Long-term studies on the use of superphosphate fertiliser for radiata pine on soils of low to medium P retention capacity in the North Island of New Zealand.

by

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ABSTRACT

At four sites of low to medium P retention in the North Island of New Zealand, several rates of superphosphate fertiliser and timings of application were initiated in young radiata pine stands. By rotation end, only those stands where foliar P levels in the unfertilised trees were lower than 0.10% were there significant growth responses to superphosphate. A single application of 125 kg P/ha was the minimum required. Based on trees' responsiveness to fertiliser P, and associated patterns of foliar P concentrations, a downwards revision of the foliar P critical level to 0.11% is warranted.

INTRODUCTION

The recognition of P deficiency in plantation radiata pine at Riverhead Forest in the 1950's prompted work on amelioration of this condition with single superphosphate (SSP) fertiliser (Weston, 1956). Substantial quantities of SSP were required to overcome deficiency and poor growth (Ballard, 1972). Whereas minimal quantities (about 25 kg P/ha) were insufficient to overcome P deficiency, larger quantities (250 kg P/ha) proved successful and in the late 50's and early 60's aerial applications of about 50 - 60 kg P/ha were routinely adopted by forest managers (Ballard, 1978). These large quantities of SSP where high by international standards of application, but provided a buffer against unevenness of spread by fixed wing aircraft. Two questions were then raised. Firstly, could application rates be lowered, and to what degree and secondly, how would P availability from SSP be affected in the long-term by soil type, with reference to the P retention capacity of the soil?

The aim of the study was to examine in details the P requirements for radiata pine, over a complete rotation, and how these requirements might be influenced by soil properties, particularly P retention capacity.

MATERIALS AND METHODS

Six forest sites where chosen at Whangapoua, Glenbervie, Maramarua, and Riverhead. At Whangapoua 3 blocks (replicates) were established (AK 286/1, 2, and 3). One block (replicate) was established at Maramarua (AK286/4) and Glenbervie (AK286/5), and 2 blocks (replicates) at Riverhead (AK286/6).

The sites:

Whangapoua Forest (AK286/1,2,3).

The soil type is a firm coarse blocky structured clay, derived from Hamilton ash over very old andesitic ash; the soils are of medium P retention (50-60%). Block 1 was on a 10° slope; blocks 2 and 3 were on 20°-30° slope. Ak 286/1 and 2 were established in 1967 (age 6), and /3 in 1969 (age 8).

Glenbervie Forest (AK286/4)

The soil type is a firm clay with a strong to medium blocky structure derived from recent weathering of old deep red weathered clays; the soils are of medium P retention

(50%). The site was located in Compartment 58 on a 10° - 30° northerly slope. Radiata pine was planted in 1965, and low pruned in 1969. The trial was established in 1970 when the trees were age 5.

Maramarua Forest (AK286/5)

The soil type is a very firm, very coarse structured silty clay derived from intense weathering of greywacke; the soils are of low P retention (15-25%). First rotation radiata pine clear felled in 1962. Natural regeneration followed, and was thinned to 600 sph in 1969. The compartment was low pruned in 1971. The trial was established in April 1971 when the trees were age 8.

Riverhead Forest (AK286/6)

The soil type is a very firm, almost massive, medium blocky, structured silty clay tending to massive at 50 cm; the soil is mapped as Waikare clay loam and has a medium P retention (30-50%). The trial was established in Compartment 18, in November 1973, when the trees were age 6. The trial areas was lightly thinned (< 20% BA removed) at establishment.

The Treatments

The treatments were aimed at answering the following basic questions:

- What is the most economic combination of rate and frequency of P application?
- What is the effect of delaying fertiliser application by 5 years?
- Can foliage analysis be used to time future applications?

The full complement of treatments is shown below in Table 1.

Table 1. Treatment schedule

Treatment no	Fertiliser Quantity	Comments
1	control	no fertiliser added
2	62.7 kg P/ha	not delayed
3	62.7 kg P/ha	delayed 5 years
4	125 kg P/ha	not delayed
5	125 kg P/ha (as 2 applications)	not delayed, and after 10 yr
6	250 kg P/ha	not delayed
7	250 kg P/ha (as 4 applications)	not delayed, and after 5, 10 and 15 yr
8	62.7 kg P/ha	applied when foliar P <0.13%
9	125 kg P/ha	applied when foliar P <0.13%
10	125 kg P/ha + 270 kg N/ha	N as urea
11	125 kg P/ha + N + trace elements	K, Mg, Ca, B, Zn, Mn, Cu

NB Mg and Ca applied as dolomite; K, Mn, Zn, and Cu as sulphates

The schedule of treatments at each site and timing of application are shown in Table 2.

