EFFECT OF FIRST ROTATION PHOSPHORUS APPLICATIONS ON FERTILISER REQUIREMENTS OF SECOND ROTATION RADIATA PINE

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ABSTRACT

Residual benefits of P fertiliser applied during the previous rotation were evaluated on a severely P-deficient soil in Riverhead Forest. Plots treated with 225 kg/ha P 19 years previously and their controls were subdivided at establishment of the second **Pinus radiata** crop. Half of each main plot received a standard establishment application of P fertiliser (17 g/seedling P) and the other half was left untreated.

Five years after establishment trees in all sub-plots which had received any fertiliser had gained at least a year's growth advantage over those which had received no fertiliser. Growth of trees in sub-plots which received a single P application in either the first or second rotation was similar and slightly greater than that of trees in sub-plots which received both applications. This slight suppression was attributed to the second P application accentuating a N deficiency induced in the old +P plots by the growth response of the first rotation crop.

Analysis of both foliage samples collected from old crop trees prior to felling and soil samples collected prior to re-establishment provided a good index of the residual effectiveness of the previous fertiliser application.

INTRODUCTION

Fertiliser trials established during the 1950s in unthrifty first rotation stands of radiata pine (*Pinus radiata* D. Don) growing on strongly weathered clay soils at Riverhead Forest, showed that the poor growth was caused by a phosphorus (P) deficiency (Weston, 1956; Conway, 1962). During the period 1958 to 1965 most of the mature first rotation stands in the North Island showing symptoms of P deficiency were aerially topdressed with superphosphate (8-10% P) at 628 kg/ha. Later trials, put in at establishment of the first of the second rotation crop on these clay soils which had received no previous fertiliser, showed that P fertiliser was required for successful re-establishment of radiata pine (Ballard, 1969). Because of the known effectiveness of large single applications of P fertilisers in supplying the P requirements of radiata pine over periods of up to 20 years during a rotation (Mead and Weston, 1968; Gentle, Humphreys and Lambert, 1965), the question arose as to what extent first rotation applications of P fertiliser would alleviate the need for fertiliser at establishment of the second crop. An opportunity to study this question came up when two pairs (control and P fertilised) of the original 1952 Riverhead trials (Weston, 1956) were felled in 1970.

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MATERIALS AND METHODS

First Rotation Plots

In 1952 two pairs of 20 × 20 m plots were established in 25-year-old radiata pine in Compartment 3, Riverhead Forest (A99/A100 and A101/A102, hereafter referred to as Blocks 1 and 2 respectively). The soil type of the area is Waikare clay loam, a strongly leached and weathered northern yellow-brown earth formed from sandstone.

One plot in each block was treated with a superphosphate compound (75% superphosphate, 15% ground Nauru phosphate and 10% ground serpentine rock) hand broadcast at a rate equivalent to 225 kg/ha P, while the other was sprayed with Zn (600 ml of $2\frac{1}{2}$% $ZnSO_4$ solution per tree). No response was recorded to the Zn treatment and thus these plots have been considered as controls. The plots within each block were separated by a 20 m untreated buffer strip and the blocks were located some 50 m apart.

These early plots were established as observational trials only and no mensurational data was collected from them until 1966. The extent of the response up to 1966 is shown by the data in Table 1 which also shows that the P application was still maintaining reasonable foliar P levels at this date.

TABLE 1—First rotation plot information 14 years after the application of 225 kg/ha P

Treatment	Block	Stocking	Basal area	Volume	Foliar analysis				
					N	P	K	Ca	Mg
		stems/ha	m^2/ha	m^3/ha	— — —	— — —	%	— — —	— — —
Control	1	890	17.8	41	0.83	0.073	0.55	0.12	0.10
	2	766	9.1	15	1.42	0.068	0.41	0.22	0.14
	Mean	828	13.5	28	1.13	0.071	0.48	0.17	0.12
+P	1	1186	57.1	386	1.25	0.11	0.75	0.21	0.16
	2	1112	36.8	223	1.38	0.14	0.54	0.34	0.14
	Mean	1149	47.0	310	1.32	0.13	0.64	0.28	0.15

Prior to felling in 1970 the corners of each plot were marked with metal standards driven well into the ground. After felling the compartment was burnt in February 1971 in preparation for planting in July.

