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Comparing the agronomic performance of soluble and slow release phosphate fertilisers: the experimental basis for RPR recommendations

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Abstract

Recent results from field trials comparing the agronomic effectiveness of water soluble fertilisers (single superphosphate (SSP), triple superphosphate (TSP)) and fertilisers of low water solubility ('slow release', reactive phosphate rock (RPR) fertilisers) are reviewed.

It is shown that the pasture production data from the 'National Series' of trials are consistent with, and can be described by, a model for the dissolution of RPR in soil. Applying both the pasture production data and the dissolution model the term 'lag time' associated with 'slow release' RPR is defined and quantified for New Zealand conditions.

Results show that on average the rate of release of P from RPR is about 30% within the year of application, 23% in year 2 and progressively less in subsequent years. It follows that when RPR is applied annually, the amount of P released annually, from the current application and from the residues of previous annual applications, is 30, 53, 70, 82, 91, 96% as a fraction of the total P applied annually. Consequently about 3.5 times the amount of RPR-P is required to achieve the same yield as soluble P in year 1, about 2 times in year 2 and 1.5 in year 3.

The lag time is defined as the time required to accumulate sufficient RPR residues in the soil from applications such that the annual amount of P dissolved from RPR each year is equal to or greater than 90% of the amount of total RPR-P applied annually. The lag time associated with RPR use is about 4-6 years depending on the site.

The agronomic performance of RPR based on the National Series data was not associated with soil pH (5.1 to 6.3), annual rainfall (700 to 1800 mm) or soil phosphate retention (13-98%). This probably reflects the narrow range and confounding effects of the soil and climate factors. The experimental basis for the current soil pH and rainfall boundary conditions are briefly discussed. Available evidence suggests that the P dissolved from RPR has the same agronomic effectiveness as P from soluble fertilisers.

The agronomic implications of these results on P fertilisers of intermediate solubility (i.e. PAPR and Longlife) are discussed in relation to field results.

Keywords agronomy, comparison, dissolution, fertilisers, Longlife, PAPR, phosphorus, RPR, slow release, soluble P, single superphosphate, triple superphosphate

Introduction

Since the introduction of reactive phosphate rocks (RPR) for direct application in New Zealand in 1987, the fertiliser industry has offered an increasing range of phosphatic fertilisers to the farmer. In addition to the traditional product super-phosphate, a water soluble and therefore 'immediately available' P source, the farmer now has available RPRs, which are relatively water insoluble and therefore regarded as 'slow release' P fertilisers. Their derivatives, such as Longlife (a mixture of RPR and superphosphate) and partially acidulated RPR (PAPR), are of intermediate P solubility.

While the term 'slow release' P fertiliser has been widely used to describe RPR, little effort has been made to define what this term means. How quickly do RPRs dissolve under New Zealand conditions and what are the agronomic implications? The purpose of this paper is to examine these questions by reviewing relevant agronomic field trial data.

Theoretical considerations

Chien *et* al. (1990) and Johnstone & Sinclair (1991) have recently discussed and defined the various methods which have been used to compare the agronomic effectiveness of P fertilisers of different P solubility. Essentially there are two fundamentally different approaches. With reference to Figure 1 these are commonly referred to as the 'vertical comparison' and the 'horizontal comparison'.

Chien *et al.* (1990) defined relative response, RR (sometimes referred to as relative agronomic effectiveness (RAE)) and Johnstone &Sinclair (1991) defined substitutionvalue, ψ (the reciprocal sometimes referred to as equivalence ratio), for a test fertiliser (T) relative to a standard fertiliser (S) (Figure 1):

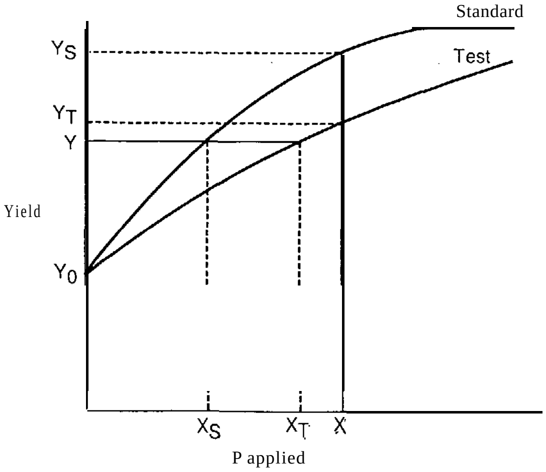

Figure 1 Schematic diagram showing the two approaches used to compare a standard and test fertiliser.

$$\text{Relative response, RR} = \frac{\text{(yield with a given rate of test fertiliser - yield of control)}}{\text{(yield with a given rate of standard fertiliser -yield of control)}} = \frac{Y_T - Y_0}{Y_S - Y_0}$$

and

$$\text{Substitution value, } \psi = \frac{\text{amount of standard fertiliser to achieve a given yield}}{\text{amount of test fertiliser to achieve the same yield}} = \frac{X_S}{X_T}$$

In essence these approaches ask two different questions. The vertical comparison (RR) measures the increase in production over control for a test fertiliser relative to a standard fertiliser when applied at the *same rate* of P. The substitution value (ψ) (the horizontal comparison) asks the question, how much test fertiliser P *is* required to achieve the *same yield as the P from the* standard fertiliser?