Table 2. Treatments at each site and timing of application

	Fertiliser applications					
Trt No	Whangapoua AK286/1	Whangapoua AK286/2	Whangapoua AK286/3	Glenbervie AK286/4	Maramarua AK286/5	Riverhead AK286/6
1	1967	1967	1969	1970	1971	1973
2	1967	1967	1969	1970	1971	1973
3	1972	1972	1974	1975	1976	1978
4	1967	1967	1969	1970	1971	1973
5	1967, 1977	1967, 1977	1969, 1979	1970, 1980	1971, 1981	1973, 1983
6	n.a	n.a	n.a	1970	1971	1973
7	67,72,77,82	67,72,77,82	69, 73,78,83	70,75,80,85	71,76,81,86	73,78,83,88
8	n.a	n.a	n.a	70,76	71,75	73,76
9	n.a	n.a	n.a	n.a	n.a	73,76/78
10	n.a	n.a	n.a	n.a	n.a	73
11	n.a	n.a	n.a	n.a	n.a	73

n.a = not applicable

Plot Installation

At all sites the plots were 20 m x 20 m with a 10 m similarly treated surround (0.16 ha total plot size).

RESULTS

The 6 blocks (or sites) were fertilised between 1967 and 1973. The tree age of the analysis for each block varies slightly due to the measurement intervals being inconsistent between sites. To simplify the comparisons between sites, the three blocks at Whangapoua have been combined as have the two blocks at Riverhead. This provides for essentially four contrasts: Whangapoua, Glenbervie, Maramarua, and Riverhead.

By mid-rotation (between ages 14 - 16 years) the ANOVA (Tables 3 and 4) shows that growth was related to both location (P0.0001) and to fertiliser treatment (P0.026) and that the behaviour of the crop with fertiliser was not different between the sites.

Table 3. ANOVA for the effect of location and treatment on Basal Area response

	Probability (P)	
Source of Variation	Mid rotation	End rotation
trial	0.0001	0.0001
treatment	0.0134	0.0001
trial*treatment	0.2377	0.0042

Table 4. ANOVA for the effect of location and treatment on Volume response

	Probability (P)	
Source of Variation	Mid rotation	End rotation
trial	0.0001	0.0001
treatment	0.0418	0.0001
trial*treatment	0.3372	0.0275

By the end of the rotation (between ages 26 - 31 years), in contrast to mid-rotation results, radiata pine had, overall, behaved differently with fertiliser treatment depending on location. To facilitate this understanding a description of the results for each site will be described.

Whangapoua

Growth

By the end of the rotation, the use of superphosphate fertiliser improved productivity substantially over the non-fertilised controls at 494 m^3/ha at age 26 to 703 m^3/ha with 63 kg P/ha (delayed 5 years) and to 726 m^3/ha with 63 kg P/ha applied at the initiation of the experiment (Fig.1). The difference between the immediate and delayed application is, however, not significant (P.05). The application of 125 kg P/ha at trial establishment, or as split applications of 2 x 63 kg P, ten years apart, significantly

(P.05) improved volume productivity over the single application of 63 kg P/ha, with 835 m^3/ha (single application) and 809 m^3/ha (split application). The difference in volume between the single (125 kg P/ha) and the split application (2*63 kg P/ha) was not significant (P.05). Applications of 63 kg P/ha every 5 years did not significantly improve volume growth (849 m^3/ha) over that achieved with the single application of 125 kg P/ha rate.

At mid-rotation, the ordering of the results in relation to treatment was similar.

Nutrition

At Whangapoua the controls were severely deficient in P at between 0.07% and 0.08% (Figure 2). All P treatments (except in the 63 kg P/ha treatment delayed) raised foliar P levels to between 0.10% and 0.13%. By mid rotation all fertilised treatments were at least 0.11%. By rotation end all treatments (with the exception of the 63 kg P/ha delayed) were at least at 0.10%. As stated above, growth was comparable in all treatments above the 63 kg P/ha level where foliar P varied from 0.11% to 0.13% and there was no growth advantage by fertilising at the 0.13% "trigger". This result indicates that a lower "trigger" level for P fertilising was warranted at this site and it is about 0.11% P.

Glenbervie

Growth

The various P treatments yielded anomalous results (Fig.3). Application of 63 kg P/ha at trial establishment yielded significantly more volume (P.05) at 932 m^3/ha (nearly 200 m^3/ha over the control at 737 m^3/ha); the delayed application of 63 kg P/ha achieved 837 m^3/ha (significant at P.05). All other applications did not improve growth. Given the lack of replication at this site, the contrast between the control plot (737 m^3/ha) and the average of the fertilised plots (743 m^3/ha) indicates that this site is not particularly responsive to P.

Nutrition

Analysis of the foliar P levels in the unfertilised controls (Figure 4) show that it ranged from 0.11% by mid rotation to 0.12% by rotation end. Although this P level is lower that published by Will (1985), it is comparable to the foliar P levels recorded for the fertilised plots at Whangapoua (as well as Riverhead and Maramarua - see later).