Second Rotation Plots

A split-plot design was employed to examine the residual effect of the first rotation fertiliser application in relation to the response achieved from the standard second rotation fertiliser application. The first rotation treatments were used as main plots (Fo and F+ for control and P treated respectively) each of which was subdivided into four equal sub-plots, two of which received no second rotation treatment (So) and two of which were given the standard establishment application of 17 g/seedling P applied as superphosphate in a spade notch 15 cm from the seedling (S+). Each sub-plot consisted of 36 1/0 *P. radiata* seedlings planted at 1.8 m spacing in a 6 × 6 array. Only the 16 inner trees were used for data gathering, thus leaving a treated buffer row.

Height to the terminal bud and collar diameter (5 cm above ground level) were recorded at establishment in 1971 and annually thereafter in winter. A composite sample of the previous spring's foliage on the uppermost whorls was collected from each sub-plot in the autumn of 1973, 1975 and 1976.

Volume and composite soil samples from the surface 10 cm of soil were collected from each sub-plot just prior to planting, using the methods outlined by Ballard (1972).

In the spring of 1975 all plots were given a basal application of urea at 200 kg/ha N.

Analytical Techniques

Soil chemical and physical properties were determined by the techniques outlined by Ballard (1972). Foliage samples were analysed using the methods reported by Mead and Will (1976).

RESULTS

Detailed results, on a sub-plot basis, are available at the Forest Research Institute, Rotorua, in an unpublished report (Ballard, 1976).

Soil Properties

Chemical properties of the Waikare clay loam (Table 2) are typical of the infertile weathered clay soils in Riverhead and other North Auckland forests — low pH, wide C/N ratio and low in both "available" and total amounts of nutrient elements. The effect of the original P application shows in the raised total and Bray 2 P levels in the +P plots. Other differences associated with the original treatment are inconsistent between blocks.

TABLE 2—Soil chemical properties of the surface 10 cm just prior to planting in 1971

Treatment	Block	pH	Total N	Carbon	C/N	Bray 2 P	Total P	Exchangeable cations Ca	Mg	K
			— — — — %	— — — —		— ppm —		— — me/100 g — —		
Control	1	4.65	0.108	1.9	17.8	1.8	54	0.86	0.67	0.21
	2	4.51	0.124	2.4	19.0	2.1	54	0.87	1.19	0.23
	Mean	4.58	0.116	2.2	18.5	2.0	54	0.87	0.93	0.22
+P	1	4.51	0.064	1.8	28.1	6.9	60	0.71	0.52	0.15
	2	4.59	0.142	2.4	16.5	5.9	104	1.85	2.04	0.36
	Mean	4.55	0.103	2.1	20.4	6.4**	82**	1.28	1.28	0.26

** Treatment effects significant at the 1% level by ANOVA.

The effect of the initial P application and subsequent tree response on soil physical properties (Table 3) was similar to but less marked than that observed in another pair of the 1952 plots. However, in this current study soil properties were examined after logging, burning and a year's fallowing of the sites (Ballard, 1972). The only significant effect was the increase in macro-porosity. Prior to felling it was observed that the soil in the +P plots was drier and better structured than that in the control plots.

TABLE 3—Soil physical properties of surface 10 cm just prior to planting in 1971

Treatment	Block	Clay	Silt	Sand	Bulk density	Porosity Macro	Porosity Total
		— — —	% — —	— —	g /cc	— — %	— —
Control	1	24	29	47	1.38	7.5	46.4
	2	28	29	43	1.24	8.6	51.4
	Mean	26	29	45	1.31	8.1	48.9
+P	1	20	33	47	1.34	16.0	48.2
	2	39	25	36	1.23	9.2	52.6
	Mean	30	29	41	1.29	12.6*	50.4

* Treatment effect significant at the 5% level by ANOVA.

Tree Growth

Treatment effects on height and collar diameter were very similar (Ballard, 1976) and will be illustrated in this paper by the collar diameter data which were less variable than those for height.

