# INCREASING GROWTH IN HIGH PRODUCTION RADIATA PINE STANDS BY NITROGEN FERTILISERS

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*Abstract*

*The recent dramatic increases of fertiliser usage in world forestry are reviewed. Contrast is made between fertiliser responses in overtly deficient and in apparently healthy stands of radiata pine in New Zealand. For the latter, growing on pumice soils, it has been found in a series of experiments that:*

*(1) Following thinning, the application of a mixed fertiliser in two successive years boosted the growth of naturally regenerated 13-year-old radiata pine. A sustained response has lasted seven years to date, with substantial gains of 61 $m^3$/ha at 540 stems/ha and 36 $m^3$/ha at 320 stems/ha.*

*(2) If fertilisers are applied more than three years after thinning the response is inconsistent or transient; no response at all has been detected in unthinned stands.*

*(3) The only nutrient to give a consistent response is nitrogen.*

*(4) The rates of nitrogen needed to give a sustained response have been partially defined; evidence to date suggests that two annual applications of urea at 250 kg/ha in successive years is the most productive.*

*(5) The data show that the stem volume increases caused by such applications of nitrogen fertilisers occur partially through a change in stem form. There is no evidence of height increases through fertiliser application.*

## INTRODUCTION

Relative to agriculture the use of fertilisers in forests began quite recently. Although as early as 1860 European foresters knew of the need to maintain the nutrient status of their forests (the removal of litter was recognised as a cause of "soil deterioration"), it was not until the 1930s that well-designed forest fertiliser trials began to be established (Tamm, 1968).

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Early experiments with wood ash in Sweden and lime in Germany were the forerunners of extensive trials with a range of fertilisers in many countries (Tamm, 1968; Baule and Fricker, 1970). Once it had been shown that not only could the harmful effects of nutrient removal be counteracted by the application of fertiliser, but also the productivity of many forests could be raised by the addition of fertilisers, management scale applications were instituted in most European countries (Tamm, 1968). This began early in the 1960s and, in Sweden and Finland in particular, the rate at which fertiliser use has increased is dramatic.

In Sweden 150 tonnes of nitrogen (mainly urea) were used in 1960. By 1966 the total was 7000 tonnes a year and, after a slight decline for several years, further increases raised the consumption to 18 000 tonnes (mainly ammonium nitrate) in 1972 (Tamm, 1968; Holmen, 1972). The total area of forests in Finland that had been treated with fertilisers to 1970 was 440 000 hectares, but by 1972 the area treated *annually* with N, P, and K fertilisers had reached 250 000 ha (Huikari, 1972).

In North America, forest fertiliser trials on any appreciable scale date only from the 1950s, but since then trials and the resulting operational fertiliser applications have expanded rapidly (Steinbrenner, 1968; White, 1968; Bengtson, 1968). The forest area fertilised annually with urea in the Pacific Northwest increased from a few thousand hectares in 1966 to over 90 000 ha in 1973 (Atkinson and Morison, 1975). Pritchett and Smith (1975) reported that, in the five years up to 1973, 100 000 ha of pine forest in the U.S. South-east were fertilised with phosphate fertilisers.

The situation in Japan and other countries has followed a similar pattern with very rapid increases in the use of fertilisers in forests. Baule (1973), in reviewing the world-wide position, found that, while a total of 2 million hectares of forests had been fertilised up to 1970, the treated area doubled in the next three years, and was expected to double again by 1975.

Extensive radiata pine plantations have been established in a number of countries. There are large areas in Chile, Australia and New Zealand, and on good sites the growth rate is 25 to 30 $m^3$/ha/yr — as against a typical figure of 5 $m^3$/ha/yr for the pine forests in Scandinavia and Canada (Raupach, 1967). It is not unexpected then, that when fertiliser trials began in New Zealand in the early 1950s work was confined to those forests where the growth was obviously unthrifty and a nutrient deficiency severely limited production. Since then the identification and correction of phosphorus (Weston, 1956; Mead, 1968; Rawson, 1972), nitrogen (Stone and Will, 1965a), boron (Stone and Will, 1965b; Will, 1971), and copper

(Will, 1972) deficiencies have raised the growth rate in a number of forests in both North and South Islands.