Maramarua

Growth

The superphosphate fertiliser treatments did not significantly improve the volume productivity by rotation end, with the exception of the heavy rate of application (250 kg P/ha) where the contrast between control and fertilised was 647 m^3/ha versus 762 m^3/ha (Fig.5). The response by mid-rotation for the fertiliser treatments was similarly ordered.

Nutrition

Foliar P levels remained at about 0.09% in the unfertilised control plot for the duration of the experiment (Fig.6). Through to mid-rotation, all the P treatments were between 0.13% and 0.15%. By rotation end, most P treatments were about 0.13% (or thereabouts) with the exception of the lowest rate of P treatment at 0.10%.

The lack of a large response to P fertiliser is due in part to the better P nutrition of radiata pine at this site, and probably in part to likely variation in P nutrition through other factors such as waterlogging/aeration on this very heavy clay soil. The lack of replication would also be a major factor in trying to interpret P responses where site variability can be large.

Riverhead

Growth

The responses to P were dramatic with unfertilised plots yielding 104 m^3/ha by the end of the rotation, compared with an average of about 540 m^3/ha for the superphosphate treatments (Fig. 7). It would appear that there is little evidence for real differences in productivity between the various P treatments, with the possible exception of the 63 kg P/ha treatment, where the average of the immediate and delayed application is 480 m^3/ha (the difference between them was not significant). Applying 125 kg P/ha either as a single or split application, or 250 kg P/ha, resulted in essentially similar productivity of about 550 m^3/ha.

Nutrition

The large response to the P treatments at Riverhead is due to the very P deficient nature of the crop at age 5 when the experiment commenced. By mid rotation the 125 and 250 kg P/ha treatments had very considerably raised foliar P levels to be well in excess of 0.13%, between 0.15 and 0.18%, as shown in Figure 8. The 63 kg P/ha treatment had maintained foliar P at 0.1%, which was well above the control plot levels at 0.06% (the foliar P elevation of the 63 kg P/ha delayed treatment is of course due to the proximity of this treatment in time to the mid-rotation period. By the end of the rotation, all treatments were yielding foliar P concentrations between 0.10% and 0.12% depending on rate (125 vs 250) and splitting of applications (1 vs 2).

DISCUSSION

Within site variation in this study has been a major problem. Where there was only 1 replication (Maramarua and Glenbervie) the growth responses were variable, and not necessarily consistent with treatment. Where the treatments were replicated as at Whangapoua and Riverhead, stronger relationships between treatments and outcomes existed. The lack of responsiveness at some sites, and the within site variation both contributed to the strong site x treatment interactions. Despite these difficulties, the trials have yielded important information, particularly with respect to the nature of the foliar P critical level.

At the Glenbervie site, control trees showed foliar P levels between 0.11% and 0.12%. Trees fertilised with superphosphate responded only slightly in growth, and only at the very highest application rates. This indicates that either the published critical value of 0.13% is high, or that some other factor is limiting growth. At Maramarua the evidence for a response to superphosphate is confused. Only one of the superphosphate treatments improved growth (the lowest rate of application), with the remaining treatments failing to show growth responses. Trees in the control (unfertilised) plots showed foliar P concentrations just below 0.10%. At Maramarua site variation is now known to be a major problem and one reason why there are relatively few NZ FRI experiments located in this forest. Aeration and waterlogging variations over relatively small distances (in the order of metres) are very likely to be contributing factors. Variation due to previous logging practice is also likely to be a major source of site variation having a major impact. Soil scalping from the harvest of a first rotation crop can remove the entire A horizon (Simcock and Rijkse, pers comm). It is possible that the lack of responses to the higher rates of superphosphate application at Maramarua was due to an interfering agent such as scalping.

At Riverhead Forest, trees in the control (unfertilised) plots showed very low foliar P concentrations (0.06%). Superphosphate applications induced dramatic growth responses, even at the lowest rate of application of 63 kg P/ha. At this rate, foliar P levels were raised to around 0.10%, and yields were about 90% of that of the heavier application rates. By the end of the rotation, foliar P levels had equilibrated at between 0.10% and 0.12% with final volume production being comparable between the fertiliser treatments.

CONCLUSIONS

At Whangapoua and Riverhead Forests, unfertilised radiata pine remained acutely P deficient for the duration of the rotation. Application of superphosphate at both sites dramatically improved productivity. At both Whangapoua and Riverhead Forests, 125 kg P/ha as a single application was the optimal treatment.; there was no advantage in applying 125 kg P/ha as 2 applications separated by 10 years, nor was there any advantage in applying P on demand (foliar P at 0.13%). The lower rate of application of 63 kg P/ha, although it improved growth, was insufficient to maintain maximum productivity over the rotation.

Based on the responsiveness of radiata to increasing rates of P fertiliser, and the associated patterns in foliar P, a downwards revision of the 0.13% "critical" level (Will, 1985) to 0.11% is warranted.

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