Mean effects (averages over all other treatments) of first and second rotation fertiliser applications were small (Table 4) and non-significant (Table 5) for the first 4 years after planting. Treatment differences became more apparent after the fifth growing season with both first and second rotation applications significantly influencing collar diameter increment. However, the magnitude of the main fertiliser effects are small in relation to responses normally obtained from P fertilisation on these soils (Berg, 1975; Ballard and Mead, 1976). This can be explained by the highly significant interaction between first and second rotation applications (Table 5) which is illustrated in a plot of individual treatment effects on collar diameter (Fig. 1). The second rotation application produced a substantial increase in growth on sites which had received no first rotation application but actually suppressed growth on sites which had been fertilised during the first rotation. Response curves in Fig. 1 and a reduction in the level of significance of th F × S interaction for the 75/76 increment indicate a relative improvement in growth performance during 75/76 on sites fertilised in the first rotation. This corresponded with the application of N to the whole experimental area in spring 1975.

Responses to single fertiliser application in either the first or second rotations were similar and over 5 years produced an advantage of at least 1 year's growth over unfertilised trees (Fig. 1). Differences in productivity between fertilised and unfertilised trees diverged with time and the trend appears likely to continue.

Growth in Block 1 was superior to that in Block 2 (Table 4). This difference reflected the first rotation productivity of the two blocks (Table 1).

Foliar P and N

Because of the nature of the trial design (split-plot with replication within main plots), the analysis of variance is more sensitive for sub-plot treatment (S) effects than main-plot treatment (F) effects. Thus despite the main effects of first and second rotation

TABLE 4—Collar diameters illustrating the main effects of the first (F) and second (S) rotation fertiliser treatments

	Collar diameter (mm)							
Effect	71	72	73	74	75	76	71/76	75/76
Fo	4.0	8.2	16	31	49	65	61	16
F+	3.7	9.0	16	29	49	73	69	24
So	3.7	8.2	15	27	44	62	58	18
S+	4.1	9.0	17	33	54	76	72	23
Block 1	4.1	9.9	19	36	56	77	33	21
Block 2	3.7	7.3	13	24	42	61	57	19

TABLE 5—Statistical analysis of treatment effects on diameter growth

		Collar diameter							
Source	df	72	72	73	74	75	76	71/76	75/76
Block (B)	1	NS	NS	NS	NS	*	*	*	(10)%
First (F)	1	NS	NS	NS	NS	NS	(10%)	(10%)	*
MPE	1								
Second (S)	1	NS	NS	NS	(10%)	*	**	*	*
B × S	1	NS	NS	NS	NS	NS	NS	NS	NS
F × S	1	NS	(10%)	(10%)	*	**	**	**	*
B × F × S	1	NS	NS	NS	NS	NS	NS	NS	NS
	8								

NS Not significantly different
(10%) Significant at the 10% level
* Significant at the 5% level
** Significant at the 1% level