Relative response and ψ have different properties. RR depends on the rate of P applied. That is, it depends where, on the response curve, the measurement is made (Chien et al. 1990; Johnstone & Sinclair 1991). (This assumes the general case where the relationship between yield and rate of P applied is curvilinear.) Relative response will therefore depend on the P status of the soil on which the fertilisers are compared. A completely inert material would give the same yield and hence an RR value of approximately 1, when compared with a soluble P fertiliser, if the initial P status of the soil were very high. Thus, measurements of RR can be misleading or easily misinterpreted if these factors are not properly considered.

In contrast, thesubstitutionvalue (ψ) is independent of P rate providing (a) the test and standard fertiliser achieve the same maximum yield when sufficient product is applied and (b) appropriate mathematical functions are used to describe the experimental results (Chien *et al.* 1990; Johnstone & Sinclair 1991).

The choice of approach depends on the objective of the study. Chien *et* al. (1990) concluded that ψ should be used if the goal were to evaluate the *economics of the products,* whereas RR would be suitable if the objective were simply to *rank fertilisers* relative to a standard. In our opinion, the choice between these approaches depends on whether *quantitative* or *qualitative* comparisons are required.

In New Zealand it is well known that RPRs release P slowly and therefore in a qualitative sense are inferior initially to soluble P fertilisers (i.e. RR <1). What is required now is quantitative information on specific questions such as: how long is the RPR 'lag time' -that is the time required before equal annual applications of RPR-P and soluble P produce the same yield? How much RPR-P is required to achieve the same yield as soluble P especially in the initial years (i.e. what is ψ), and what are the agronomic implications of the answers to these questions. It is for these reasons we have adopted the 'horizontal comparison' approach in this paper.

RPR dissolution model

A mathematical model describing the dissolution rate of fertilisers of low solubility in soil (Watkinson 1989) has been tested against data for phosphate rocks (PR) in two field trials and the results show good agreement between the measured amounts of residual PR in soil over time and that predicted by the model (Figure 2).

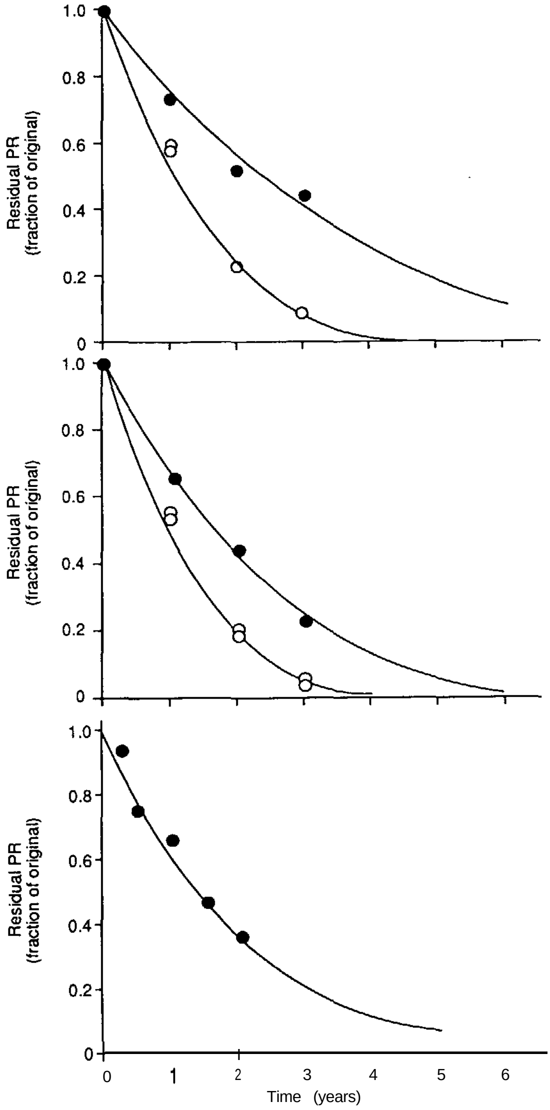

Figure 2 The effect of time on residual RPR in soil measured in field experiments. (Symbols represent measured RPR residues and solid line is the best fit cubic from the model to the data points) for (a) ○ North Carolina and Chatham Rise RPR and ● for Florida PR (b) as for (a) but with PR/elemental S mixtures and (c) North Carolina RPR.