*In contrast*, it was not until the late 1950s that any real thought was given to establishing fertiliser trials in the thrifty and very high producing forests growing on the pumice soils of the central volcanic plateau of the North Island. In 1964, in Kaingaroa Forest, a trial was established in thinned 6-year-old regeneration: an N, P, K, Mg fertiliser mixture was applied three times at 2-yearly intervals. Ballard (1971) summarised results up to 1970 and concluded that there had been a growth response to the fertiliser of 3.8 $m^3$/ha/yr. However, a further application of N produced no additional growth (Edmonds and Allison, 1974). This trial was followed by a number of others in state and privately owned forests. The most detailed and extensive series of trials is established in N.Z. Forest Products Limited plantations, near Tokoroa.

This paper gives the results, up to 1974, of trials which highlight both the responses that can be obtained, and also the conditions necessary to achieve a sustained increase in growth.

## EXPERIMENTAL METHOD AND RESULTS

The following trials were laid out in stands of thinned 13- to 14-year-old radiata pine resulting from regeneration (see Fig. 1). The soil is a yellow-brown pumice soil (N.Z. Soil Bureau, 1968), typical of those that occur over the greater part of the 500 000 ha of forest plantations in the central region of the North Island. The annual rainfall of 1250 to 1750 mm/yr is evenly distributed through the year. The trials are at altitudes of 300 to 500 m.

The experimental units (plots) are 0.16 ha (40 m × 40 m), with an inner 0.04 ha (20 × 20 m) measurement plot.

Unless otherwise stated the trees have been measured for total stem overbark volume by Barr & Stroud dendrometers. A system of auditing the measurement party's work, together with the practice of graphing the height-diameter profile of each tree by a computer-plotter, has been invaluable in ensuring a high standard of measurement.

### *Investigation of Response to a Mixed Fertiliser — Trial No. 1*

In 1967, following a production thinning, four replications of fertilised and control plots were established in each of two residual stockings — 620 and 370 stems/ha; the mixture of fertilisers applied contained N, P, Ca, K, S, Mg, Zn, Ca, Mn, B, and Mo. Full details of fertilisers and rates used are given in the Appendix.

