USE OF SOIL TESTING FOR PREDICTING PHOSPHATE FERTILISER REQUIREMENTS OF RADIATA PINE AT TIME OF PLANTING

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ABSTRACT

The ability of soil tests for extractable phosphorus to predict height growth and fertiliser requirements of radiata pine (**Pinus radiata** D. Don) seedlings at time of planting in the field was examined.

The Bray 2 and Olsen tests proved to be the most satisfactory of the tests examined for predicting height growth of radiata pine seedlings on unfertilised soils. The correlation coefficients improved as the length of the growth period considered was increased from 1 to 3 years after planting. The Bray 2 test accounted for 60% of the variability in 3-year height growth of seedlings. A value of 12 ppm P was found to correspond to minimal 3-year height growth on fertile soils.

However, none of the soil P tests examined or other soil parameters (pH, silt, clay, P retention, bulk density, and loss on ignition) proved useful for accurately predicting the response of seedlings over a 3-year period to 85 g of superphosphate applied, at time of planting, on an individual seedling basis.

Superphosphate requirements ranging from 170 g per seedling when the Bray 2 test shows less than 3 ppm of P to nil when the Bray 2 test shows more than 12 ppm were tentatively deduced.

INTRODUCTION

Phosphorus deficiency was first shown to be a major factor in the poor growth of radiata pine (*Pinus radiata* D. Don) in New Zealand during the 1950s (G. C. Weston, 1956). Since that time, application of phosphate fertilisers has been adopted as a routine management practice in many New Zealand forests. Current practice is to apply fertiliser by hand to individual seedlings at time of planting, followed by an aerial application at about canopy closure. The timing and need for the aerial application is based upon foliar analysis data, foliar P having been shown to be closely related to the P status of radiata pine growing under a wide range of conditions in New Zealand (Will, 1965). The prerequisite for foliar analysis that trees exist on the site precludes its use for predicting fertiliser requirements at time of planting. At present, fertiliser recommendations at

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time of planting are based on the previous history of the site and on responses to fertiliser applications recorded in trials on similar sites, where they exist. Such recommendations are, at best, very arbitrary.

Soil analysis has been shown to be an effective alternative to foliar analysis for predicting the P status of established stands of radiata pine (Ballard, 1970). Provided satisfactory relationships between soil test values and seedling response to fertiliser can be established, soil analysis should provide a reliable and practical means of determining fertiliser requirements before planting.

The object of this investigation was to attempt to obtain soil test calibration data suitable for predicting the P status and fertiliser requirements of sites before planting.

METHODS

Field response and growth data were obtained from a series of fertiliser trials established at time of planting throughout New Zealand from Waitangi in the North Island to Nelson in the South Island. The trials were selected to meet the following requirements:

(1) Phosphorus must be the only (major) factor limiting growth in the control plots;

(2) Fertiliser must have been applied as superphosphate, on an individual tree basis, within the first year after planting;

(3) The trial must have been in existence for at least three growing seasons. A minimum period of up to canopy closure would have been more desirable as this is the period over which the time of planting application is expected to be effective, but such a limitation would have removed most trials from consideration;

(4) Height measurements must have been recorded annually.

Height increase and the height increment as a percentage of initial height were calculated for the growth of trees in the untreated control plots. The percentage responses of the fertiliser treatments compared to the control were also determined for each year of measurement.

Superphosphate (9% P) application rates within the trials sampled consisted of 57, 85, and 114 g/seedling. The rate of 85 g/seedling was the only rate common to all trials.

Soil samples were collected from the control plots of each trial from the 0-10 cm depth using a 2.5 cm diameter closed cylinder auger. Each sample was a composite of several cores (at least one core/10 m^2). Where trials consisted of more than one block, or showed obvious variability between replicates, separate samples were taken from blocks and replicates.

Soil Analysis

Available P was extracted by the Olsen, Bray 1 and 2, and Truog (before and after ignition) methods as outlined by Ballard (1970). In addition, P extracted by the Olsen test using 4, 8 and 16 hour extraction periods and by 1% citric acid (A. J. Weston, 1956) was also determined. Bulk density, mechanical analysis, pH, loss on ignition, and percentage P retention were determined by standard New Zealand Soil Bureau procedures (New Zealand Soil Bureau, 1968).

RESULTS AND DISCUSSION

Table 1 shows properties of the soils from the fertiliser trials used in this investigation. All are moderately to strongly weathered, fine textured, acid soils on which responses to phosphatic fertilisers were obtained.

