Proceedings of the New Zealand Grassland Association 57: 133-137 (1996)

Phosphorus status of pastoral soils where reactive phosphate rock fertilisers have been used

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Abstract

The dissolution rate of Sechura phosphate rock (particle size 75-150 pm) was determined at 95 New Zealand sites with a range of soil and environmental properties. Rates ranged from 0 to 70% of the phosphate rock dissolved per year with an average dissolution rate of 3 1 %/year. An initial model based on stepwise linear regression analysis indicated that the rate of dissolution was negatively associated with soil pH and positively associated with rainfall and exchangeable soil magnesium. There was also an effect of soil type and drainage. The amount of residual RPR accumulated from previous fertiliser application can be determined by a new soil test. This, together with the dissolution rate estimated from the nature of the RPR and the soil and site factors, can be used to indicate likely soil P status.

Keywords: dissolution, fertiliser, phosphorus, reactive phosphate rock, soil test

Introduction

Reactive phosphate rocks (RPRs) currently comprise 6.3% of the North Island fertiliser market. These are slow-release fertilisers in which the phosphate becomes available for plant uptake only as the fertiliser particles dissolve. The effectiveness of RPRs as direct application fertilisers depends, on their dissolution rates, which are themselves influenced by soil and environmental properties.

Although dissolution rates have been measured in laboratory incubations, these studies are influenced by the build-up of reaction products (phosphate and calcium). This, together with the lack of plants and absence of environmental effects such as rainfall, limits the use of these studies for determining dissolution rates of RPR in the field.

Numerous field investigations have been made of RPR effectiveness over the last 30 years, including the National Series of Forms of Phosphate Fertiliser Trials. Edmeades *et al.* (1991) summarised these trials and used them as a basis for recommending guidelines for RPR use. However, the trial data were limited to a relatively narrow range of soils and environments. More extensive field investigation of the effects of soil and environment on the dissolution rate of RPR is required to provide more comprehensive guidelines for RPR use.

Determination of soil P status has been a problem where RPR fertilisers have been used. This *is* because the Olsen P test used in New Zealand for assessing soil P status does not detect residual RPR in the soil and can therefore underestimate soil P status (Perrott et *al.* 1993). Two new soil tests which include residual RPR have been proposed. These are the iron oxide-impregnated paper (Pi) test (Menon et *al.* 1989) and the mixed anion- and cation-exchange membrane test (Saggar *et al.* 1990). However, full evaluation and calibration of these tests would require a large number of field trials at sites with varied fertiliser history covering use of both superphosphate and RPR, and differing RPR application times. The influence on these tests of soil and climatic factors, which effect RPR dissolution rates, would also need evaluation. Because of the time and experience invested in the Olsen test by New Zealand laboratories, scientists and consultants, it is unlikely to be replaced by one of the new tests without thorough evaluation and accumulation of experience with the new test.

Another approach is to continue with the Olsen test but determine the amount of residual RPR in soil and calculate its contribution to soil P status (Perrott *et al.* 1993). A new soil test for RPR residues in soils has been developed (Perrott & Wise 1995) and is offered by the AgResearch Soil Fertility Service, The test enables the amount of residual RPR accumulated in soil as a result of previous fertiliser applications to be determined. However, interpretation of test values required for fertiliser advice requires knowledge of the dissolution rate of RPR in the soil.

This paper summarises results obtained from field trials designed to determine effects of soil and environmental factors on RPR dissolution rates in soil. The paper also describes the use of the RPR test for estimating the contribution of residual RPR to soil P status.

Methods

Sites and treatments

Ninety-eight pastoral sites were selected from throughout New Zealand to provide the diversity in soil and environmental factors influencing RPR dissolution (Table 1). Paired plots (1 m × 3 m) were laid down at each site to provide two replicate fertilised plots and two replicate unfertilised plots. Sechura phosphate rock (PR) (75–150 μm particle size) was applied to the fertilised plots at a rate of 100 kg P/ha. The sites were maintained under grazing management (either dairy, sheep or beef) for 2 years. No herbage measurements were made.

Table 1 Some soil and site characteristics for the 98 selected sites.

