MANAGEMENT SIGNIFICANCE OF RESPONSES TO FERTILISING *PINUS RADIATA*

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ABSTRACT

Managers rarely include the use of fertiliser in their major silvicultural decisions. Usually those decisions are made first and fertiliser is used as an adjunct to management. In this paper several situations are explored where inclusion of fertiliser in the system might have altered the assumptions on which management decisions were made. These situations include the type of land to acquire for planting, the silvicultural regime to apply, and the appropriate strategy of yield regulation.

INTRODUCTION

Decisions about forest fertilisation have rarely been made as part of a silvicultural system. Normally the major decisions about what land to purchase, what species to plant, how to tend that species, and in what pattern to harvest it have been made first. Any option of using fertiliser has been adopted later, usually with little modification of original silvicultural decisions. The management significance of response to fertilisation is that in some cases it should lead to a thorough re-evaluation of silvicultural programmes.

CHOICE OF LAND

The largest internal market for timber in New Zealand and the largest labour pool for prefabrication of wood products for export lie in the Auckland region. Yet the soils in the Auckland area that have been made available for afforestation are extremely poor. They are usually phosphorus (P) deficient, varying in texture from weakly podzolised compact clay to podzolised sandy soils, many with a pan at shallow depth. Digging for kauri gum in the past led to massive disturbances and loss of topsoil by erosion.

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Growth in the first rotation on the clay soils of Riverhead Forest (the forest closest to Auckland) was catastrophically poor. In the worst areas there was almost no merchantable yield from radiata pine (*Pinus radiata*) after 40 years. Other species were tried (*P. elliottii, P. taeda* and *P. pinaster*) because they seemed to tolerate the conditions better, although it was known that, when growing well, radiata pine would out-yield them. Phosphorus deficiency was first diagnosed when the majority of the stands were over 20 years old. Superphosphate fertiliser was applied at relatively low rates (*c.* 300 kg/ha) to enable recovery of merchantable volume. Much of Riverhead has since been clear-felled and replanted with radiata pine which receives applications of at least 1000 kg/ha superphosphate when deficient. Growth in trial plots similarly fertilised (Hunter and Graham, 1982) indicates a current height growth equivalent to site index 30 m and that a much higher volume will be harvested in the second rotation. This enables the forest to be evaluated in the light of its advantages, such as its closeness to Auckland, rather than its disadvantages, such as the very poor growth in the first rotation.

Large areas (110 000 ha) of intensively podzolised soils exist in North Auckland. In contrast to the moderately podzolised clays of forests like Riverhead, these were considered virtually unplantable. Early research into afforesting these sites was only partly successful, probably because of insufficient attention to the necessity for site cultivation. However, in 1976 at two sites (Waipoua State Forest and the Utakura plantation of Whitecliffs Sawmilling Company) the combination of ripping and bedding with fertiliser application at establishment was successful (Hunter, 1981). By age 4 years the trees at both sites that had received nitrogen (N) and phosphorus fertiliser at establishment in cultivated plots were 4.7 m tall with nearly 100% survival. Unfertilised trees in the uncultivated plots were only 0.55 m tall with 68% survival at Utakura and 2.00 m tall with 97% survival at Waipoua, and were very unthrifty crops. At age 4 the experiment was redivided and refertilised with superphosphate alone (100 kg P/ha), N and P (200 kg N/ha, 100 kg P/ha), and NPK (as for N and P, potassium (K) at 100 kg/ha). At Utakura copper and magnesium were also applied to the NPK plot.

In Table 1 the basal area and average height at the two sites up to age 7 are shown. There were minor differences between the two sites in the initial response to the fertiliser. At Waipoua, P alone reduced growth below the control while at Utakura it gave

TABLE 1: THREE-YEAR BASAL AREA AND AVERAGE HEIGHT GROWTH OF 4-YEAR-OLD RADIATA PINE ON A CULTIVATED PODZOLISED SAND AFTER FERTILISATION