TABLE 1 - Properties of soils from selected fertiliser trials

Plot	Location	Soil Group*	pH	Bulk Density (g/cc)	Clay (%)	Silt (%)	Loss on Ignition (%)	P Retention (%)	Available P Bray 2 (ppm)	Available P Olsen 1/2 (ppm)
A397	Waitangi S.F.	N.Y.B.E.	4.6	1.18	19.3	48.6	6.6	32.2	2.29	2.54
A280	Maramarua S.F.	N.Y.B.E.	5.3	1.03	37.3	31.7	12.6	62.7	1.23	2.06
A363	Riverhead S.F.	PODSOL	4.1	1.24	7.6	47.6	4.3	11.0	1.82	2.95
A248	Riverhead S.F.	N.Y.B.E.	4.5	1.05	29.3	40.7	3.2	39.2	9.54	6.32
A386	Riverhead S.F.	N.Y.B.E.	4.9	1.12	33.3	38.7	10.2	62.7	1.98	1.69
A364/A	Riverhead S.F.	N.Y.B.E.	4.5	1.29	39.6	31.6	7.6	33.4	1.53	2.41
A364/B	Riverhead S.F.	N.Y.B.E.	4.5	1.34	30.6	31.6	8.6	35.2	1.09	1.36
A364/C	Riverhead S.F.	N.Y.B.E.	4.5	1.33	23.3	47.6	7.1	35.4	3.23	3.34
A285/42	Riverhead S.F.	N.Y.B.E.	4.8	1.12	30.6	36.6	8.1	43.7	1.11	1.67
A285/45	Riverhead S.F.	N.Y.B.E.	4.8	1.09	17.3	48.7	7.2	31.2	1.89	2.71
A285/5	Riverhead S.F.	N.Y.B.E.	4.7	1.12	30.6	40.6	8.7	42.0	1.42	1.86
A285/8	Riverhead S.F.	N.Y.B.E.	4.7	1.10	34.6	41.6	9.1	54.5	1.73	2.12
A285/34	Riverhead S.F.	N.Y.B.E.	4.8	1.09	34.6	39.6	7.9	52.5	1.32	2.50
N141/4	Nelson	Y.B.E.	4.7	1.24	30.3	18.7	7.1	33.7	2.26	2.22
N149/2	Nelson	Y.B.E.	4.8	1.30	24.7	26.7	7.0	39.2	1.91	2.22
N230	Nelson	Y.B.E.	4.7	1.39	30.4	27.7	6.6	41.2	1.97	2.01

* N.Y.B.E. = Northern Yellow-Brown Earth

Y.B.E. = Yellow-Brown Earth

Height Growth, and Soil Tests on Unfertilised Sites

A preliminary screening of methods of expressing soil test values (weight and volume basis) and statistical models (linear, logarithmic, and quadratic) showed that the best fit for height growth in the control plots was obtained with soil test values expressed on a weight basis using a linear model. Correlation coefficients between height growth parameters and soil test values are shown in Table 2 for each of the first 3 years after planting.

TABLE 2 - Correlations between height growth of control trees and soil test values

Dependent Variable	Years after Planting	Soil test								
		Olsen 1/2	Olsen 4	Olsen 8	Olsen 16	Bray 1	Bray 2	Truog	Truog Ign.	Citric
		r								
% height increase	1	0.305	0.186	0.425	0.330	0.142	0.391	0.291	0.171	0.136
	2	0.465	0.354	0.583	0.402	0.327	0.570	0.320	0.009	0.028
	3	0.512	0.435	0.604	0.451	0.412	0.617	0.359	0.008	0.075
Actual height increase	1	0.276	0.317	0.530	0.447	0.264	0.491	0.387	0.144	0.001
	2	0.653	0.552	0.746	0.558	0.524	0.740	0.453	0.085	0.243
	3	0.693	0.617	0.755	0.546	0.606	0.780	0.508	0.087	0.239

$r \geq 0.606$ Significant at the 1% level

$r \geq 0.482$ Significant at the 5% level

Theoretically, relationships between growth increments and increasing soil P values should be reasonably linear over the lower range of soil P values but thereafter take on a pronounced curvilinear form as soil P values approach and exceed those critical for normal growth. The failure of the logarithmic or quadratic models to provide a better fit than the linear model is a reflection of the low P status of these sites, on all of which responses to applied P were obtained.