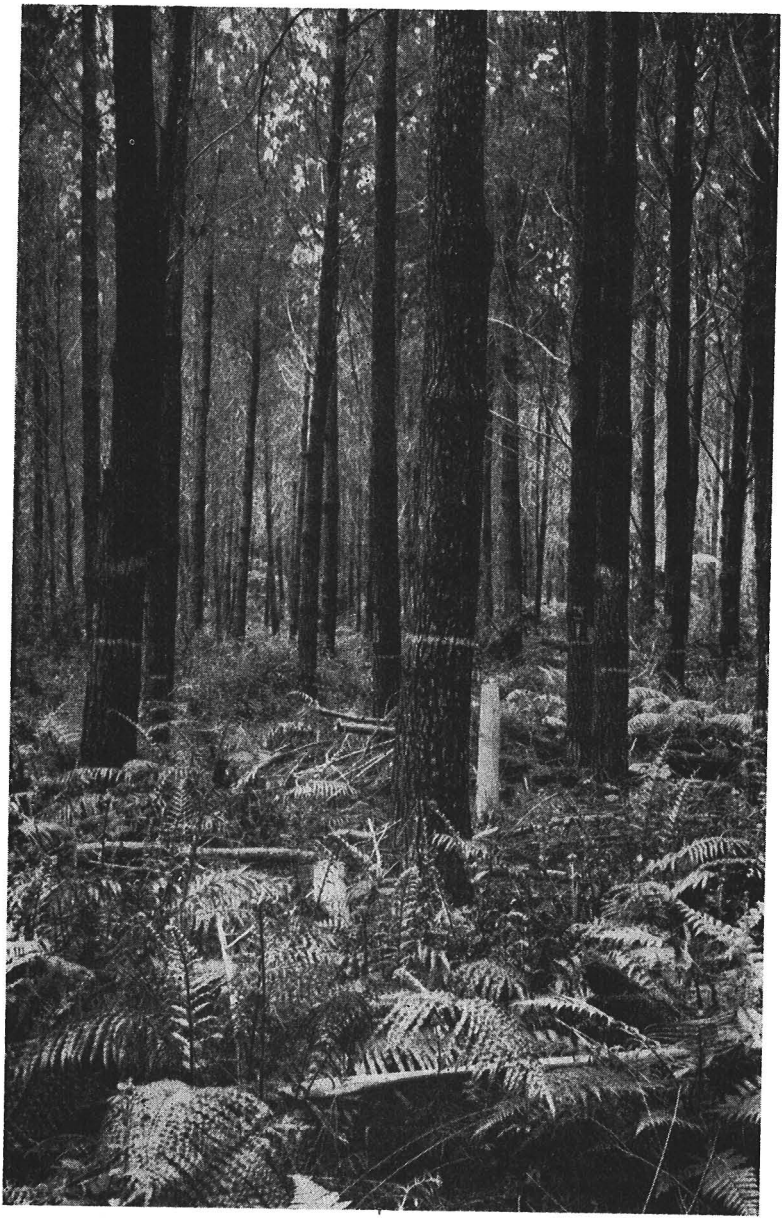

FIG. 1: *Radiata pine fourteen years after naturally regenerating, thinned to 620 stems/ha.*

TABLE 1: AVERAGE VOLUMES ($m^3$/ha), FOR TRIAL No. 1

| | *540 stems/ha* | | *320 stems/ha* | |
|---|---|---|---|---|
| | *Fertilised* | *Control* | *Fertilised* | *Control* |
| 1967 .... .... | 212 | 212 | 154 | 151 |
| 1968 .... .... | 271 | 263 | 197 | 190 |
| 1969 .... .... | 350 | 316 | 251 | 236 |
| 1970 .... .... | 401 | 358 | 292 | 267 |
| 1971 .... .... | 454 | 395 | 330 | 298 |
| 1972 .... .... | 511 | 446 | 376 | 339 |
| 1973 .... .... | 568 | 504 | 425 | 392 |
| 1974 .... .... | 618 | 543 | 478 | 439 |

Hand-broadcast applications were carried out in September 1967 and again in 1968 (without trace elements).

Table 1 gives the average volumes/ha for the four treatments from 1967 to 1974. Light mortality in the first year reduced the stocking to 540 and 320 stems/ha. Nearly all plots were affected but none to an extent necessitating the introduction of mortality as a covariate in analyses.

As is illustrated in Fig. 2, a major result has been a sustained increase in volume production, lasting seven years to date, for both stocking classes. Total gain through fertilisation, 1967-74 was statistically estimated to be 61 $m^3$/ha (540 stems/ha) and 36 $m^3$/ha (320 stems/ha). Based on the control figures, this represents a gain in mean annual increment of about 20%. 90% confidence *lower bounds* were calculated to be 46.2 and 27.3 $m^3$/ha, respectively.

Examination of the height growth (1967-1974) reveals an important point when evaluating these responses. The aver-

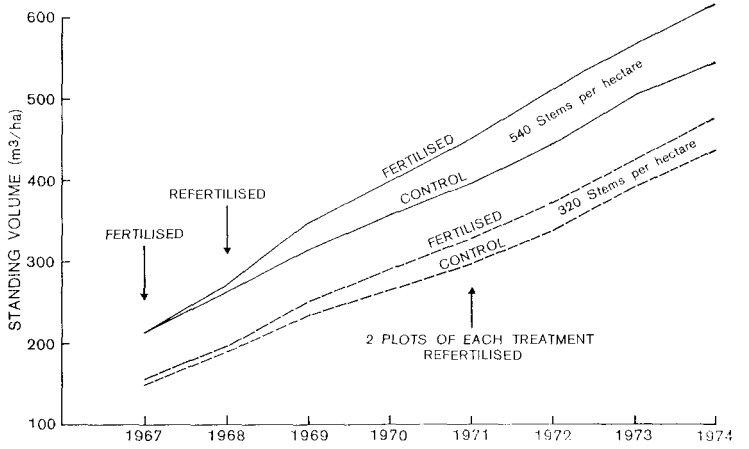


FIG. 2: *Changes in volume with time, Trial No. 1.*

age height increment (m) (1967-74) for each treatment was:

| | *Fertilised* | *Control* |
|---|---|---|
| 540 stems/ha .... .... .... | 9.3 | 9.7 |
| 320 stems/ha .... .... .... | 9.3 | 9.2 |

Thus, no height response to fertilisation occurred: responses were in diameter alone.

In 1971, 4 years after thinning, fertiliser was applied to two previously fertilised plots and two control plots in each stocking class. Urea, dolomite and potash were applied at the rates given in the Appendix. In 1971-2 all these plots showed marginally significant responses but no increased growth thereafter. The response in the previously fertilised (1967 and 1968) plots was no different from that in the former controls.