Treatment	*Basal Area (m^2/ha) Tree Age*			*Average Height (m) Tree Age*		
	5	6	7	5	6	7
Utakura						
Not refertilised	7.9	12.4	16.0	5.14	6.09	7.80
P alone	9.2	14.5	18.6	5.43	6.78	8.90
N and P	10.2	16.1	19.4	5.07	6.05	7.37
N, P, K, Cu, Mg	10.9	19.3	25.2	5.28	6.83	9.27
Standard error	0.4	0.5	0.8	0.2	0.1	0.3
Significance	**	**	**	n.s.	**	*
Waipoua						
Not refertilised	7.4	10.2	15.0	5.31	6.57	8.27
P alone	6.9	11.4	17.2	5.53	7.50	9.90
N and P	11.9	17.3	24.8	4.90	4.97	6.25
NPK	10.6	17.8	27.2	5.57	7.30	9.61
Standard error	1.8	2.3	2.8	0.6	0.6	0.7
Significance	n.s.	*	**	n.s.	n.s.	*

n.s. not significant. * significant at 5%. ** significant at 1%.

a modest growth increase. Foliar analysis showed that N and K deficiency were more seriously affected by P application at Waipoua than at Utakura. By age 7, however, all treatments except the N and P treatment had given very similar basal area growth at both sites. Potassium deficiency was stronger in the N and P plot at Utakura than at Waipoua. The difference between the NPK plots and the unfertilised plots (on average 10.7 m^2/ha) is the largest known 3-year gain to fertiliser in radiata pine in New Zealand. Moreover, the basal area in the NPK plots is 90% of that in central Kaingaroa plots known to the writer and the current growth rate is equal.

Both P alone and NPK have significantly increased height growth over the non-fertilised plots. The application of N and P seems to have reduced growth in height, however. This reduction was associated with particularly low foliar concentrations of K and Cu, although those conditions are not unique to this treatment, being to some extent true of all but the NPK plots. A mean top height at age 7 was calculated for the NPK plots and found to lie on the site index 33 m curve (Burkhart and Tennent, 1977).

Mead *et al.* (1980) reported similar large gains to fertiliser, after draining and cultivation, on West Coast pakihis (gley podzols).

In the past, forestry organisations had relatively little choice of land for afforestation, land that was unsuitable for agriculture being somewhat grudgingly allowed to go into trees. Today there is a slightly greater choice. In deciding what land to buy, location, topography, growth rate (which is affected by fertility), and distance to markets are all important. Many interactions and trade-offs are involved. Although from the magnitude of the response to inputs reported here it is clear that growing a forest on very poor soils calls for new skills on the part of managers and considerable research input if productivity is to be maximised, considerable success has been achieved in growing radiata pine on very infertile soils and infertility *per se* should not be a reason for rejecting land for afforestation. Would it be wise, however, to prefer such land? Forest organisations are encouraged to acquire land such as this, classified in Class VI or worse by the Land Capability Unit of the Ministry of Works: that is to say, land offering significant difficulties for pastoral farming. The alternative Class VI land available for afforestation is usually more fertile but steep and unstable and sometimes high and cold.

Inputs to the infertile site in the form of fertilisation and cultivation could total $1400/ha over the life of the crop but would average $500/ha. Those costs would compound at 10% over the life of the crop to between $5 000 and $14 000/ha depending on the intensity and timing of the fertiliser inputs. On the other hand, the steep country would require hauler logging at perhaps twice the cost per cubic metre of skidder logging the generally easy terrain of the infertile country and would require very much more expensive roading. If at relatively high altitude or latitude with a short growing season, the alternative site would also produce less volume per hectare. When evaluated by marginal cost analysis across a wide range of possible costs, these immutable disadvantages appeared to be more significant than correctable deficiency in nutrients.

This comparison between steep and flat land was extended using the program, SILMOD. A direct sawlog regime at two site indices (26 and 30 m) and three rotation ages (25, 30, and 35 years) was simulated. The comparison was deliberately weighted in favour of the steeper land in that high cultivation and fertiliser costs were used for the flat land ($600/ha and $800/ha, respectively) while all other costs were kept constant — *i.e.,* there was no allowance for increased costs of planting and tending the steeper land. Despite this, at the two shorter rotation ages and at comparable site index, the flat infertile land had a higher rate of return. Steep land had the advantage at the longest rotation age. This is a reflection of the high costs early in the rotation accruing to the flat land and the effect piece size increase has on reducing hauler logging costs on the steep land. The advantage was absolutely in favour of the flat land if, as a result of climatic limitation, growth on the steeper land was poorer.

