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PREDICTING THE P REQUIREMENTS FOR THE EARLY GROWTH OF RADIATA PINE BY SOIL ANALYSIS USING A SEQUENTIAL EXTRACTION PROCEDURE WITH THE BRAY AND KURTZ REAGENT

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EXECUTIVE SUMMARY

The decline in extractable P in forest soils subjected to repeated extraction with the Bray reagent follows an inverse logarithmic law. The logarithmic coefficients and the first extraction value for P were found to be highly correlated with radiata pine height and diameter response to P fertilisation on cultivated soils, and provides a much better estimate of the need for P fertiliser at time-of-planting than the conventional Bray test for "available" P.

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PREDICTING THE P REQUIREMENTS FOR THE EARLY GROWTH OF RADIATA PINE BY SOIL ANALYSIS USING A SEQUENTIAL EXTRACTION PROCEDURE WITH THE BRAY AND KURTZ REAGENT

by

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ABSTRACT

A sequential extraction procedure for "available" P using the Bray reagent is described. The procedure shows a decline in soil extractable P to follow an inverse logarithmic law. One of the coefficients from the function and the first Bray P extraction value were found to be highly correlated with radiata pine height and diameter response to P fertilisation on cultivated soils. Qualitatively and quantitatively, the sequential test is markedly better the single test to define the P requirements for radiata pine at time-of-planting.

INTRODUCTION

Phosphorus (P) deficiency is a major nutritional limitation for plantations of *Pinus radiata* in New Zealand (Will, 1973). The Bray Number 2 reagent for the removal of acid-soluble and adsorbed soil P (Bray and Kurtz, 1945) is routinely used in New Zealand to measure "available" P in forest soils prior to the plantation establishment. The Bray test was calibrated for a range of predominantly North Island forest soils by Ballard (1974). A soil P concentration of 12 ppm was defined as being "adequate" for the newly planted nursery seedlings. Between 0 and 12 ppm P, a graded series of superphosphate applications were advised. However, in the 10 years since the test was implemented, not all recommendations for phosphate fertiliser applications have been correct. Many soils registering less than 12 ppm P have been found to be adequate for the early growth of pines, whilst other soils testing greater than 12 ppm have been found to be inadequate (Skinner, FRI unpubl. data). The aim of this study was to re-evaluate the Bray P soil test, using a sequential extraction procedure to better define a forest soil's P supplying capacity.

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PART I: PRELIMINARY INVESTIGATIONS WITH 2 CONTRASTING FOREST SOILS

MATERIALS AND METHODS

Soil samples were collected from surface horizon (0-10 cm) in the control plots of 2 field experiments designed to test the effectiveness of superphosphate and phosphate rock as P sources for radiata pine. The trials at Waipoua State Forest (AK734/1) and at Tairua State Forest (AK 734/3) are described by Hunter and Graham (1983) and Hunter, Graham and J. Hunter (1988). The Waipoua soils are spodsols (podzolised sands) with a very low capacity to retain P; the Tairua soils are andesols (old deeply weathered ashes) with a very high P retentive capacity. 2.5 g soil samples were sequentially extracted up to 10 times, with each extraction lasting 1 minute with the Bray and Kurtz No 2 reagent (0.1 N HCl and 0.03 N NH4F) as the extracting solution. For each extraction, the samples were gently shaken with 25 ml of reagent, and after centrifuging, the supernatant sampled. The remaining supernatant was decanted, and the soil sample re-extracted. The solutions were analysed for P based on the method of Murphy and Riley (1962), modified by Nicholson (1984). The method has been adapted for use on an AutoAnalyser, and boric acid is added to eliminate possible interference from fluorides.