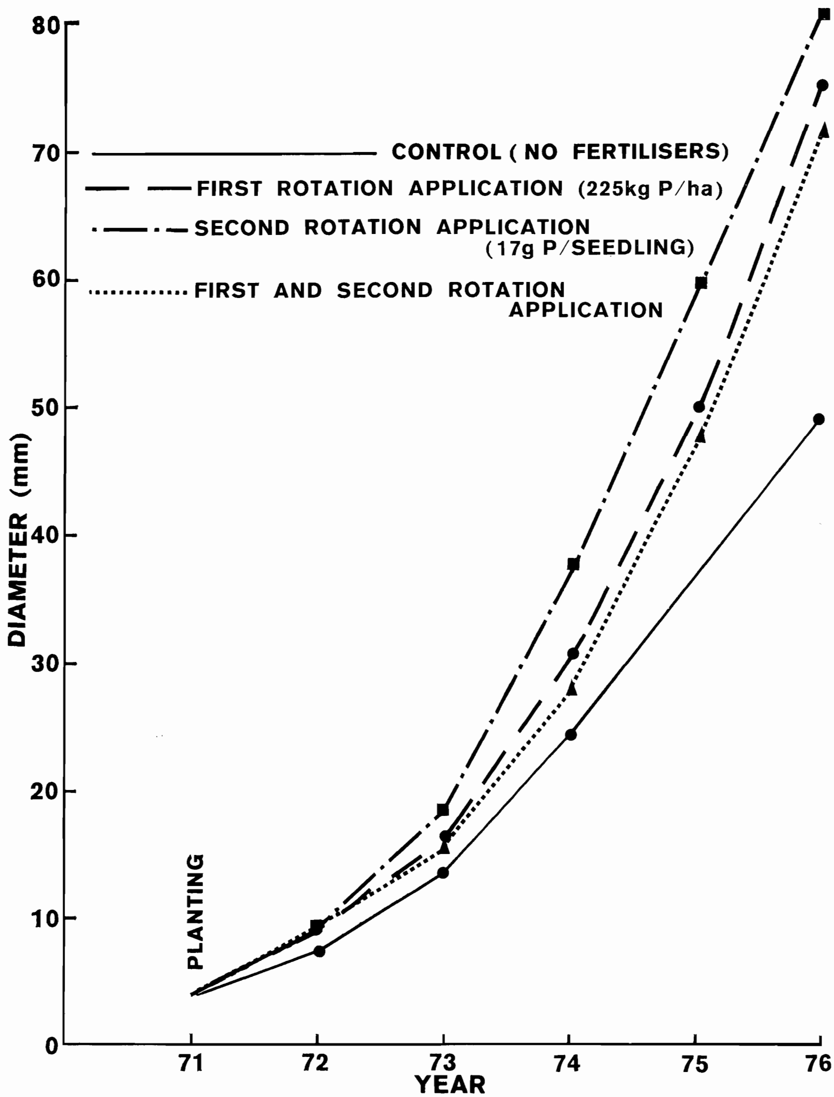


FIG. 1—Individual treatment effects on collar diameter.

P applications on foliar P concentrations being very similar (Table 6), the effects of the latter show up as more significant (Table 7). Foliar P levels in all treatments declined at an almost identical rate over time (Fig. 2). The decline rate in Block 2 (the poorer block) was, however, greater than that in Block 1.

As expected, foliar P levels in trees which received P in both the first and second rotation were greater than those in trees which received a single application which in turn were greater than those in trees which received no fertiliser at all. An unexpected feature of the results was the higher foliar P levels in the trees which received a single application in the first as opposed to the second rotation — this may be partially accounted for by a dilution effect as the trees in the plots which received the single second rotation application were larger than those in the plots treated in the first rotation only (Fig. 1). Five years after establishment of the second rotation crop foliar P levels in all plots had fallen below those considered optimal for radiata pine growth (0.12-0.14%).

Both first and second rotation applications of P reduced foliar N levels, with the larger and most significant reduction being associated with the first rotation application. These P fertiliser effects on foliar N are not adequately explained by a dilution effect associated with the response to P; trees which only received the second rotation applica-

TABLE 6—Levels of N and F in foliage and soil illustrating the main effects of the first (F) and second (S) rotation fertiliser applications

	Foliar P (%)			Foliar N (%)			Soil N (%)	Bray P (ppm)
Effect	73	75	76	73	75	76	71	71
Fo	0.116	0.085	0.074	1.73	1.60	1.58	0.116	1.9
F+	0.154	0.118	0.098	1.56	1.29	1.36	0.103	6.4
So	0.121	0.094	0.075	1.68	1.48	1.53	0.108	3.8
S+	0.149	0.109	0.097	1.61	1.41	1.41	0.111	4.6
Block 1	0.131	0.102	0.089	1.60	1.53	1.56	0.086	4.4
Block 2	0.139	0.101	0.083	1.69	1.36	1.38	0.133	4.0

TABLE 7—Statistical analysis of treatment effects on N and P in foliage

		Foliar P			Foliar N		
Source	df	73	75	76	73	75	76
Block	1	NS	NS	NS	NS	NS	*
First	1	**	NS	NS	(10%)	(10%)	*
MPE	1						
Second	1	**	**	**	NS	NS	NS
B × S	1	NS	NS	NS	NS	NS	NS
F × S	1	NS	NS	NS	NS	*	NS
B × F × S	1	NS	NS	NS	NS	NS	NS
SPE	8						

NS Not significantly different
(10%) Significant at the 10% level
* Significant at the 5% level
** Significant at the 1% level