Estimated gains for 1971-2 were 7.7 $m^3$ (540 stems/ha) and 4.6 $m^3$ (320 stems/ha) but 90% confidence lower bounds were only 2.5 $m^3$ and 1.5 $m^3$, respectively.

*Investigation of Effective Nutrient(s) — Trials No. 2 and No. 3*

In September 1969, Trial No. 2 was established in a stand that had been thinned the previous year to 490 stems/ha. It was a $2^3$ factorial, replicated in four randomised blocks, to measure the effectiveness of urea plus blood and bone (N), superphosphate (P), and dolomite-potash (Mg + K) singly and in combination at the rates given in the Appendix; a basal application of trace elements was given to all plots. In 1970 plots were refertilised at the same rates.

By 1971 there had been significant growth responses to N and (Mg + K) but with no interaction. Volume increases over the control ($m^3$/ha) were:

| | *N* | *Mg + K* |
|---|---|---|
| 1969-70 .... .... .... | 6.4* | 8.9** |
| 1970-71 .... .... .... | 11.0*** | 5.7* |

*Significant at the 5% level.
**Significant at the 1% level.
***Significant at the 0.1% level.

The analysis of form factors (volume/$m^2$ of basal area), in 1971 was of interest. Form factors for the 8 treatments were:

| (a) | (b) | (c) | (d) |
|---|---|---|---|
| N + (Mg + K) | N + P + (Mg + K) | N | (Mg + K) |
| 11.95 | 11.80 | 11.76 | 11.67 |
| (e) | (f) | (g) | (h) |
| N + P | P | P + (Mg + K) | Control |
| 11.64 | 11.49 | 11.42 | 11.36 |

Using Duncan's multiple range test at the 5% level, treatments (a), (b) and (c) were judged significantly different from the control. There was evidence, therefore, that the fertiliser responses to N had caused a change in tree form.

Further fertiliser applications, applied three, four and five years after thinning, gave only indications of additional responses — not statistically significant. In contrast the 1969 and 1970 nitrogen applications were still giving a response.

Trial No. 3, a $2^4$ factorial, was laid out in 1973 following thinning to a residual stocking of 620 stems/ha. The treatments were replicated twice, in blocks of 8, with the ABCD interaction totally confounded. The factors were N, P, Mg, and K, at the rates given in the Appendix, except that blood and bone and trace elements were omitted.

In 1973-4 there was a highly significant response to N, with an estimated volume increase over the control of 8.8 $m^3$/ha. No other treatment responded.

*Experiments in Unthinned Stands — Trial No. 4*

In 1971 three trials, each of eight plots, were laid out in areas of 1956-58 regeneration, with stockings, respectively, of (1) 1100, (2) 740, and (3) 440 stems/ha. Fertilisers (applied to 4 plots in each trial) were urea, 250 kg/ha and dolomite, 500 kg/ha.

The dendrometers could not be efficiently used in these unthinned conditions. The best alternative was judged to be DBH measurement, plus a second diameter measurement at 5.5 metres.

Results are given in Table 2.

TABLE 2: MEAN DIAMETERS (cm) AT 5.5 m IN 1973

| | *1100 stems/ha* | | *740 stems/ha* | | *440 stems/ha* | |
|---|---|---|---|---|---|---|
| *Plot* | *Fertilised* | *Control* | *Fertilised* | *Control* | *Fertilised* | *Control* |
| 1 | 20.6 | 18.8 | 21.3 | 22.1 | 28.7 | 26.4 |
| 2 | 20.8 | 20.1 | 21.1 | 21.1 | 27.9 | 22.6 |
| 3 | 19.8 | 20.8 | 23.1 | 23.6 | 22.6 | 26.2 |
| 4 | 19.6 | 20.8 | 24.4 | 22.4 | 24.1 | 27.9 |
| Mean | 20.2 | 20.1 | 22.5 | 22.3 | 25.8 | 25.8 |

Analysis of these data (with initial DBH as a covariate), showed no response to fertiliser.

The plots were refertilised in 1973, with an application of urea, at 500 kg/ha, but the treated plots still gave no significant growth response.

