EFFECTS OF NITROGEN FERTILISER ON RADIATA PINE GROWING ON PUMICE SOILS

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ABSTRACT

This paper presents and discusses the most recent broad findpings from fertiliser trials on the pumice plateau. Response to N alone occurred over most of the pumice soils. However, the higher altitude flow tephra sites of southern Kaingaroa did not respond to N alone, but did respond to mixed fertiliser containing N, P, K, Mg and B and responded in some places to Mg fertiliser. No height response to N fertiliser was found in any trials; basal area responses have been observed only where the canopy still had room to expand, as a result of prior thinnings or pruning. A fertilised stand that was allowed to remain in a very highly stocked state to age 23 showed higher mortality than in the parts of it left unfertilised. In one detailed study of tree shape change in recently thinned 15-year-old radiata pine, diameter increment at intervals up the tree differed fairly consistently between fertilised and unfertilised plots over 80% of the tree length.

INTRODUCTION

Managers continue to be interested in nitrogen fertilising of high producing stands on the pumice plateau. That interest may increase as managers assimilate the implications of the value rise associated with an increased clearfell diameter (Bunn, 1981). Two papers appeared in the last decade dealing with fertiliser on the pumice plateau (Woollons and Will, 1975; and part of Mead and Gadgil, 1978). In the five years since the latter paper was written new trials have been established which amplify or modify their conclusions.

METHODS AND MATERIALS

The location of the trials discussed in this paper is shown in Fig. 1. They are described in outline in Table 1.

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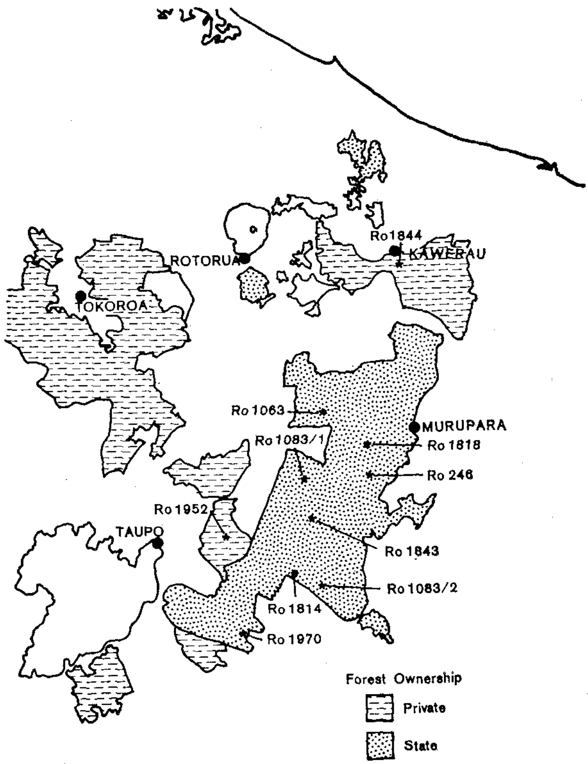

FIG. 1: *Location of recent nitrogen trials in the Bay of Plenty forests.*

Diameters of all trees have been measured annually in winter at permanently marked breast height. A sample of 8-10 trees per plot was measured at the same time for height. These data were processed through the permanent sample plot system. Only basal area and height as calculated within that system will be discussed in this paper.

In RO 1818, 60 dominant trees (5 per plot) were measured and marked at 0.7 m, 1.4 m, 3.0 m, 6.0 m 9.0 m, 12.0 m, 15.0 m and 18.0 m tree height in 1980. They were remeasured in winter 1982 at the same point. Four bark thicknesses were recorded by bark gauge at each height at each time. Analysis of covariance of diameter in 1982 on diameter in 1980 was made for each height up the tree. Polynomial taper equations of proportional diameter on proportional height were also calculated.