CHOICE OF REGIME

The acceleration of growth that occurs when fertiliser is applied to a deficient stand appears to be due only partly to the increased efficiency of physiological processes from raised foliage nutrient concentrations. Of more importance is an increase in foliage mass (Miller and Miller, 1976; Brix, 1981). This sometimes appears to occur at the expense of foliar concentrations (Hunter and Hoy, 1983). The close relationship between foliage mass and conducting stem tissue has been established for several species (Grier and Waring, 1974; Waring *et al.*, 1982). The relationship may carry over into the size of the branch conducting tissue (Will and Hodgkiss, 1977). Recently the diameter change in branches in the lowest unpruned whorl was assessed over 2 years in a fertiliser and thinning trial in Golden Downs Forest, Nelson. Three thousand seven hundred branches at 4 m from the ground on 480 trees (20 per treatment plot) were measured for diameter just before treatment and again after 2 years. Initial average diameter was 2.32 cm. After 2 years branch diameter differed very significantly between the three stocking levels and with fertilisation (Table 2). There was no interaction between fertiliser and thinning. Initial branch diameter was used as a covariate in the statistical analysis.

TABLE 2: MEAN BRANCH DIAMETERS, 2 YEARS AFTER THINNING AND FERTILISING, IN A WHORL 4 m FROM THE GROUND IN 7-YEAR-OLD RADIATA PINE

Treatment	*Mean Branch Diameter (cm)*
Residual stocking after thinning:	
250 stems/ha	3.43
500 stems/ha	3.19
750 stems/ha	3.02
Standard error of difference	0.08
No fertiliser	3.08
300 kg N, 50 kg P/ha	3.35
Standard error of difference	0.06

A similar effect from N fertilisation on branch size has been noted in a thinning, pruning, N fertiliser trial in Kaingaroa (Forest Research Institute, 1981).

Thus it has been demonstrated that the appropriate inputs can raise growth even on very infertile sites to levels normally encountered only on the most productive sites (indicated site indices of 33 and 30 m have been reported in this paper) yet probably at the expense of giving the trees the other silvicultural characteristics of larger trees — *e.g.*, an increase in branch size. Stands growing on nutrient-deficient soils, such as the first-rotation Auckland clay soil crops and those growing on N-deficient coastal sands, were identified by Fenton (1971) as suitable for management on a framing (building timber) regime. This was because of their naturally small branch size and because their growth rate was too slow to lay down a large enough cylinder of clearwood to cover the expense of pruning. Most of the stands in these forests are still managed on a framing regime despite the fact that their growth either has been or could be greatly accelerated by fertilisation (Hunter and Graham, 1982; Hunter and Hoy, 1983). With increasing areas being planted, these forests, too, may in future be producing for export.

The fertiliser effect may alter decisions about whether to adopt a clearwood tending regime. To maximise the return of pruning, stands need to be early waste-thinned to low stockings. There is an opportunity cost of lower volume production per hectare. Sometimes industrial commitments to industry may require a high per hectare volume production and lead to a compromise in final-crop stocking. Fertiliser may help in increasing yields of tended stands. In Table 3 basal area increment over 2 years in a thinning, pruning, and N fertiliser trial in 5-year-old radiata pine at two sites in Kaingaroa (Forest Research

TABLE 3: PERCENTAGE BASAL AREA INCREMENT BY TREATMENT IN A THINNING, PRUNING, FERTILISER TRIAL AT TWO SITES IN KAINGAROA FOREST IN 5-YEAR-OLD RADIATA PINE. INCREMENT IS GIVEN AS PERCENTAGE OF INCREMENT IN UNTHINNED UNPRUNED PLOTS

Treatment	*Unfertilised* *Site 1*		*Unfertilised* *Site 2*	*N fertilised* *Site 1*	*N fertilised* *Site 2*
Unthinned 2500 stems/ha	100	= base =	100	105	90
Unthinned 600 stems/ha, pruned	85		95	105	102
Thinned to 600 stems/ha, unpruned	38		37	58	61
Thinned and pruned 600 stems/ha	35		24	45	44

Institute, 1981) is shown. (Treatments that differ by more than 15% increment are significantly different from one another at 5% probability.)

