USE OF THE BRAY SOIL TEST IN FORESTRY

1. PREDICTING PHOSPHATE RETENTION CAPACITY

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(Received for publication 1 December 1977)

ABSTRACT

Relationships between phosphate retention and Bray (0.1M HCl + 0.03M NH_4F) extractable aluminium, iron and calcium were examined in the topsoils of 128 forest soils collected from throughout New Zealand.

Aluminium extracted using 1- and 30-minute extraction periods was highly significantly correlated with P retention ($r = 0.882$ and 0.920 respectively). Iron and Ca in the same extracts were closely related to P retention only within a few specific soil groups and not over all soils. Other soil properties commonly used to characterise forest soils; carbon, cation exchange capacity, pH and total P, were also significantly correlated with P retention over all soils. However the correlation coefficients were smaller than those from Bray extractable Al and stepwise regression procedures indicated their effects were predominantly indirect through association with extractable Al.

In the interest of efficient fertiliser use, critical levels of Bray 2 (1-minute extraction) extractable Al below or above which water-soluble fertilisers should not be used on forest soils are tentatively proposed.

INTRODUCTION

Phosphatic fertilisers are being used on a routine basis in many of New Zealand's exotic forests. Currently about 6000 ha of radiata pine are being fertilised with P annually and it is projected that this could increase five or six fold over the next decade (Ballard and Will, 1978). Almost all of the P fertiliser applied is in the form of superphosphate.

In most forestry operations it is not practicable to make frequent applications of fertiliser and thus there is an interest in the duration of the effectiveness of single applications. The two soil conditions most likely to restrict the long-term effectiveness of soluble phosphate fertilisers, such as superphosphate, are (1) very low soil P-retention capacities which allow leaching of applied P from the root zone and (2) excessively high P-retention capacities which result in conversion of P to unavailable forms. Under both these conditions in acid forest soils, water-insoluble P fertilisers such as rock phosphate have been shown to have superior long-term effects compared to soluble P sources (Humphreys and Pritchett, 1971; Pritchett and Smith, 1974). In addition to acting as

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N.Z. J. For. Sci. 8(2): 239-47 (1978).

a guide to the selection of suitable P fertilisers, a knowledge of a soils' P-retention capacity is also of value where monitoring of the tree nutrient status by foliar analysis is practised. As the duration of P fertiliser effectiveness tends to be related to soil P-retention, it can be used as a guide to the frequency of foliage sampling required on any soil type to effectively monitor the need for refertilisation.

The method routinely used to characterise the P-retention capacity of soils in New Zealand involves a 24-hour equilibration (or 16 hours by some laboratories) of the soils with a buffered P solution containing 500 mg P per 100 g air-dry soil (Saunders, 1965). Although this single equilibration method is a lot less laborious than those which rely on construction of adsorption isotherms, its use for routine advisory testing would nevethless involve a considerable laboratory work-load. This would be reduced if P retention could be predicted from currently or more readily determined soil properties related to it. Ballard and Pritchett (1974) found that for soils in the SE U.S.A. the levels of aluminium (Al) and to a lesser extent iron (Fe) extracted by several soil test methods used for estimating available P, including the Bray 2 method, were closely correlated with P retention. The Bray 2 soil test is currently used for routine estimation of available P in New Zealand forest soils (Ballard, 1974) and determination of an extra element in the extract would involve little extra work.

The objectives of this study were (1) to obtain information on the P-retention capacities of a wide range of soils used for forestry in New Zealand and (2) to examine the relationships between P retention and other soil properties, in particular levels of Al, Fe and Ca extracted by the Bray 2 soil test, for these soils.