TABLE 1: DESCRIPTION OF THE TRIALS

Trial No.	*Date Established*	*Tree Age at Establishment*	*Previous Recent Silviculture*		*Stocking at Treatment (stems/ha)*	*Treatments*	*Factorial Layout*	*No. of Replications*
			Thinned	*Pruned*				
RO 246	1964	5	Yes	Yes	1000	Mixed fertiliser (200 kg N/ha + P, K, and Mg)	No	3
RO 1063	1980	4	No	Yes	1500	N (200 kg N/ha) and Mg (100 kg Mg/ha)	Yes	4
RO 1083/1	1976	5	No	No	Max. 3000	N fertiliser (200 kg N/ha), thinning and pruning	Yes	2
RO 1083/2	1977	6	No	No	Max. 3000	As 1083/1	Yes	2
RO 1814	1980	6	No	No	1500	Mg (100 kg Mg/ha), Mg plus mixed fertiliser (N, P, K, B, Cu)	No	4
RO 1818	1980	16	Yes	No	200	N fertiliser (200 kg N/ha)	No	6
RO 1843	1981	15	No	No	370/200	Thinning, N fertiliser (200 kg N/ha)	Yes	4
RO 1844	1981	20	No	No	500/200	Thinning, N fertiliser (200 kg N/ha)	Yes	4
RO 1952	1979	9	Yes	Yes	300	3 rates of N fertiliser (100, 200, 300 kg N/ha) P fertiliser, "lime"	No	3
RO 1970	1979	6	No	Yes	1500	3 rates of N fertiliser (100, 200, 300 kg N/ha), mixed fertiliser (N, P, K, Mg, B)	No	4

Both basal area and height data were statistically analysed using GENSTAT on the ICL-2980. Analyses of covariance were made using the initial measurement (before treatment) as the covariate. In trials where there was a factorial layout with thinning, the thinned and unthinned portions were analysed separately. Differences due to treatment are discussed in this paper only when they are significantly different at the 5% level.

Foliage was sampled and chemically analysed for nutrient content using the methods given in Nicholson (1983).

RESULTS AND DISCUSSION

1. *The Need for Nutrients other than Nitrogen*

Early experiments in Kaingaroa State Forest and on N.Z. Forest Products Ltd land used mixed fertiliser containing N, P, K, Mg and micronutrients. Later experiments tended to show that responses obtained were apparently mainly from N alone (Woollons and Will, 1975).

A recent foliar nutrient survey covering mainly northern and central Kaingaroa showed that radiata pine stands were on average marginal for nitrogen and magnesium, adequate for phosphorus and potassium (Forest Research Institute, 1982). Foliage analyses of material from control plots (unfertilised) in the trials in north and central pumice soils (Table 2) demonstrate the same nutritional pattern.

Response to phosphorus fertilisation when foliage concentrations approach 0.20% d.w. is generally small or non-existent (Mead and Gadgil, 1978). There was no basal area response to added P in RO 1952 either by itself or in interaction with N. Likewise the "liming" treatment containing P, K and Mg failed to produce growth greater than the control.

Will (1966) has described a transient yellowing of foliage in young radiata pine in north and central Kaingaroa which occurs in spring particularly after the crop has been pruned and is associated with low foliar Mg concentrations. Nitrogen is used in plants to build protein and construct the chlorophyll molecule. One Mg atom is surrounded by four nitrogen atoms in the centre of the chlorophyll molecule (Barker, 1979). It seemed possible, therefore, that a shortage of magnesium could limit the response to applied nitrogen. Transient Mg deficiency symptoms had been observed in crops adjacent to RO 1063 so the trial site was pruned to create Mg stress. Two years after fertilising with