The data in Table 2 show that correlations between soil test values and actual height increase are consistently larger than those using percentage height increase as the parameter of height growth. This suggests that the initial height of the seedling at planting is not of particular importance in determining subsequent height growth.

Correlation coefficients between soil test values and both height parameters show a marked increase with each yearly extension of the growth period. Obviously, in the first year after planting, height growth is being influenced primarily by such factors as vigour of the planting stock (not related to height), planting procedures, and other factors important in the establishment of the seedling, rather than soil P values. With increasing time of establishment on the site, however, growth becomes controlled more and more by the site factors most limiting to growth—in this case soil P values. It is possible that had the growth data covered more than 3 years the correlations may have been further improved.

The significant correlations in Table 2 show that some soil P tests provide a good reflection of the availability of soil P to young radiata pine seedlings. The Bray 2 and Olsen tests are superior to others examined. These results are similar to the order of success of these tests for predicting the productivity of mature radiata pine on similar soils (Ballard, 1970). Increasing the extraction period of the Olsen test provided no appreciable improvement over the standard 30 minutes extraction for prediction purposes. The Bray test accounts for 60% of the variability in height growth which, considering the variability in climatic and site conditions between trials, is a satisfactory result. The regression equation of height increase (Y in cm) on Bray 2 test values (X as ppm) is:

$$Y = 10.05\ X + 31.2$$

The Bray 2 test value corresponding to a 3-year height increase of 150 cm, minimum increase expected on fertile soils for the regions covered by the trials, is 12 ppm P. This value is considerably higher than the critical value of 5 ppm established for mature stands of radiata pine (Ballard, 1970). This is probably due to differences between the modes of nutrition of young and mature stands. In mature stands the P supply to the tree is met mainly by nutrient cycling (Will, 1964) with little net demand on the soil, whereas in young stands prior to canopy closure the P requirements are met almost entirely by net withdrawal from the soil. Thus, net demands per unit weight of soil exploited by young trees are likely to be greater than those of mature trees. The Olsen 8 test accounts for 58% of the variability in height growth but lacks the analytical convenience of the Bray 2 test with its one minute extraction period. It is also known to seriously underestimate the availability of P to pines growing on weakly weathered soils (Ballard *et al.,* 1971).

Other than soil P tests, loss on ignition is the only other variable significantly correlated with 3-year height growth (Table 3). This variable is, however, more closely correlated with soil test values than height growth. The partial correlation coefficient between height growth and loss on ignition corrected for Bray 2 test values is only $r = -0.190$ compared to the uncorrected correlation coefficient of $r = -0.568$. This indicates the indirect relationship of this variable to height growth.

Soil Tests and Response to Fertiliser

A preliminary screening of statistical models showed that the best fit was achieved using soil test values expressed on a unit weight basis and the logarithmic transformation of the percentage response variable. Correlations between soil test values and log percentage response to three applications rates of superphosphate over a 3-year period are shown in Table 4.

The correlations for the 57 and 114 g treatments were obtained from only five sets of data and three of these were from three blocks within one trial. Thus, despite some of the correlations being highly significant they are of little practical value, having come from such a restricted range of data. The correlations for the 85 g treatment, which is common to all trials, are considerably smaller than those for the other two application rates and fail to achieve significance even at the 5% level. Data in Table 3 show that none of the other soil variables examined is significantly correlated with log percentage response to 85 g superphosphate. To examine the possibility that some other soil characteristic such as P retention or pH might be influencing the degree of response to fertiliser within specific soil test values, partial correlations between log percentage response to 85 g and the soil variables of pH, P retention, loss on ignition, bulk density, silt, and clay corrected for the influences of soil test values were computed. None of these partial correlations achieved significance even at the 10% level and are not

TABLE 3 - Matrix of correlations between soil and growth (actual height increase and log % response to 85 g superphosphate over 3 years) variables for all plots