MATERIALS AND METHODS

Soils

The 128 soils used in this investigation were the topsoil (0-7.5 cm) samples collected by Dr D. S. Jackson during a nation-wide survey of environmental variables influencing the productivity of *Pinus radiata* D.Don. Each sample was a composite of 7 to 10 subsamples collected from random points within a 0.04-ha plot. For distribution of the plots throughout New Zealand, see Jackson and Gifford (1974) Fig. 2. For purposes of statistical analysis and interpretation the soils were grouped according to the New Zealand genetic classification system (N.Z. Soil Bureau, 1968). There were 11 recent soils (Recent), 14 yellow-brown sands (YBS), 5 brown-grey earths (BGE), 12 yellow-grey earths (YGE), 23 yellow-grey earth/yellow-brown earth intergrades (YG/YBE), 14 southern yellow-brown earths (SYBE), 26 central and northern yellow-brown earths (YBE), 6 podzolised yellow-brown earths and podzols (PYBE), 7 yellow-brown pumice soils (YBP) and 10 yellow-brown loam, brown loam and brown granular loams (BL).

Chemical Analysis

Phosphorus retention was determined by equilibrating 5 g air-dry soil samples for 24 hours with 25 ml of 0.032M KH_2PO_4 (addition of 5 mg P per gram of soil), buffered at pH 4.6 with NaOAc/HOAc. Phosphorus in the equilibrium solution was determined colorimetrically by an automated procedure of the vanado-molybdate method. The P retention value was obtained by expressing the amount of P removed from the solution as a percentage of the original amount. Saunders (1965) found that the retention value obtained by this method correlated very closely with the amount retained from adding the active ingredient of superphosphate (mono calcium phosphate) to soil.

Duplicate 2.5 g air-dry soil samples were extracted with 25 ml of a 0.1M HCl + 0.03M NH_4F solution using extraction periods of 1 minute (Bray 2) and 30 minutes (Bray 3). Following extraction and filtration, Al, Fe, and Ca were determined in the solution by atomic adsorption spectrophotometry using lanthanum chloride as a releasing agent.

Total P, pH, carbon, and cation exchange capacity (CEC) of soils were determined by standard N.Z. Soil Bureau procedures (Blakemore, Searle and Daly, 1972). Results of all soil chemical analyses were expressed on an oven-dry basis.

RESULTS AND DISCUSSION

Mean P retention values for each soil group, together with other soil properties are given in Table 1. The soil groups are arranged in approximate order of increasing degree of weathering except for the last two groups (YBP and BL) which are intrazonal soils formed from volcanic parent material. Phosphorus retention values for zonal soils show the same relationship to degree of weathering as found by Saunders (1965); increasing from the weakly weathered brown-grey earths up to a maximum for the moderately weathered southern yellow-brown earths and declining for the more strongly weathered soils. The P retention values recorded for the various soil groups are close to those recorded for the same groups by Saunders (1965) except the mean value for the YBS group is a lot lower (9.8 *v.* 2.3). This is probably a reflection of most coastal forests being situated on the more recently stabilised members of the YBS group.

Over all soil groups levels of Al extracted by both the Bray 2 and Bray 3 methods are highly significantly correlated with P retention (Table 2). Although the correlation for the Bray 3 method is slightly better than that for the Bray 2 method the slightly improved prediction of P retention is unlikely to justify using a longer extraction period and altering an extraction technique which is already used for other purposes. The precision of the prediction given by Bray 2 extractable Al is at least the equivalent of that found for the more conventionally used Tamm extractable Al by Saunders (1965) for a similar range of New Zealand soils. Other elements in the Bray extract such as Fe and Ca, which in certain forms in the soil are known to be involved in P retention, are poorly correlated with P retention (Table 2), although within certain soil groups they are significantly correlated (Table 3). However, only in the case of the YGE group are they more closely associated with P retention than Bray extractable Al.