TABLE 2: FOLIAGE NUTRIENT CONCENTRATIONS FROM UNFERTILISED PLOTS

Trial	Element % d.w.					ppm			
	N	*P*	*K*	*Ca*	*Mg*	*B*	*Zn*	*Ca*	*Mn*
1. TRIALS ON NORTHERN AND CENTRAL PUMICE SOILS									
Kaingaroa									
RO 1063	1.46	0.14			0.09				
RO 1083/1	1.43	0.19	1.10	0.14	0.08				
RO 1818	1.35	0.20			0.10				
RO 1843	1.35	0.22							
Fletchers									
RO 1952	1.28	0.19	1.01	0.17	0.08	12			
Tasman									
RO 1844	1.43	0.17				25			
2. TRIALS IN SOUTHERN KAINGAROA									
RO 1083/2	1.48	0.14			0.07				
RO 1970	1.51	0.14	0.82	0.17	0.07	10	43	10	
RO 1814	1.65	0.12	0.70	0.09	0.04	13	28	8	311
Nutrient concentration Considered · —									
adequate	1.5	0.15	0.80		0.10			5	
marginal								3	
deficient	1.2	0.12	0.40	0.10	0.08	8	10	2	10

Source: Will, 1978.

N and Mg there is a response in basal area to N alone with no contribution from Mg either by itself or in combination with N.

The southern part of the pumice plateau (Waimihia and Matea), however, appears to be different. Response to applied N in RO 1083/2 in Matea was small absolutely and relatively to RO 1083/1. There was no response to N alone in RO 1970 in Waimihia. In fact the basal area growth becomes progressively (but not statistically significantly) worse over the three N rates. There was, however, a response to the mixed fertiliser. After three years there was 1 m^2/ha more basal area in those plots than in the control (a 14% increase in basal area increment over that time). It is not clear at this stage what element or elements are required in addition to N. Foliage analysis from the control plots (Table 2) shows that the phosphorus concentrations tend to be closer to the deficiency level (0.13% P) and that magnesium concentrations are also lower than in more northerly pumice soils. Low magnesium concentrations (approximately 0.06%) are also endemic in trials with newly planted trees on these soils

(M. F. Skinner, pers. comm.). With concentrations as low as those observed in RO 1814 visual deficiency symptoms become very marked and growth is greatly reduced (average height at age 6 was 2.2 metres). Application of Mg fertiliser increased height growth by 35% and basal area (at the root collar) by 18% in two years. Mixed fertiliser applied with Mg had little additional effect.

The soils of the southern plateau clearly differ from the more northerly soils. The latter are composed of a great depth of air-fall ashes covering several palaeosols, the former are developed on very deep flow tephra originating from the most recent Taupo eruption. Northerly soils offer deep rooting, plentiful moisture storage and access, in the palaeosols, to nutrients such as Mg, missing from the more recent ash showers (Knight and Will, 1970). Southern flow tephra accumulations are frequently too deep to permit root access to buried soils and, having a blocky and sometimes welded texture, appear to restrict root access markedly. Tree growth is slower on these higher altitude sites. In default of information implicating other nutrients, therefore, response to N would appear to be directly proportional to tree growth rate.

Thus recent results confirm that on the more northerly pumice soils there is no basal area response to elements other than N. This finding does not, however, apply to the southern end of the pumice plateau.

2. *Pattern of Response to Nitrogen Fertiliser*

2.1 *Basal Area Response to N*

2.1.1 Pattern of Response with Time

The pattern of basal area response with time since N fertiliser application is generally similar in responding trials. The pattern of percentage response is illustrated in Fig. 2. Within one year an increase in basal area increment is observed. The maximum percentage difference in increment between fertilised and unfertilised plots is usually observed either in year 1 or year 2. Thereafter the percentage difference in increment tends to reduce to zero in 3 to 5 years. No trials exist in stands of normal stocking in Kaingaroa where the response has been followed for more than 5 years. However, one of the early N.Z. Forest Products trials has been followed for 12 years. The total response was at least maintained. An identical but stronger pattern is observed in N