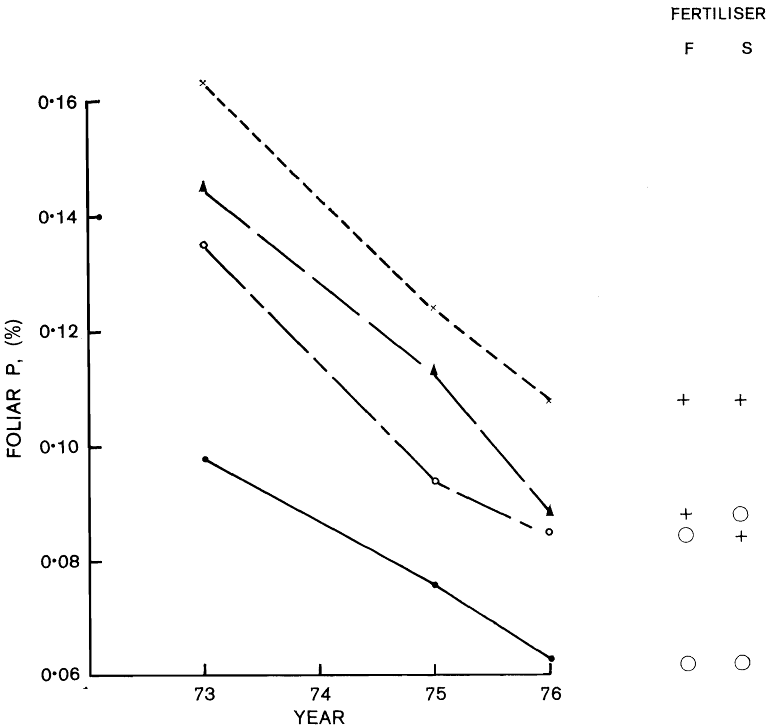
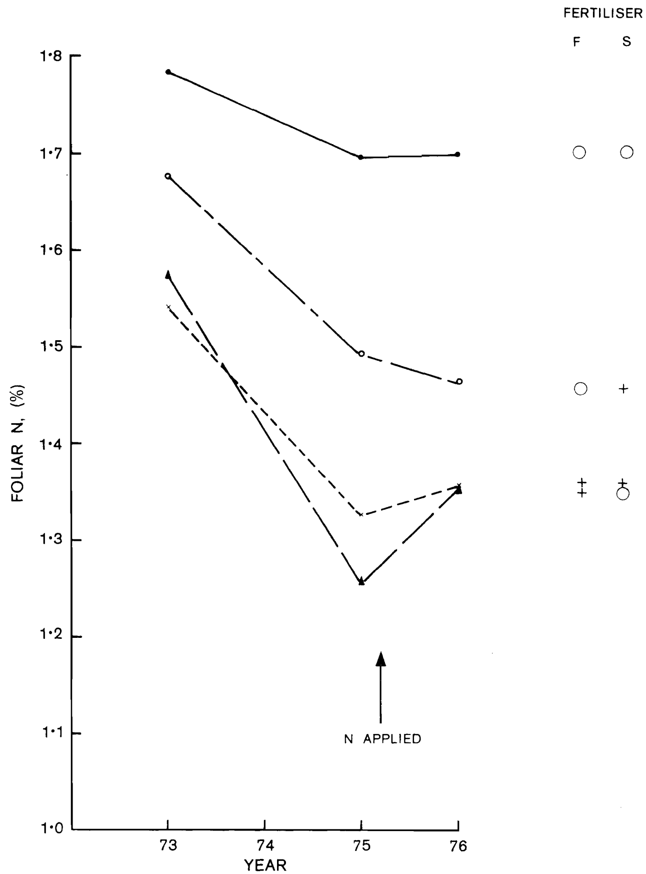


FIG. 2 (above)—Individual treatment effects on foliar P concentrations (A99-A102).

FIG. 3 (right)—Individual treatment effects on foliar N concentrations (A99-A102).



tion showed the biggest response yet had higher foliar N levels than trees which received first rotation P applications (Fig. 3). It is apparent from Fig. 3 that trees which did not receive fertiliser in the first rotation had a higher N status in the second rotation than those that did.