RESULTS AND DISCUSSION

The 2 soils show a marked contrast in sequentially "available" P (Fig. 1). The Waipoua soil shows an initially high concentration of P at 14 ppm which decreases rapidly to less than 1 ppm by the third extraction. The Tairua soil releases about 6 ppm P for each of the first 4 extractions, decreasing to about 4 ppm between extractions 4 and 9. Radiata pine at the 2 sites shows a marked contrast in its responsiveness to fertiliser P (Hunter and Graham, 19..). At the Waipoua site the P response is marked; at the Tairua site, the response is small. According to Ballard (1974), the Waipoua soil shows adequate levels for "available" P, whereas the Tairua soil should be deficient. In terms of soil buffer power for P, the sequential extractions show the Waipoua soil to have very little buffering ability, whereas the reverse is true for the Tairua soil.

PART II: TESTING THE SEQUENTIAL EXTRACTION PROCEDURE FOR A RANGE OF NEW ZEALAND FOREST SOILS.

MATERIALS AND METHODS

Field trials

During the mid-1970's and early 1980's the FRI established a large number of fertiliser trials with radiata at time-of-planting. The protocol for the establishment of these trials is described by Ballard and Mead, (1976), cited by Ballard (1978). In summary, the trials were classified as either "Pilot Trials" which were simple fertiliser trials with DAP and weed control, or "Uniform Establishment Trials". These latter trials were split-plot factorials with either weed control or cultivation as the main plots, and graded doses of N and P (from 0 to 45 g of each nutrient in factorial combination) as the sub plots. During the installation of the trials, composite soil samples were collected from the control plots at depths of 0-10 and 10-20 cm. The soil analyses are described below. Experiments at 35 sites located across New Zealand which incorporated P fertilisation as a factor were used for the analysis described here. Fifteen of the experiments included cultivation as a factor, whilst the remainder were entirely cultivated prior to planting.

Collection of Field data

For each trial the tree heights and diameters at the root collars were extracted from the trial data for the control and NP fertilised plots; rainfall and temperature averages from nearby meteorological recording stations were extracted from the records (New Zealand Meteorological Service); Soil resistance to penetration to a depth of 50 cm were recorded using a "Bush Recording Penetrometer". The assessments were made along transects over each main-plot where soil cultivation was the main-plot factor. Additional indices for soil physical conditions were obtained from water infiltration (time taken for water to drain form an infiltrometer ring) and air permeability (Steinbrenner (1959)). The elevation for each site was obtained from NZ Lands and Survey Topographic Maps; aspect and slope were recorded from site observations.

Laboratory analyses

Duplicate soil samples were sequentially extracted with the Bray reagent as outlined above under Methods.

Statistical procedures

(i) Fitting a function to the sequential extraction data

For each sample attempts were made to regress Bray P measurements against the sequential number of the extraction using non-linear regression with several functions. Functions tried were selected because their derivatives indicated that coefficients might be useful in determining the beginning level of Bray P, the ending level of Bray P after an "infinite" number of extractions, and the extent or change in the rate of decline of P measured with each successive extraction. The coefficients for each sample of the function with the best average fit for all the extractions were recorded.

(ii) Fitting a model to the soil sample and field data

The effects of fertilisation on height and diameter growth were regressed against the following variables in a stepwise multilinear procedure:

- cultivation dummy variable, 1 = yes, 0 = no;
- average annual rainfall (mm);
- average annual temperature °C;
- air permeability;
- water infiltration rate (minutes);
- depth to resistance greater than 50 cm;
- the "base" P, or average of the last 5 extractions;
- the a coefficient of the regressed function chosen from method (i);
- the b coefficient of the regressed function;
- the c coefficient of the regressed function;
- the absolute value of the a coefficient;
- A dummy variable for the b coefficient, 1 = more than 0.3;
- the sum of the a and b coefficients;
- the value of the first Bray P extraction, ppm;
- the integral of the fitted function from 0.5 to 10.5 (effectively a precise estimate of the sum of the extractions).

RESULTS AND DISCUSSION

Part A: A qualitative assessment of the Bray extractions

A schedule of fertiliser trials and a categorised listing of responses is shown in Table 1. The sequential extractions for "available" P with the Bray reagent are shown in Fig. 2, and appear to fall into 4 categories.