	Average	Minimum	Maximum
Rainfall (mm/year)	1270	350	4320
Bulk density (g/cm^3)	0.85	0.20	1.28
Olsen P	17	3	137
QT Ca	7.7	1.0	19.3
pH	5.7	4.9	6.4
Phosphate retention (%)	40	2	98
CEC (meq/100 g)	13.6	3.5	41.2
Exchangeable Ca (meq/100 g)	9.5	0.7	35.3
Exchangeable K (meq/100 g)	0.64	0.19	3.13
Exchangeable Mg (meq/100 g)	1.75	0.25	6.01
Exchangeable Na (meq/100 g)	0.28	0.02	1.17
% Exchangeable Ca (%)	67	20	92
Lime requirement	1.9	-1.3	5.0
Topography	62 flat, 28 sloping & 8 hilly		
Soil type^a	64 Sedimentary, 22 Ash, 4 Peat & 8 Pumice		

a As used by AgResearch Soil Fertility Service.

Soil sampling

Soil samples (15 cores, 25 mm diam. 0-75 mm depth) were taken immediately before and immediately after fertiliser application. The plots for both treatments were then sampled (0-75 mm) at 2-monthly intervals for 12 months and thereafter at 3-monthly intervals for another 12 months. In addition, soil samples were taken from the 75-150 mm depth immediately before fertiliser application and at 12 and 24 months.

Chemical analyses

Soil chemical measurements (Table 1) were made on samples collected before fertiliser application. Residual PR-P was determined using a sequential extraction procedure (Perrott & Kerr 1994). In this method phosphate extracted by sulphuric acid (acid-P), after prior removal of alkali soluble P, is determined for both fertilised and unfertilised soils and residual PR-P calculated by difference (Perrott & Kerr 1994).

Mathematical analyses

The rate constants were calculated for individual sites. There was little evidence of any changes in acid-P in the control plots over time, so these were averaged and the average subtracted from the acid-P for the fertilised plots. These residual levels of applied P for both the treated plots were then regressed against time using the dissolution model developed by Watkinson (1994a; 1994b), allowing for different intercepts for the two plots, to obtain the rate constant. The dissolution model was fitted using the non-linear routine of Genstat (Rothamsted Experimental Station 1993).

Results

Movement of PR below 75 mm

Increases in acid-P below 75 mm in the fertilised plots (12 and 24 months compared with zero time) were not significant for individual sites. Averaged over all the sites the increase was significant, but small (7 and 10 μg P/g at 12 and 24 months, respectively), compared with acid-P levels due to RPR in the upper 75 mm of the soil (80 to 670 μg P/g) (Table 2). Therefore, loss of RPR due to movement of particles below 75 mm was not considered in determining dissolution rates.

Table 2 Mean changes of acid P (μg P/g) in 75-150 mm samples (averaged over 74 sites).

Treatment	12 months	24 months
Fertilised	7.2	10.4
Unfertilised	1.7	0.9
SED	2.46	2.09

Dissolution rates

Acid-P data for 4 of the sites are presented in Figure 1 as examples. The values for the unfertilised soil were significant compared with those for fertilised soils (Perrott & Kerr 1994) and hence their subtraction was required in all cases. The situation for the Otanomdmo site (Figure 1), which was a peat soil, was exceptional.

The dissolution rates ranged from 0 to 70% of the rock dissolved per year, with an average rate of 31%/year (Figure 2). Data for 3 of the sites were not included because of various problems in those trials.

Correlation of dissolution rate constants with soil and site factors

The initial investigation was carried out using stepwise regression. Initial regressions indicated an association with topography, with the steeper sites having faster dissolution. Because of the possibility that this may have resulted from surface movement of fertiliser particles (i.e., RPR loss rather than dissolution), the 8 hilly sites were removed from the final regression analysis. This changes the average dissolution rate to 30%/year, with a maximum rate of 70%/year. The final model (which explained about 55% of the variation) indicated that the dissolution rate was associated with soil pH, soil type, exchangeable Mg, rainfall and drainage.

Figure 1 Dissolution of Sechura phosphate rock (particle size range of 75–150 pm) at four sites. (a) Oruanui (25%/year); (b) Opua (7%/year); (c) Oreti (20%/year); (d) Otanomomo (45%/year). (Symbols: ● control plots; ■ fertilised plots. Lines are fitted curve for fertilised plots and acid-P levels for samples taken from fertilised plots before fertiliser application).