Other soil properties such as pH, carbon, CEC and total P, commonly determined to characterise forest soils for various purposes, are also highly significantly correlated with P retention over all soil groups (Table 2). Carbon and CEC in particular show potnetial as predictor variables. However, two considerations, one practical and the other theoretical, would tend to mitigate against their use as routine predictors of P retention. Firstly, neither carbon nor CEC are routinely determined on forest soil samples sent into the Forest Research Institute, particularly those sent to obtain fertiliser recommendations; thus their use for prediction of P retention would involve additional analyses — the techniques for determining both these properties are fairly laborious. Secondly, as there is no evidence that carbon and CEC are directly involved in retaining P (see discussion below) there is always the danger that the relationship will not hold

TABLE 1—Mean values for soil properties by soil groups

Soil group	Number of samples	P* retention	Bray 2 Al	Bray 2 Fe	Bray 2 Ca	Bray 3 Al	Bray 3 Fe	Bray 3 Ca	pH	Carbon	CEC	Total P
		%	ppm	ppm	me/100g	ppm	ppm	me/100g		%	me/100g	ppm
Recent	11	6.0 ± 1.2	294	166	3.30	674	476	7.58	6.2	0.6	3.9	528
YBS	14	9.8 ± 0.8	458	250	2.94	933	581	4.19	5.6	1.1	5.5	421
BGE	5	7.7 ± 1.6	638	238	1.80	1104	712	4.31	6.2	0.7	3.5	803
YGE	12	24.1 ± 1.7	1242	239	3.45	2098	420	4.44	4.6	3.2	15.5	573
YG/YBE	23	26.2 ± 1.1	1332	290	1.82	2429	536	2.32	4.8	2.4	14.0	311
SYBE	14	38.6 ± 3.4	1963	318	1.71	3418	551	2.37	4.8	4.1	19.5	582
YBE	26	33.7 ± 2.2	1534	348	2.32	2867	507	3.16	4.8	3.3	18.4	409
PYBE	6	31.9 ± 11.2	1204	174	2.15	2141	213	3.06	4.7	4.0	19.9	496
YBP	7	35.4 ± 4.9	2721	92	3.90	3513	189	4.59	5.5	5.0	17.4	500
BL	10	69.4 ± 8.3	3263	239	3.90	5395	302	4.92	5.0	8.4	30.0	1216
All	128	28.8	1442	263	2.54	2507	475	3.79	5.1	3.2	15.1	525

* Mean value and its standard error.

TABLE 2—Selected simple correlations between soil variables

Variable		P retention	Bray 2		Carbon	pH
			Al	Fe		
Bray 3	Al	0.920**	0.945**	—	—	—
	Fe	—0.221*	—	—	—	—
	Ca	—0.078	—	—	—	—
	Al + Fe	0.915**	—	—	—	—
Bray 2	Al	0.882**	—	—	—	—
	Fe	0.098	—0.098	—	—	—
	Ca	0.008	0.011	—0.088	0.186*	0.164
	Al + Fe	0.901**	—	—	—	—
Carbon		0.794**	0.688**	0.024	—	—0.349**
CEC		0.883**	0.755**	0.120	0.812**	—0.448**
pH		—0.360**	—0.242**	—0.201*	—0.349**	—
Total P		0.447**	0.400**	—0.083	0.484**	0.118

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

for soils outside the range used in the calibration. For instance, Saunders (1965) found that carbon was significantly correlated with P retention over all the soils they examined except podzols and gley soils, as in these latter soils higher than normal levels of carbon accumulate because of their very low pH and poor aeration respectively. An examination of correlations within soil groups (Table 3) shows that carbon, CEC, pH and total P, in addition to being significantly correlated with P retention, are also highly significantly correlated with Bray extractable Al and inter-correlated with each other (Table 2). Stepwise regression analysis (Table 4) suggests that while their strong correlation with P retention is mainly due to their correlation with extractable Al (note reduction in partial F values following entry of extractable Al), both CEC and carbon do make a significant independent contribution to accounting for variation in P retention. The significant correlation of pH and total P can be almost entirely accounted for by their relationship to extractable Al and CEC. The nature of the small independent contribution of CEC and carbon is not clear, but as neither are directly involved in the retention of phosphate ions in the soil (Saunders, 1965) it is probably through their being correlated with some unmeasured component directly involved in P retention.