Category 1 sites: Bray P concentrations in the first extract are low (less than 9 ppm) and the decline in extractable P is rapid. According to Ballard (1974) establishing radiata pine on these sites requires an application of P at time-of-planting. Field data for radiata pine at these sites (see later) confirms the need for P. These soils are low in "available" P, and have little to slight capacity to buffer against P removal.

Category 2 sites: Although Bray P concentrations in the first extract are less than 12 ppm, the decline in "available" P with successive extractions is gradual. According to Ballard (1974), radiata pine established at these sites should be responsive to P; field trials indicate that P fertiliser is not required.

Category 3 sites: Bray P concentrations in the first extract are in excess of 12 ppm, but the decline on successive extractions is rapid. Although these soils would not be predicted as requiring P fertiliser for the establishment of radiata pine, field trials (see later) confirm the need for P.

Category 4 sites: Bray P concentrations in the first extract are markedly in excess of 12 ppm, and although "available" P declines slowly with successive extractions, P concentrations by the tenth extraction are still relatively high, usually in excess of 10 ppm. According to Ballard, radiata pine established on these sites should not be responsive to P; field trials (see later) confirms the result.

In summary, soils with extractable P in the first extract less than 9 ppm require P fertiliser for the establishment of radiata pine only if the decline in P in successive extractions is rapid. If the decline is gradual, P is not required. Where extractable P is greater than 12 ppm, fertiliser is required only if the decline in successive extractions is rapid.

Part B: A Quantitative Assessment Of The Sequential Bray Test

(i) A function to fit the sequential Bray P extractions

One function was found to fit the extractions on the surface soil samples almost perfectly. The function was of the form:

BP = a + b*EXP(-c*N)

where BP = bray P value,
a,b,c are fitted coefficients,
N = sequential number of the extraction.

A generalised curve is shown in Fig. 3. Plots of the data and curves from 2 sites are shown in Figure 4. The a coefficient estimated the value which the extraction values were approaching, whilst the sum of the a and b coefficients indicated the intersection of the function with the Y-axis. The derivative of the function is:

f' = -c*b*EXP(-c*N)

It can be seen that the c coefficient is very important in determining the slope of the curve, and that higher values of c indicate more concavity, and hence a more rapid initial decline in extracted P. In 2 cases the R^2 value was less than 0.8; this occurred when the extracted P increased with repeated extraction and then declined.

(ii) Predicting the effect of fertilisation

A stepwise multilinear procedure was employed to create models of the effects of fertilisation on height and diameter as dependent variables, and the variables listed as independent variables. Interaction terms were created to represent effects of correlated primary variables. The best fit for the height effect was a model which included the following independent variables:

- cultivation dummy variable;
- cultivation dummy variable * square of the c coefficient from the sequential Bray P extractions;
- cultivation dummy variable * inverse of the first Bray P extraction value.

The coefficients for the model of height effects are shown in Table 2. The implications of this for the lmodel were that sequential Bray P and the first Bray P value were only correlated with the effect of fertilisation in the presence of cultivation.

The data set was separated into 2, and analyses performed separately for the effect of fertilisation in the presence of cultivation, and in the absence of cultivation. In the absence of cultivation, the only significant models of fertiliser effects were mean estimates. Neither Bray P nor sequential Bray P were significantly correlated with the effects.

The models fitted for sites were cultivation was employed are shown in Tables 3 and 4. The plots of residuals against the independent variables showed no trace of bias, and the distributions of residuals were not significantly different from a normal distribution. If only the Bray P measurements or the square root of the Bray P measurements were used in the model, the R-squared values would be 0.33 for the effect on height, and 0.32 for the effect on diameter.