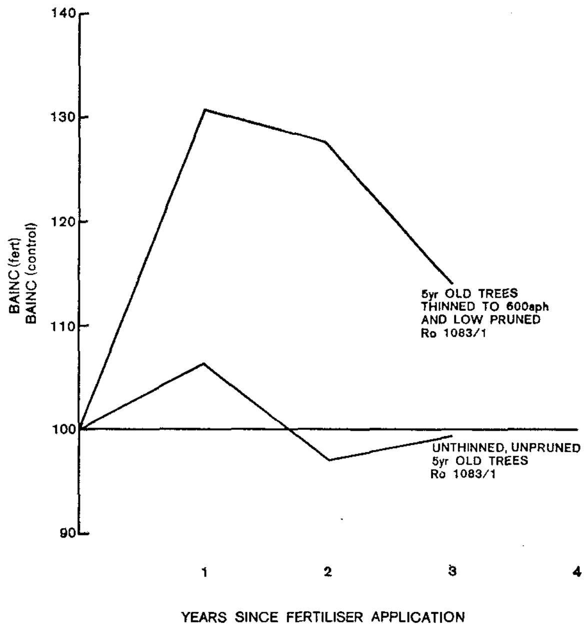

FIG. 2: *Nitrogen effects on basal growth with time since fertiliser treatment.*

trials in other parts of the country (Hunter, 1981; Hunter and Hoy, 1983).

2.1.2 Interaction with Silviculture and Tree Age

Mead and Gadgil (1978) report increases in basal area growth following fertilisation in two trials on the pumice plateau. Woollons and Will (1975) report mainly volume figures.

In our trial series N fertiliser increased basal area growth over that of plots at a comparable silvicultural state only when a full canopy had not yet developed or there had been some degree of silvicultural disturbance (thinning and/or pruning) to a full canopy. Table 3 shows the response in the first year following fertiliser treatment. It was not possible to present a complete table for a later year. However, as Fig. 1 shows, generally the first year response is a good indicator of the presence and strength of the total response. Young unthinned trees, closing the canopy, will respond to N fertiliser (although the response in RO 1083/1 was transient, see Fig. 2) whereas older trees need a recent thinning to promote a response. In young trees pruning has a similar effect on response to thinning. While it is clear that the absolute response to N fertiliser is greater in the younger trees it is not clear whether the relative rate of response varies with age. The response to N fertiliser may be a constant percentage of base growth rate independent of tree age.

Table 4 shows that in terms of site productivity it may be misleading to refer to a response to N fertiliser if by the term response we imply that site productivity has been increased. In each of the three trials for which the comparison is possible, the greatest per hectare productivity is associated with the undisturbed stand. After the silvicultural treatment (without which in the older two trials there is no change in basal area growth following fertilisation) basal area growth is reduced. Fertiliser merely increases the rate of recovery from silvicultural treatment. It can either partly or completely counter the reduction in growth after pruning or thinning.

2.1.3 Effect of Varying Rates of N Fertiliser

Woollons and Will (1975) reported one trial with rates of fertiliser application varying from 0 to 115 kg N/ha which

TABLE 3: GAIN IN BASAL AREA GROWTH IN THE FIRST YEAR AFTER NITROGEN FERTILISER TREATMENT

Trial	*Silvicultural Treatment*	*Tree Age*	*Gain over Silviculturally Similar Control*	
			m²/ha	*As % of Control Growth*
RO 1063	Pruned	4	1.10	17
RO 1083/1	nil	5	0.92	17
	Part pruned	5	1.68	40
	Thinned only	5	0.83	37
	Thinned + pruned	5	0.38	20
RO 1952	Pruned + thinned	9	0.37	10
RO 1843	Thinned	15	0.25	15
	nil	15	nil	nil
RO 1818	Thinned	16	0.28	17
RO 1844	Thinned	20	0.19	14
	nil	20	nil	nil

TABLE 4: BASAL AREA INCREMENT IN THE FIRST YEAR AFTER TREATMENT (m^2/ha)

Trial	Nil	+ N	Treatment Thinned	Thinned + N
1083 (unpruned only)	5.5	6.4	2.2	3.1
1843	2.1	2.0	1.7	2.0
1844	1.9	1.9	1.4	1.6

showed a clear response to fertiliser, with the highest response at the highest rate, but a very variable pattern across the lesser rates. Mead and Gadgil (1978) reported on a trial in 7-year-old radiata pine in Kaingaroa which showed a linear basal area response to fertiliser across 0, 230 and 460 kg N/ha. In the current series of trials there are two rates trials, one of which in Waimihia (RO 1970) showed no response to N alone. The other trial (RO 1952) in 9-year-old radiata pine showed a maximum response at 100 kg N/ha. Thus the shape of the response curve to N on the pumice plateau is still equivocal. However, when results from rates trials around the country are grouped there appears to be an optimum response at 200 kg N/ha (Hunter, 1981). This may need further elucidation on the pumice plateau soils.