Depending on the severity of the silvicultural treatment, application of N fertiliser on pumice soils can either totally overcome or help to overcome the loss per hectare productivity. A similar effect of N fertiliser has been noted in older crops after production thinning (Hunter *et al.*, in prep.). It might be possible, therefore, for a manager to satisfy the constraints of both required volume and required clearwood return by incorporating routine use of fertiliser in conjunction with silvicultural tending.

YIELD REGULATION

The optimum clearfelling age is usually determined as the age of greatest economic return on a single hectare base. The forester is rarely able to clearfell at exactly that age, however. Matching a relatively constant commitment to industry to the usually fluctuating areas of forest reaching clearfelling age requires adjustment of clearfelling age.

A very simple illustration of this situation is shown in Fig. 1 where, in a 9-year segment of a cutting plan only 160 ha were planted in the central 3 years instead of the intended 200 ha. It is assumed that the crop will yield from 400 m^3/ha at age 22 to 460 m^3/ha at 25 in 20 m^3/ha/yr increments and is due for clearfelling at 23. In order to achieve an even flow of timber the clear cut would be set at 185 ha/yr to year 8, then increasing in

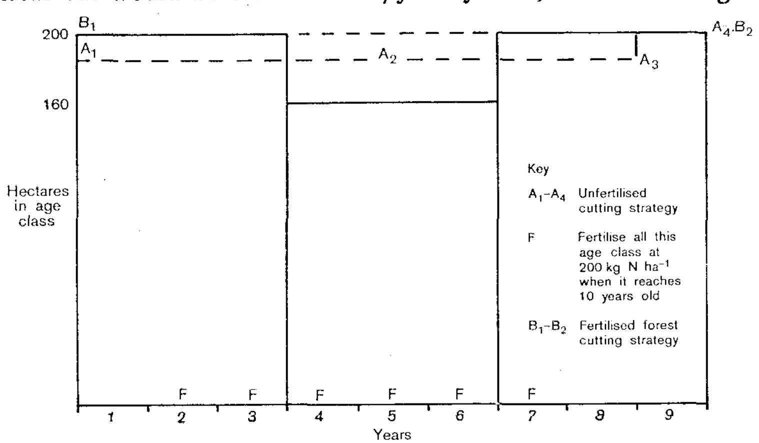

Fig 1: ***A 9-year segment of a cutting plan showing the effect of forest fertilisation on cutting strategy.***

the ninth year to 200 ha/yr. Clearfelling age would fluctuate by a year around 23 years. In real life situations clearfelling age variations are very much greater than this and in these circumstances modest volume gains from fertiliser are inadequate to completely correct the deficit. Large fluctuations in current-crop clearfelling age can have major repercussions for harvesting and utilisation equipment since, unlike the old stands, tree diameter can be expected to increase strongly over time thereby changing log size and mix. Within the range of capability of one type of harvesting machinery, variations in size can have important effects on harvesting cost.

Gains of up to 10% in volume at clearfelling can be achieved by fertilising thinned crops on the pumice plateau with 200 kg N/ha (Woollons and Will, 1975). If the problem with the example cutting plan had been noticed in time and the appropriate opportunity taken to apply N fertiliser, a revised cutting strategy with a higher total cut and less carry over of stands would have been possible. A similar fertilisation strategy has been suggested to deal with the age-gap problem in Oregon and Washington (University of Washington, 1979). Return on investment can be evaluated in the normal way but is usually increased if consideration is given to the various opportunity costs — for example, buying in logs to meet commitments. Opinions are divided about the validity of allowing the cost of fertilising one compartment to be a charge against the volume immediately available from another (Hyde, 1976) although if such a formula is adopted the apparent returns can be very large.

Allison (1974) gave a worked example of the cumulative effect of forest fertilisation on the profitability of a forest. He pointed out that the cumulative difference increased indefinitely to the advantage of the fertilised forest because it had larger piece sizes, lower haulage distance, and lower forestry costs which more than offset the cost of fertilisation at any rate of interest.

CONCLUSIONS

Fertilisation is a tool that the manager can incorporate in his overall silvicultural management system and thereby greatly increase his flexibility of management. When considered in its proper place, as part of the overall system, fertilisation can lead to different decisions about what land to purchase, how to tend the crop, and what clearfelling strategies are possible.

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