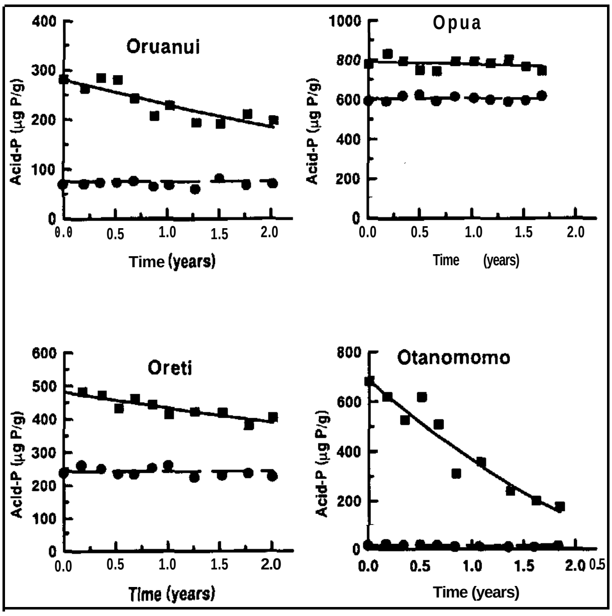
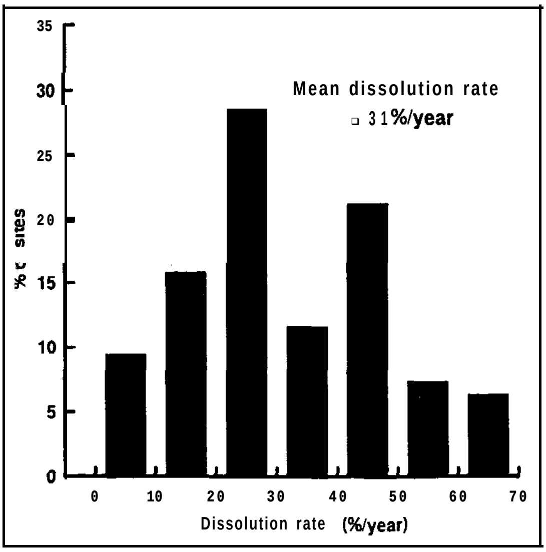


Figure 2 Distribution of the dissolution rates for Sechura phosphate rock with particle size range of 75-150 µm across the 92 sites.



Discussion

Dissolution rates

Although movement of RPR below 75 mm was significant when averaged over all sites, the actual increase in acid-P below 75 mm was very small (Table 2) and was therefore not considered in determining dissolution rates.

The correlation of dissolution rate constants with pH (negative) and rainfall (positive) is consistent with previous findings (Edmeades *et* al. 1991). Drainage has a negative effect (dissolution is faster in poorly drained soils), confirming the positive influence of soil moisture on the dissolution rate. It is possible that exchangeable Mg indicates the ability of the soil to remove Ca from soil solution and therefore the positive correlation of dissolution rate constants with exchangeable Mg is a reflection of the enhancement of dissolution by removal of Ca from solution (Robinson & Syers 1990; 1991).

The distribution of dissolution rates given in Figure 2 is specific to Sechura PR with a particle size of 75-150 µm. The rate constants estimated from this model can be used to calculate dissolution rates for other RPRs, provided the solubility and particle size distribution are known (Watkinson 1994c). For example, for the four soils described in Table 3 the dissolution rate of "as received" Sechura PR is 8% to 20%/year compared with 12% to 32%/year for Sechura PR with a particle size range of 75-150 µm (Table 3).

Contribution of residual RPR to soil P status

Estimation of the contribution of RPR residues to soil P status requires information on:

(a) the amount of residual RPR in the soil, and
(b) an estimate of its dissolution rate.

Residual RPR has been determined by P fractionation but it can also be determined using the recently developed routine RPR test (Perrott & Wise 1995). Unlike the P fractionation procedures, the latter test does not require a soil sample from an unfertilised plot.

Table 3 Estimated dissolution rates and P release from Sechura phosphate rock in the 7th year of four trials (Perrott *et al.* 1992).

