herbicide application as a significant factor affecting tree diameter growth during the study, as mentioned previously.

Covariance analysis revealed that height growth was also significantly affected by initial height at the start of each measurement period. However, both herbicide and fertiliser application still significantly influenced height increment in the second 10-month measurement period, and fertiliser did so over the entire 20-month period. Finally, initial volume was a significant covariate in all measurement periods for volume response.

Inferences can be made concerning the relative influences of herbicide and fertiliser on growth by comparing increments for certain treatments and treatment combinations to the control (H0F0). For instance, the growth increment due to fertiliser can be calculated by subtracting the increment for H0F0 from the mean increment for H0F1 + H0F2. The increment due to herbicide can be obtained by subtracting the mean increment for (H0F1 + H0F2) from that for (H1F1 + H1F2). These calculations are valid since there were no

herbicide × fertiliser interactions. Moreover, since data were subjected to covariance analysis, treatment responses were obtained with greater precision and comparisons among absolute values for treatment responses are therefore valid.

The aforementioned calculations showed that the dbh increment due to fertiliser over the course of the study was 0.4 cm but increment due to herbicide was 1.2 cm. For height, fertiliser accounted for 0.6 m whereas herbicide accounted for 0.1 m. Finally, for volume, fertiliser caused 11.7 dm^3 of increment while herbicide application caused 18.1 dm^3; only the herbicide increment was statistically significant. Together, [((H1F1 + H1F2)/2) – H0F0] fertiliser and herbicide produced added increments of 1.6 cm diameter, 0.7 m height, and 29.9 dm^3 volume over the control but only the diameter and height increments were significant.

Laboratory analyses showed that herbicide and fertiliser had very little influence on foliage nutrient concentration (Table 3). Herbicide treatment raised the concentration of some nutrients slightly (nitrogen, potassium, calcium, magnesium) and actually depressed the concentration of phosphorus, although none of these trends were significant. Fertiliser elevated some concentrations (nitrogen, potassium) and lowered others (phosphorus, calcium, magnesium), but again without statistical significance. The lack of significant alteration of foliar nutrient concentrations does not necessarily imply that fertiliser was ineffective in stimulating tree growth response. Growth dilution effects may be partly responsible for lower nutrient concentrations in treated trees, particularly for the tissue elements not added in fertiliser (Jarrell & Beverly 1981). Total foliar biomass was not determined in this study and so it is impossible to determine if nutrient content increased even though nutrient concentration remained virtually unchanged. The nitrogen and phosphorus foliar concentrations of the H0F0 treatment (20.06 g N/kg and 1.36 g P/kg) were slightly below those levels considered to be optimum for early growth of the species (24–26 g N/kg and 1.5–1.7 g P/kg) (P.J. Knight, Forest Research Institute, unpubl. data). These data show that the trees were not overtly suffering a nutrient deficiency and so a large increase in foliar nutrient concentration should not necessarily be expected after fertiliser treatment.

TABLE 3–Mean foliage nutrient concentrations (g/kg dry weight) by treatment

Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Individual treatment effects					
H0F0	20.06	1.36	8.90	3.02	2.05
H0F1	19.83	1.31	8.99	2.45	1.66
H0F2	21.19	1.29	8.63	2.68	1.95
H1F1	20.81	1.30	9.40	3.07	2.00
H1F2	20.98	1.23	9.12	2.65	1.77
Herbicide effects					
H0	20.36	1.32	8.84	2.72	1.89
H1	20.90	1.27	9.26	2.86	1.89
Fertiliser effects					
F0	20.06	1.36	8.90	3.02	2.05
F1	20.32	1.31	9.20	2.76	1.83
F2	21.09	1.26	8.88	2.67	1.86

CONCLUSIONS

This study has shown that herbaceous/shrubby weed control can be just as influential as fertiliser in increasing *E. regnans* growth. Reduced weed competition due to herbicide treatment caused significant diameter and volume increment in the 20 months after treatment, while fertiliser significantly influenced only height growth. It is unclear why herbicide was more important to diameter and volume growth, and fertiliser was more important to height growth. The results indicate that herbaceous/shrubby competition can be a major factor restricting early growth of *E. regnans*. This has substantial implications for the management of young eucalypt plantations.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Claire Bullock for her technical support during the conduct of this research and to Dr Craig McKinley and three anonymous reviewers for their helpful comments.

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