2.2 *Height Growth Response to Nitrogen Fertiliser*

Woollons and Will (1975) stated that no height response was observed in the trials on which they reported. That finding is confirmed by the presently discussed set of trials where analysis of both mean height and mean top height over several years has failed to show a difference due to nitrogen fertiliser. A strong height response to N fertiliser was observed in very nitrogen deficient radiata pine on recent stands (Hunter and Hoy, 1983). The lack of a height response but the presence of a basal area response may be a feature of stands, like those on the pumice plateau, that are designated marginal (Will, 1978) for nitrogen.

2.3 *Effect of Nitrogen Fertiliser on Tree Shape*

Woollons and Will (1975) pointed out that in one of their trials in 13- to 14-year-old radiata pine the diameter response to fertiliser was found mainly in the upper portion of the trees. Their trials were measured routinely by dendrometer. Mead and

Gadgil (1978) reported on an 11-year-old stand. After three growing seasons there were significant differences in individual tree volumes but no change in tree form.

The trials reported here are routinely measured for height and breast height diameter only. However, changes of tree form of the type reported by Woollons and Will (1975) are managerially important, because reductions in overall taper in the sawlog position of the tree would increase saw-timber recovery. Therefore changes in tree diameter at different heights from the ground were assessed two years after fertiliser treatment on 60 trees in the 16-year-old trial (RO 1818). Table 3 shows that the trial responded to N fertiliser at breast height.

Analyses of covariance of 1982 diameters on 1980 diameters for each height up the tree showed that at each height the 1982 diameter was significantly greater in the treated trees than in

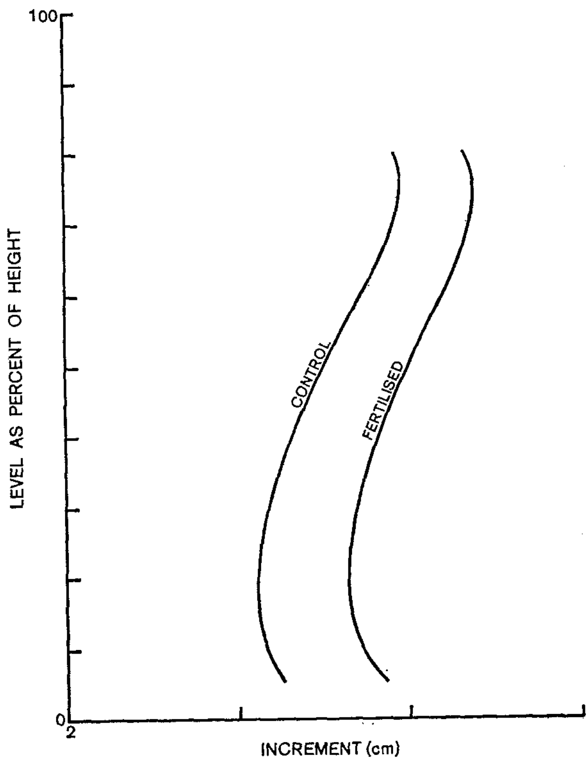

FIG. 3: *Taper equations of underbark diameter increment in radiata pine with and without N fertiliser.*

the untreated trees. The increase in diameter resulting from fertiliser was maximum at breast height and in the upper green crown although there was relatively little variation along the length of the tree. This pattern was also apparent from the taper equations. For Fig. 3 the taper equations were reprocessed to yield diameter increment between 1980 and 1982. It is clear from Fig. 3 that the overall taper of the first three sawlogs (up to 80% of the current 26 m height) had not been reduced by fertiliser treatment. It may even have been very slightly increased. The treated trees do not appear to have a greater taper in the top 20% of their height but this is unlikely to be of much managerial significance.