Site	Sechura application rate (kg P/ha/year)	Olsen P (µg P/ml)	Annual yield (t DM/ha)		Estimated dissolution rate for Sechura PR (%/year)		Residual RPR (kg P/ha)	Estimated P release from residual RPR (kg P/ha/year)[C]
			Predicted	Actual	(75-l 50 m)[A]	As received[B]		
Puketona	Mean[D]	16.8	6.12	8.93	27	17	100	17
	33	16.7	6.21	6.85			100	17
	66	16.3	8.20	9.36			150	25
Waitoa	Mean	12.6	9.32	9.51	32	20	90	16
	35	14.3	9.45	10.46			70	14
	70	14.3	9.45	11.57			190	37
Te Kuiti	Mean	7.0	6.76	10.71	12	8	70	5
	37	7.0	6.76	9.82			80	6
	74	9.0	9.20	10.66			240	18
Winchmore	Mean	4.6	7.46	6.53	27[E]	17[E]	30	5
	20	4.3	7.13	6.55			20	4
	40	6.3	8.76	9.59			70	12

A Dissolution rate applies to Sechura phosphate rock with particle size range of 75-l 50 µm.
B For Sechura phosphate rock with particle size distribution reported by Smith et *al.* (1990).
C Calculated from residual RPR. estimated dissolution rate constant and assuming a similar particle size distribution to applied fertiliser.
D Values meaned over the four application rates, 0.5, 0.75, 1 .O and 2.0 x maintenance rate. The maintenance rates are 33, 35, 70 and 20 kg P/ha/year for the Puketona, Waitoa, Te Kuiti and Winchmore sites respectively.
E Assumes a rainfall of 2000 mm/year to accommodate irrigation.

To demonstrate the use of the RPR test, residual RPR measurement and dissolution rate estimation were made for 4 field sites where Sechura PR and triple superphosphate (TSP) fertiliser had previously been applied annually for 6 years. The residual effectiveness of the RPR on dry matter production was measured in the 7th year (Perrott et al. 1992). Actual dry matter yields from the RPR treatments were first compared with predicted yields calculated from the Olsen P-values and the response curve for the TSP treatments (Table 3). In all cases Olsen P underestimated pasture growth.

The dissolution rate constants for these sites were calculated from the soil pH, soil exchangeable Mg, soil type, rainfall and drainage. These constants were used to calculate dissolution rates for the standard phosphate rock (Sechura PR, 75–150 pm) used to measure dissolution rates at the 98 sites described above. The calculated rates are given in Table 3 and these values can be compared with those in Figure 2. However, in practice, RPR fertilisers have a wider ranges of particle sizes and this influences the dissolution rate. Therefore, dissolution rates, calculated using the method of Watkinson (1994c), are also given in Table 3 for the particle size distribution (45.4% 75-150 pm, 49% 150–250 µm, 4% 250–500 µm and 1.6% 500-1000 pm) of the "as-received" Sechura PR used in these trials (Smith et al. 1990). These latter figures indicate the likely performance of Sechura PR fertiliser at these sites.

A detailed consideration of the calculated release of P over time from the residual RPR in the soil for RPRs currently on the New Zealand market indicates that it is warranted to assume that, for practical purposes, the residual RPR in the soil has a particle size distribution similar to that of the original fertiliser. Therefore, the particle size distribution of the "as-received" fertiliser, together with the amount of residual RPR, was used to estimate the release of P from the residual RPR in the soil (Table 3). These figures give an indication of the release of P from the accumulated RPR residues in the soil. The data in Table 3 indicate that in most cases considerable amounts of P would have been released from the residual RPR. For example, where Sechura PR had been applied for 6 years at the maintenance rate the P released from the residual RPR ranged from 4-17 kg P/ha/year (20–52% of the maintenance amount for soluble fertiliser). Where application had been at twice the maintenance rate the P released from the residual RPR ranged from 12-37 kg P/ha/year (equivalent to 60–106% of maintenance amount for soluble fertiliser). These amounts would probably account for the difference between the estimated and actual dry matter yields.

This approach assumes that the efficiency of P utilisation by pasture is the same for P dissolved from RPR as for the soluble P in TSP. Although there has been speculation of possible differences in efficiency, as yet no conclusive evidence has appeared. Such differences, if they occur, are probably too small to be measured in field experiments.

Conclusions

The dissolution rate of RPR at a specific site can be estimated from the fertiliser properties (RPR solubility and particle size distribution) and the soil and environmental factors (soil type, soil pH, exchangeable soil Mg, rainfall and drainage). If the amount and nature of residual RPR in the soil is known, its contribution to soil P status can be estimated.

ACKNOWLEDGEMENTS

This work was funded by a grant from the New Zealand Foundation for Science and Technology. We acknowledge the assistance of Amanda Judge, who co-ordinated the trials and the AgResearch field staff who laid down and sampled individual trials.

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