Despite considerable variation in slopes and intercepts of regressions within soil groups (Table 5) the overall relationship between P retention and Bray 2 extractable Al (Fig. 1) gives a reasonably good differentiation of soils into a low, intermediate and high P retention range. In a calibration of Bray 2 extractable Al values against leaching losses of superphosphate applied in the field to soils in the southeastern U.S.A., Ballard

TABLE 3—Correlation coefficients (r) between P retention and soil variables by soil groups

Soil group	Number of samples	Bray 2			Bray 3			pH	Carbon	CEC	Total P
		Al	Fe	Ca	Al	Fe	Ca				
Recent	11	0.491	—0.110	—0.050	0.416	—0.243	—0.317	—0.550	—0.013	0.169	—0.281
YBS	14	0.469	0.001	0.427	0.387	—0.025	0.369	—0.363	0.270	0.445	0.149
BGE	5	0.943**	0.940**	0.974**	0.907*	0.848*	0.309	—0.619	0.868**	0.922**	0.235
YGE	12	0.074	0.664*	—0.453	0.376	0.640*	—0.209	0.143	0.290	0.544	0.424
YG/YBE	23	0.685**	0.247	—0.303	0.772	0.417	—0.328	0.368	—0.025	0.230	0.221
SYBE	14	0.741**	0.259	0.119	0.688**	—0.150	0.039	—0.180	0.411*	0.848**	0.030
YBE	26	0.744**	—0.074	0.065	0.734**	—0.011	0.135	0.057	0.776**	0.793**	0.278
PYBE	6	0.997**	0.983**	0.887*	0.998**	0.927**	0.849*	0.898**	—0.613	0.957**	—0.003
YBP	7	0.562	0.220	0.146	0.567	—0.292	0.061	—0.807*	0.529	0.621	0.051
BL	10	0.890**	—0.189	—0.169	0.914**	—0.401	0.175	—0.119	0.784**	0.828**	0.818**

* Significantly at the 5% level.
** Significantly at the 1% level.

TABLE 4—Partial F values for entry of soil variables into a stepwise regression of P retention on these variables

Variable entered	Partial F value for entry of variable							R² for regression
	Bray 3 Al (1)	Bray 3 Fe (2)	Bray 3 Ca (3)	pH (4)	Carbon (5)	CEC (6)	Total P (7)	
—	692.9**	6.5*	0.8	18.7**	214.5**	448.0**	31.4**	—
(1)	—	1.7	0.1	9.0**	35.4**	66.5**	4.4*	0.846**
(1) + (6)	—	2.23	0.1	0.2	5.9*	—	1.6	0.900**
(1) + (6) + (5)	—	3.3	0.8	0.2	—	—	0.5	0.904**

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

TABLE 5—Regressions of P-retention (%) on Bray 2 extractable aluminium (ppm)

Soil group	Number of samples	Regression coefficient	Constant	Correlation coefficient
Recent	11	0.0159	1.35	0.491
YBS	14	0.0048	7.56	0.469
BGE	5	0.0105	0.98	0.943**
YGE	12	0.0013	22.56	0.074
YG/YBE	23	0.0096	13.43	0.685**
SYBE	14	0.0158	7.52	0.741**
YBE	26	0.0149	10.84	0.744**
PYBE	6	0.0225	4.75	0.997**
YBP	7	0.0057	19.82	0.562
BL	10	0.0179	10.95	0.890**
Overall	128	0.0171	4.05	0.882**

** Significant at the 1% level.

and Pritchett (1974) found excess leaching losses occurred in soils containing 400 ppm or less Bray 2 extractable Al. Using the regression in Fig. 1, this extractable Al value corresponds to a P retention value of 11%. However a Bray 2 extractable Al value of 700 ppm apparently gives a much better separation of New Zealand soils with P retentions of approximately 11% and below from those with higher retention values (Fig. 1). What constitutes excessive P retention in a forestry context is not really known. The soil (Bladen silty clay loam) on which Pritchett and Smith (1974) found rock phosphate to give a better long-term response than superphosphate, the author (Ballard and Fiskell, 1974) found to contain about 1500 ppm Bray 2 extractable Al. At this value there is a fairly wide range of P retentions in New Zealand soils and a