*Investigation of Rates of Application — Trials No. 5 and No. 6*

Trial No. 5 was established in 1970 following thinning. It consisted of 0, 25, 50, 75, and 100% of the mixed fertiliser cited in the Appendix. Residual stocking in the plots was 490 stems/ha and treatments were replicated four times.

Volume increases ($m^3$/ha) in 1970-71 were:

| 0 | 25% | 50% | 75% | 100% |
|---|---|---|---|---|
| 51.8 | 50.4 | 54.6 | 52.9 | 62.2*** |

The trial was *not* refertilised in 1971, and little response in 1971-75 increment was detected in any treament.

Trial No. 6 was established in 1974; four replications of the following treatments were laid out in a residual stocking of 490 stems/ha.

(a) Control

(b) Urea at 250 kg/ha

(c) Urea at 500 kg/ha

(d) Urea at 250 kg/ha, with a further application at 250 kg/ha to be applied in 1975.

This trial will be remeasured and the results analysed in 1976.

## DISCUSSION AND CONCLUSIONS

The results of these experiments show that the growth of stands of radiata pine growing on pumice soils on the central plateau of the North Island can be appreciably increased by the application of fertiliser. The trials do indicate, however, that there are three major conditions necessary to achieve an appreciable gain.

(1) A thinning, before fertiliser application is essential.

(2) Only applications of nitrogenous fertiliser are effective.

(3) If urea is used, at least two consecutive annual applications at 250 kg/ha, applied within 2 years of thinning are required.

Of the five trials mentioned, Nos. 1, 2, 3 and 5 were thinned and all gave significant responses; in complete contrast, Trial No. 4, in unthinned conditions, gave no growth response. This pre-condition of thinning has not been encountered in earlier nutritional work in New Zealand where large responses have been achieved to the correction of overt deficiencies — *e.g.*, to phosphate deficiency in Riverhead forests (Mead, 1968).

Trials Nos. 2 and 3 convincingly demonstrate that nitrogen is the only nutrient to give a consistent growth response. Phosphorus did not increase growth. The response to magnesium and potassium occurred in Trial No. 2 essentially for only one year, but neither element gave a response in Trial No. 3; the response is thus inconsistent. Potassium is unlikely ever to be limiting in pumice soils (Knight and Will, 1970) so the obtained response is likely to be a transient one to magnesium, similar to that reported by Will (1966).

The sustained growth gain illustrated in Fig. 2 is encouraging. The growth gain was most rapid during the first two to three years before gradually declining, but to date the growth rate in treated plots is still above that in the controls. Similar sustained responses for up to 10 years have been reported by overseas investigators (*e.g.*, Moller and Rytterstedt, 1974). Waring (1971) has reported results of several trials with radiata pine in which large compounding responses occurred to fertiliser applications at planting.

The results of Trial No. 5 showed that one application of 250 kg/ha of urea gave a temporary increase in growth. In contrast, Trials Nos. 1 and 2, with two annual applications at the same rates, have given a continuing response. Until information is available from Trial No. 6, two consecutive applications are regarded as optimal.

The importance of making these applications in consecutive years, and soon after thinning, is emphasised from the results of Trials Nos. 1 and 2; the application of fertiliser 3 to 5 years after thinning gave minimal response only. This principle is endorsed by the results of the trial reported by Ballard (1971).

It should be remembered that, for these trials, no evidence of increased bole growth is readily visible in the forest. Consequently exact and extensive sectional measurements are important. From Trial No. 2 there is evidence that the diameter response to fertiliser is largely found in the upper portion of the trees. Basal area measurements alone, therefore, show only a fraction of the total response.

These experiments provide conclusive evidence that fertiliser applications can markedly increase the growth of radiata pine on the pumice soils of North Island, New Zealand. There are constraints to the method and timing of these applications and optimal procedures are still being worked out.

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## APPENDIX

The composite fertiliser applied per hectare consisted of:

| | |
|---|---|
| 250 kg | urea (115 kg N) |
| 125 kg | blood and bone (8 kg N*, 6 kg P) |
| 625 kg | superphosphate (62 kg P, 62 kg S, 125 kg Ca) |
| 500 kg | crushed dolomite (50 kg Mg*, 110 kg Ca) |
| 250 kg | potash (130 kg K) |
| 5.6 kg | zinc oxide |
| 5.6 kg | manganese sulphate |
| 11.2 kg | copper sulphate |
| 22.4 kg | borax |
| 175 g | sodium molybdate |

* = approximate figures