2.4 *Effect of Nitrogen Fertiliser on Stand Mortality*

Increases in seedling mortality have resulted from the application of N fertiliser (urea) in a spade slit soon after transplanting (Ballard, 1978). No such mortality has been observed following broadcast applications of up to 460 kg N/ha to more mature trees. No treatment related mortality has been observed during the life of the current series of trials either. However, the trial in 5-year-old radiata pine (RO 246) was left without further thinning at approximately 1000 stems/ha (an abnormally high stocking). When reassessed in 1981 (aged 23) it was found that the fertiliser plots had an average stocking of 764 stems/ha and differed significantly from the unfertilised plots which had an average stocking of 818 stems/ha. The maximum difference in basal area of 2.4 m^2/ha in 1972 had been eroded in 1981 by the extra mortality of the fertilised plots.

Basal area per tree (piece size) was still 5% higher, however, in the fertiliser plots. We failed to identify any particular diameter class as the main contributor to this mortality.

This result may prove with time to be an unrepeatable curiosity. However, a reasonable short-term inference is that N fertiliser treatment is more suited to tended stands with stockings sufficiently low to avoid significant crop tree mortality before clearfelling.

CONCLUSIONS

The series of trials reported here confirm that a large proportion of the forest growing on pumice soils is responsive to nitrogen fertiliser provided the stand has been recently treated silviculturally. That portion of the forest estate that lies on the deep flow tephra soils (the Waimihia and Matea parts of Kaingaroa) seems to require more than N alone.

We have confirmed that height responses to N do not seem to occur on the pumice soils. Changes in basal growth are usually observed. The magnitude of the response seems to vary directly with both site index and to a certain extent with amount of N applied. The pattern of that response over time is similar to that observed in other N trials. The evidence for a managerially important change in tree shape following fertiliser treatment is still unclear. It did not happen in the one trial studied in this series.

Where the basal area gains have been projected forward using currently available growth models they appear on average to be equivalent to a gain of 35 to 50 m^3/ha volume at clearfelling for the younger stands and 15 to 30 m^3/ha for the older crops.

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REFERENCES

Ballard, R., 1978. Use of fertilisers at establishment of exotic forest plantations in New Zealand. *N.Z. Jl For. Sci., 8* (1): 70-104.

Barker, A. V., 1979. Nutritional factors in photosynthesis of higher plants. *J. Plant Nutr., 1* (3): 309-42.

Bunn, E. H., 1981. The nature of the resource. *N.Z. Jl For., 26* (2): 162-99.

Forest Research Institute, 1982. *Report of Forest Research Institute for 1981.* N.Z. Forest Service, Wellington.

Hunter, I. R., 1981. Growth increases following application of nitrogen fertiliser to exotic forests. *In Nitrogen Balances in New Zealand Ecosystems.* DSIR, Palmerston North.

Hunter, I. R.; Hoy, G. F., 1983. Effect of nitrogen fertiliser on the growth and nutrition of radiata pine growing on a recent coastal sand. *N.Z. Jl For. Sci., 13* (1): (in press).

Knight, P. J.; Will, G. M., 1970. An appraisal of nutrient supplies available for tree growth in a pumice soil. *Earth Sci. J., 4*: 1-16.

Mead, D. J.; Gadgil, R. L., 1978. Fertiliser use in established radiata pine stands in New Zealand. *N.Z. Jl For Sci., 8* (1): 105-34.

Nicholson, G., 1983. Methods of plant, soil and water analyses. N.Z. For. Serv., For. Res. Inst. Bull. (in press).

Will, G M., 1966. Magnesium deficiency: the cause of spring needle tip chlorosis in young pines on pumice soils. *N.Z. Jl For., 11*: 88-94.

————, 1978. Nutrient deficiencies in *Pinus radiata* in New Zealand. *N.Z. Jl For. Sci., 8* (1): 4-14.

Woollens, R. C.; Will, G. M., 1975. Increasing growth in high production radiata pine stands by nitrogen fertilisers. *N.Z. Jl For., 20*: 243-53.