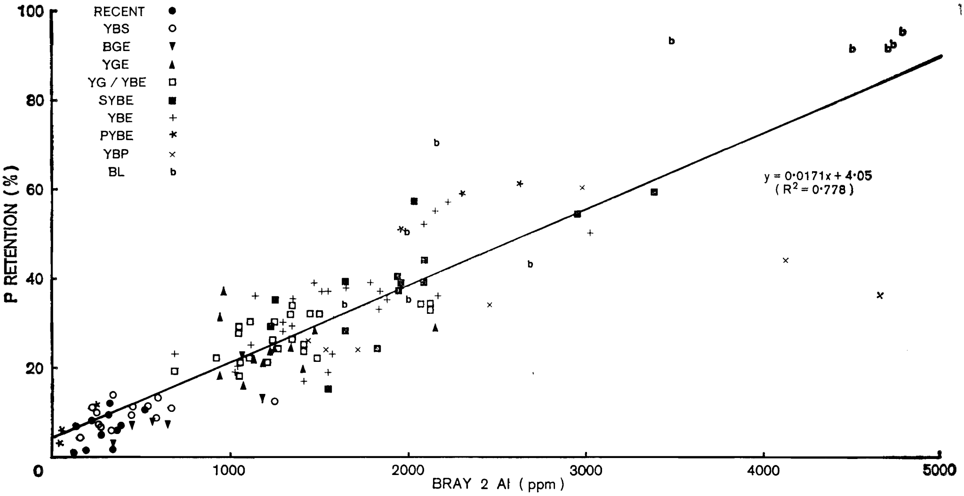

FIG. 1—Relationship between P retention and Bray 2 extractable Al.

value of about 2000 ppm gives a clearer differentiation between soils in this range and those above it (Fig. 1). It is hoped that a series of trials currently being established, which compare superphosphate with various rock phosphates on soils with a range of P retentions, will give more precise definition to these critical points which at present are largely based on conjecture.

Perhaps the most convenient and rapid means of obtaining an indication of a soil's properties is through its classification. However since soils are seldom classified directly on the basis of the property of interest, particularly in a genetic classification such as New Zealand has (N.Z. Soil Bureau, 1968) there is usually considerable variation in a soil property within any particular classification unit even though there may be broad correlation over classification units. This is certainly true for P retention for the range of soils used in this study (Fig. 1). Most or all of the Recent, YBS, and BGE soils fall into the low range and also some of the PYBE soils. Other members of the PYBE group fall into the high range. The three soils of this group in the low range are all podzols. There is a less clear-cut differentiation between the intermediate and high range, but in general the YGE, YG/YBE and YBE soils fall in the intermediate range, the BL and YBP soils fall into the high range and the SYBE occur about equally over the two ranges. Broad classification units such as soil groups do not appear to be entirely satisfactory for separating soils into distinct P retention groups suitable for advisory purposes.

Most P fertilisers used in current forest fertilisation operations are applied to soils in the YG/YBE, PYBE, YBE and BL groups. Of immediate concern insofar as efficient use of superphosphate is concerned should be podsol members of the PYBE group and BL soils. These soils are readily identifiable by levels of Bray 2 extractable Al. Although it is advocated that insoluble rock phosphate fertilisers be used in preference to superphosphate on soils exhibiting extremes of P retention, it must be remembered that rock phosphates need to be solubilised before they can be taken up by plants and a soil pH of below 5.5 is usually required for an adequate rate of solubilisation. Most forest soils in New Zealand with pH's higher than this, i.e., members of the Recent and YBS groups, are not currently fertilised with P, but may be at some future date following nutrient removal in harvested products. Most members of these groups also fall in the low P-retention range and thus some strategy other than the use of rock phosphates, such as use of frequent small applications of soluble fertiliser, will have to be employed to increase fertiliser efficiency.

In conclusion, it appears that the determination of Al levels in the 1-minute Bray 2 extract offers a practical and reasonably precise means of estimating the P status for forest soils in New Zealand.

ACKNOWLEDGMENTS

The author would like to thank Dr D. S. Jackson for making the soil samples available and Mr Phillip Allen for doing the chemical analyses.

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