Variables	Correlation Coefficients (r)									
	Height Increase	Log % Response	Olsen 1/2	Olsen 4	Olsen 8	Olsen 16	Bray 1	Bray 2	Truog	Citric
Height Increase (3 yr)	1.000									
Log % Response (85 g)	-0.601	1.000								
Olsen 1/2	0.693	-0.350	1.000							
Olsen 4	0.617	-0.360	0.926	1.000						
Olsen 8	0.755	-0.433	0.938	0.945	1.000					
Olsen 16	0.546	-0.288	0.824	0.917	0.939	1.000				
Bray 1	0.606	-0.306	0.916	0.961	0.902	0.840	1.000			
Bray 2	0.780	-0.339	0.944	0.896	0.919	0.774	0.908	1.000		
Truog	0.508	-0.159	0.771	0.722	0.706	0.656	0.733	0.800	1.000	
Truog Ign.	0.087	-0.340	0.267	0.229	0.274	0.311	0.225	0.152	0.081	
Citric	0.299	0.043	0.755	0.742	0.650	0.635	0.758	0.692	0.508	1.000
Bulk Density	0.103	-0.133	-0.243	-0.165	-0.130	-0.040	-0.260	-0.216	0.066	-0.314
% Clay	0.053	0.003	-0.218	-0.283	-0.311	-0.508	-0.255	-0.080	-0.062	-0.329
% Silt	-0.359	0.265	0.315	0.404	0.224	0.375	0.461	0.161	0.152	0.635
Clay + Silt	-0.332	0.293	0.121	0.151	-0.069	-0.103	0.241	0.094	0.101	0.351
Loss on Ignition	-0.568	0.258	-0.674	-0.592	-0.682	-0.648	-0.557	-0.607	-0.430	-0.582
pH	-0.297	0.242	-0.338	-0.409	-0.402	-0.458	-0.402	-0.252	-0.131	-0.346
P Retention	-0.239	0.150	-0.240	-0.266	-0.315	-0.420	-0.208	-0.101	-0.077	-0.259

r 0.606 Significant at the 1% level   r $>$ 0.482 Significant at the 5% level

TABLE 4—Correlations between soil test values and log % response over 3 years to superphosphate applications

Soil test	Treatment (g superphosphate/seedling) 57	85	114
	r		
Olsen ½	−0.848*	−0.350	−0.682
Olsen 4	−0.963**	−0.360	−0.637
Olsen 8	−0.895*	−0.433	−0.415
Olsen 16	−0.848*	−0.288	−0.514
Bray 1	−0.985**	−0.306	−0.475
Bray 2	−0.879*	−0.339	−0.495
Truog	−0.503	−0.159	+0.113
Truog Ign.	−0.716	−0.340	−0.475
Citric	−0.686	+0.043	−0.876*

** Significant at the 1% level

* Significant at the 5% level

reported in this paper. This suggests that the considerable proportion of the variation unaccounted for by soil test values can probably be attributed to factors such as: (1) Variation in methods of application. Even though a criterion for acceptance of trials in this study was that fertiliser had to be applied on an individual seedling basis we have found that different methods of application have a considerable influence on the response obtained; (2) Variable degree of weed competition between trials; (3) Variable influence of climate on response; (4) Other factors become limiting to growth following application of fertiliser. Although it was assumed soil P was the major factor limiting growth on all sites, we have no indication that P was still the major controlling factor once P was applied.

Obviously, to obtain data of value in accurately predicting fertiliser requirements, trials designed specifically for this purpose must be used. Such trials should cover a complete range of soil conditions, should have basal fertiliser applications to ensure that P is the only limiting nutrient, and should have a range of rates of P fertiliser applied in a standard manner. Unfortunately such a programme would take 6 to 7 years to yield the necessary information we need to predict requirements up to canopy closure, while the need is immediate. On the basis of the data relating height growth and soil test values and our experience from field trials, tentative predictions may be made which will be more valuable than the current arbitrary decisions. Foliar analysis and growth data from trials in Riverhead State Forest have shown that 114 g superphosphate/tree does not maintain foliar P levels or growth at an optimum up to 6 years of age. These soils typically test below 3 ppm Bray 2 P and probably require a dressing of about 170 g superphosphate/tree. Trials in Maramarua and some sites in Riverhead, testing in the vicinity 3-6 ppm Bray 2, have shown 114 g superphosphate are required to maintain foliar P levels above critical values (0.10 to 0.11% P) for at least 5 years. Sites testing between 6 ppm and the critical value of 12 ppm established for normal growth probably need application rates of about 57 g/tree. Based on this reasoning, we now use the following calibration on a routine basis for making recommendations on fertiliser requirements at time of planting in New Zealand forests:

Bray 2 P (ppm)	Fertiliser requirements (g superphosphate/tree)
<3	170
3-6	114
6-12	57
>12	0

It should be appreciated that this is only an interim calibration based on very limited information, but one which should provide a more reasonable criterion than that used previously. It should also be emphasised that this calibration is of value only for time of planting applications designed to meet requirements up to canopy closure.

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