GENERAL DISCUSSION

The Bray reagent is but one of many soil P extractants that have been used to generate correlations between "available" P and plant growth. In New Zealand the test is routinely used to asses forest soils for their P fertility. Because the test is essentially correlative, and calibrated for New Zealand soils over a limited range of sites, it should not be surprising that anomalies in predictions for soil P fertility arise. The research behind the sequential technique was undertaken in an effort to find a simple procedure likely to be correlated with he more difficult analysis for soil P buffer power. The model presented may represent a means of predicting the effect of fertilisation on the early growth of radiata pine on cultivated sites. The sequential procedure appears to be a substantially better means of predicting the response to radiata pine to P fertilising than the single Bray P extraction. The test should be validated with an independent data set.

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REFERENCES

BALLARD, R. 1974: Use of soil testing for predicting phosphate fertiliser requirements of radiata pine at time of planting. *New Zealand Journal of Forestry Science 4(1)*: 27-34.

BRAY, R.H., KURTZ, L.T. 1945: Determination of total, organic and available forms of phosphorus in soils. *Soil Science 59*: 39-45.

HUNTER, I.R.; GRAHAM, J.D. 1983: Three year response of *Pinus radiata* to several types and rates of phosphorus fertiliser on soils of contrasting phosphorus retention. *New Zealand Journal of Forestry Science 13(2)*: 229-38.

HUNTER, I.R.; GRAHAM, J.D.; HUNTER, J.A.C. 1988: Uptake of phosphorus and nitrogen by radiata pine fertilised with superphosphate and rock P and growing on soils of contrasting P retention. *New Zealand Journal of Forestry Science* (in press).

BALLARD, R.: MEAD, D. 1978: Use of fertilisers at establishment of exotic forest plantations in New Zealand. *New Zealand Journal of Forestry 8(1)*: 70-104.

NICHOLSON, G.M. 1984: Methods of Soil, Plant and Water Analysis. *FRI Bulletin No 70, Forest Research Institute, New Zealand Forest Service.*

WILL, G.M. 1973: Nutrient deficiencies in *Pinus radiata* in New Zealand. *New Zealand Journal of forestry Science 11*: 88-94.

Table 1: Trial locations, identification, and fertiliser responses*

Location	Trial No.	Height effect	Diameter effect
Auckland	739/1	170	64
Auckland	739/2	126	34
Auckland	850/1	245	59
Auckland	850/2	331	102
Auckland	850/3	39	13
Auckland	578/3	43	13
Auckland	578/4	55	17
Auckland	662	289	65
Auckland	580	217	51
Auckland	581	81	21
Auckland	522	141	37
Auckland	741	115	26
Auckland	925/3	36	18
Rotorua	1984	15	10
Rotorua	1985	28	7
Rotorua	1964	27	18
Rotorua	1063	11	12
Wellington	261/1	21	-1
Wellington	261/2	-6	5
Wellington	203	18	4
Nelson	489	186	69
Nelson	422	138	31
Nelson	439	88	5
Canterbury	396	1	1
Canterbury	404	11	3
Canterbury	394	53	12
Westland	180	47	3
Westland	223	313	44
Southland	416	28	18
Southland	503	2	2
Southland	472	17	-2
Southland	482	23	8
Southland	560	24	11

* response = height or diameter fertilised - height or diameter unfertilised.

Table 2: Unweighted least squares linear regression of effect of fertilisation on height (all sites)

Predictor	Coefficient	Std error	Student's T	P
variable				
Constant	37.993	13.350	2.84	0.0067
Cultivation	-37.811	18.708	-2.02	0.0491
Cult*C**2	45.483	7.1788	6.34	0.0000
cult*1/BrayP1	194.37	43.180	4.50	0.0000
Cases included		50	Missing case	0
Degrees of freedom		46	P value	0.0000
Overall F	29.19			
Adjusted R squared		0.6332		
Residual mean square		2673		

Table 3: Unweighted least squares linear regression of effect of fertilisation on height (cultivated sites)