Foliar N levels in Block 2 were considerably lower than those in Block 1 in 1975 and 1976. These lower levels were associated with a lower growth rate in Block 2 but surprisingly not with a lower total N concentration in the soil (Table 6).

The application of N at 200 kg/ha in spring 1975 had only a small effect on foliar N 7 months later (Fig. 3): in the plots which received no first rotation P application it only reduced the rate of fall off in foliar N with time while in plots which received the first rotation application it raised foliar N levels slightly, but not to levels considered optimal for radiata growth. However, associated with the N application there was a marked increase in foliage mass and an improvement in colour, particularly in the F+ main plot of Block 2.

DISCUSSION

Growth and foliar analysis data from this trial showed that the residual effect of a heavy phosphate dressing applied to the first rotation crop 19 years previously produced as large a response in the second rotation crop as a standard establishment application. This result must not be taken to indicate that wherever the previous crop was topdressed with P fertiliser there will be no need to apply P at establishment of the following crop. The residual effectiveness of P fertilisers depends upon a number of interacting factors such as amount of P applied, fertiliser source used, soil properties (pH and P-retention capacity), climatic conditions, silvicultural operations (logging intensity, burning) and time since application which make it practically impossible to predict purely from the fertiliser history of an area.

Fortunately it appears that both foliar analysis, using the old crop just before felling, and soil analysis can provide a reasonably accurate indication of the extent to which previous applications will alleviate the need for establishment applications: foliar analysis 4 years before clearfelling indicated that the P status of the old +P plots was in the marginal range of 0.12-0.14% (Table 1), while soil analysis by the Bray 2 method (Ballard, 1974) also indicated that the P status of these plots just prior to planting was marginal. Both methods indicated that the old control plots were severely P deficient. In view of the apparent marginal P status of the old +P plots, as indicated by foliar and soil analysis, it may appear surprising that no response was produced by applying extra P to them at establishment of the second rotation crop. Although the calibrations of our soil and foliar analysis techniques are not foolproof the data presented in this report would tend to suggest that the lack of response was due to other factors restricting the response:

1. Very low foliar N levels in the old +P plots (associated with visual symptoms of deficiency in one of the plots) in conjunction with initial signs of response to the recently applied N suggest that a N deficiency limited the response to additional P in the old +P plots. The lower N status of the old +P plots may have resulted from a greater removal of N in the harvested crop (the old control plots had virtually no merchantable timber on them) or from a greater loss during burning (the heavier slash conditions probably generated a hotter fire on the +P plots).

2. Growth rates in all plots were slow in the first 3 years after establishment (Fig. 1). Evidence from site preparation × fertiliser trials (Ballard and Mead, 1976) now indicates that this slow establishment is usually associated with poor soil physical conditions. When such conditions are corrected (by ripping etc.) the responsiveness to P fertiliser usually increases markedly and, on clay soils at least, largely alleviates the need for N fertilisation at establishment.

The soil in the trial would most probably have benefited from ripping prior to establishment, for although the previous fertiliser treatment and associated response had visually improved soil physical conditions, much of this improvement appeared to be lost between logging and re-establishment a year later. Compaction and puddling during logging on these wet clay soils has a very adverse effect on soil physical conditions.

The possibility of substantial residual effects from fertiliser applications to previous rotations emphasises the potential wastefulness of any system using standardised (times and amounts) fertiliser prescriptions for particular forests or soil types. Although such a system has advantages for long-term budgetary planning these intangible benefits are unlikely to offset the potential disadvantages. Reliance on periodic foliage and soil testing for determining fertiliser requirements has many advantages including the ability to predict when and where fertiliser is not required.

Many of the P-deficient forest soils in New Zealand are similar to that on which this trial was established — strongly weathered acid clay soils with a medium to high P-retention capacity. Thus the long-term residual effect recorded in this study augers well for the future P fertiliser needs of these soils. Radiata pine stands on these soils are currently receiving an application at establishment followed by at least one or two applications of 1.2 tonne/ha superphosphate during the rotation. It appears likely that it will be possible to reduce either the rates or the frequency of application to following rotations. In terms of future fertiliser requirements the results of this study also point out that correction of a nutrient deficiency and the associated improved growth can hasten the onset of other nutrient deficiencies — in this case of N.

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