Predictor	Coefficient	Std error	Student's T	P
variable				
Constant	1.2191E-01	13.935	0.01	0.9931
C**2	45.483	7.6316	5.96	0.0000
1/BrayP1	194.37	45.910	4.23	0.0000
Cases included		35	Missing cases	0
Degrees of freedom		32	P value	0.0000
Overall F		34.69		
Adjusted R squared		0.6646		
Residual mean square		3023		

Table 4: Unweighted least squares linear regression of effect of fertilisation on diameter (cultivated sites)

Predictor	Coefficient	Std error	Student's T	P
variable				
Constant	31.242	8.6452	3.61	0.0010
C**2	9.4042	2.5342	3.69	0.0008
Square root of Bray P	-5.2073	1.8288	-2.85	0.0076
Cases included		35	Missing cases	0
Degrees of freedom		32	P value	0.0000
Overall F		17.66		
Adjusted R squared		0.4950		
Residual mean square		303.1		

Figure 1. Comparison of two contrasting forest soils

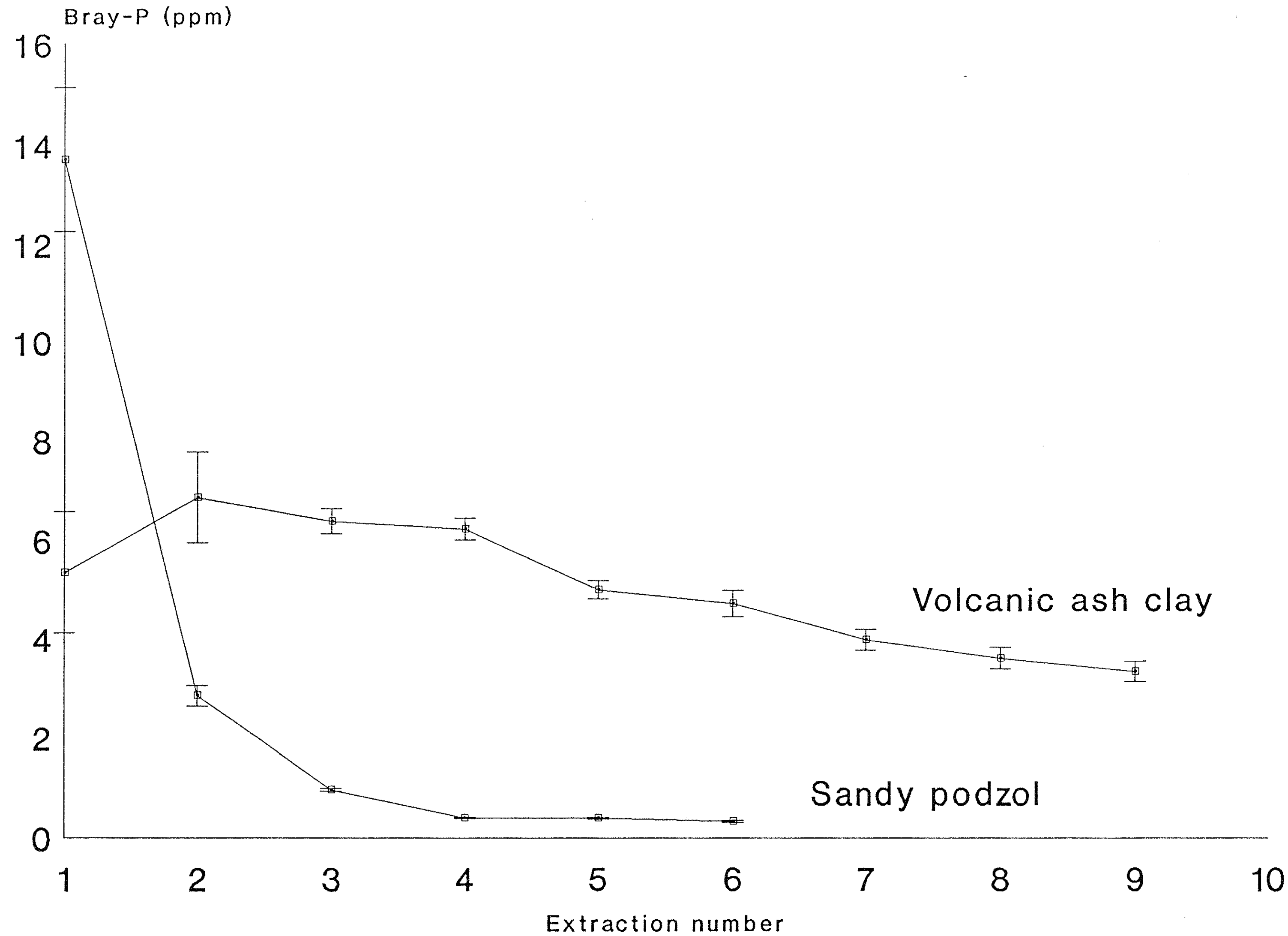

Figure 2. Comparison of forest soil categories 1-4

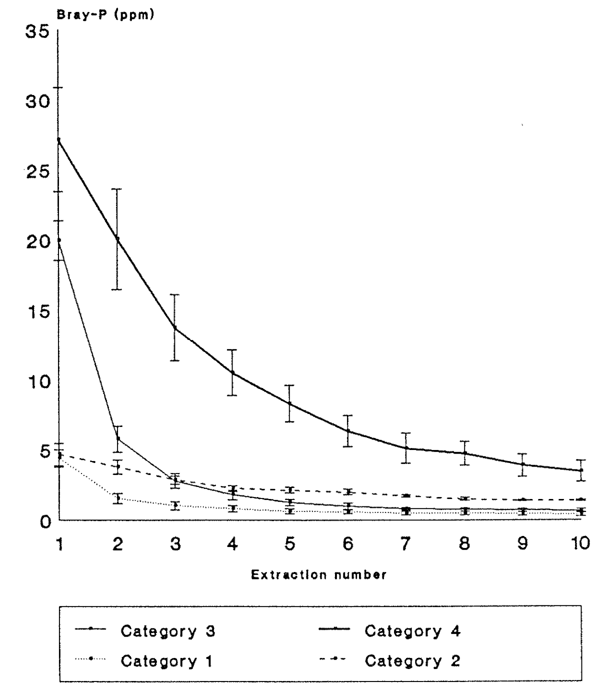

Figure 3. A generalised plot of the Bray P decline function

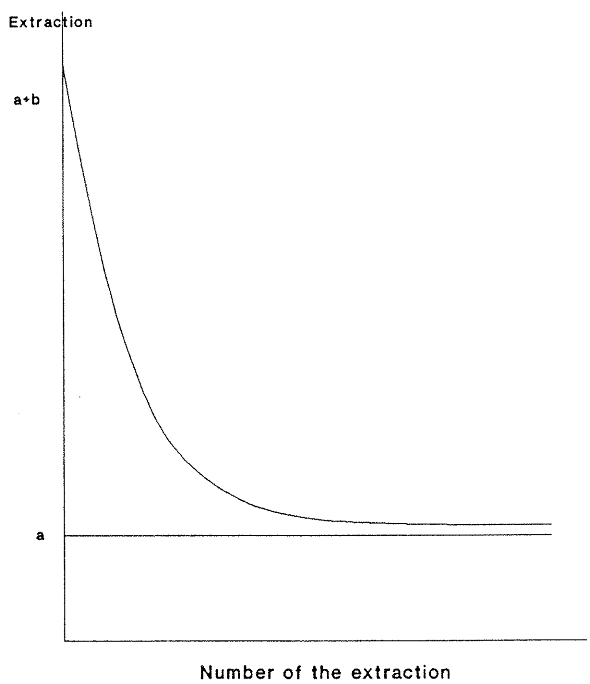

Figure 4. Sample plot of Bray P decline

Two different sites