The model describes dissolution over time as:

$$m/m_0 = (1 \quad kt)^3, t \le 1/k \qquad - (1)$$

where m = residual mass of phosphate rock (PR) at time t

m_0 = mass of PR applied

k = dissolution rate constant of the PR (at a given PR particle size distribution) in the soil

Since m/m_0 represents the amount of residual RPR remaining in the soil then:

$(1-m/m_0)$ is the amount of RPR dissolved. Furthermore, if it is assumed that the P dissolved from RPR (including the RPR residues accumulated from previous topdressings) over 12 months were equivalent to that from a soluble P fertiliser applied over the same period, then,

$$1 - m/m_0 = 1/\psi$$

where ψ is the substitution value discussed earlier. From equation (1). therefore:

$$\psi = 1 - (1 - kt)^3, t \le 1/k \qquad - (2)$$

rearranging:

$$1 - (1 - \psi)^{1/3} = kt \qquad - (3)$$

Equation (2) requires the standard fertiliser to dissolve quickly and before appreciable dissolution of the test fertiliser. This would be true for triple superphosphate. Significant positive deviations of experimental data from equation (2) could constitute evidence for a greater effectiveness of dissolved P from RPR relative to TSP.

This model can be tested in a number of ways. Pasture production (DM) data from trials comparing soluble and RPR-P can be used to estimate ψ for any interval of time, as discussed earlier. In addition, measurements of RPR residues in soils at a given time or at a range of times can be used to estimate k, and hence ψ can be calculated from equation (2). The values of ψ based on both approaches can then be compared. A further approach is suggested by equation (3). If the function $F(\psi) = 1 - (1 - \psi)^{1/3}$, (based on DM) were plotted against time a linear relationship would be expected with intercept zero and slope k. The values of k thus derived can be compared with those derived from direct soil RPR measurement.

The MAF National Series of trials

In 1982, the Ministry of Agriculture and Fisheries began a series of 19 small-plot trials throughout New Zealand, the primary objective of which was "to delineate the conditions of soil and climate which are suitable for the effective use of direct application reactive phosphate rock as a maintenance of P fertiliser". The project ran for 6 years. A description of the trials and the pasture production results are reported fully elsewhere (Smith *et al.* 1990).

Based on these results, Sinclair et al. (1990a) calculated the reciprocal of the substitution values ψ, (referred to in their paper as equivalence ratios) for Sechura RPR relative to soluble P fertiliser (in this instancetriplesuperphosphate) as ~4, 1.89, 1.13, 1.08, 0.85 and 0.75 for years l-6 respectively, at a DM equivalent to 0.75 x maintenance of TSP.

However, not all the data from the National Series can be used directly to test equations (2) or (3) for the following reasons:

1. All the 19 trials proceeded for at least 3 years but only 15 lasted 5 years, and 12 for 6 years.
2. Variability of DM data precluded individual measurements of ψ for each site, so that the data for several sites had to be pooled.
3. An apparent molybdenum (MO) deficiency increasingly developed with time on some sites (see Figure 5). Sechura RPR, it is now known, contains significant amounts of Mo as an impurity. Thus, the effect of Sechura RPR as a source of P was confounded by Mo on these sites (Smith *et* al. 1990, Sinclair *et al.* 1990b). Of the 12 sites which ran for 6 years, 5 wereregardedasMoadequateand7 as Mo inadequate (Table 1).
4. An estimate of ψ in year 1 was not possible on the 5 MO adequate sites because of the small response to RPR.
5. RPR residues in soil after 6 years were measured directly in only 11 of 12 sites (Table 1) and it was necessary to omit the results from site 13 due to an unaccountable loss of RPR, possibly through being partially washed off plots under irrigation.

Table 1 Rate constants for dissolution of Sechura phosphate rock in National Series trials running for 6 years. Calculated from measured residual RPR in soil samples (O-75 mm) taken from triplicate plots after 6 years of annual application, and equation (1).

Site No.[1]	Adequate MO[1]	Rate Constant (/year)	Lag time[2] (year)	Fraction dissolved in year of application
1	Yes	0.07	7.7	0.20
2	No	0.17	3.2	0.43
3	No	0.14	3.8	0.36
4	No	0.10	5.4	0.27
5	No	0.16	3.3	0.41
6	Yes	0.11	4.9	0.30
7	Yes	0.10	5.4	0.27
13	Yes	0.19	2.6	0.47
14	Yes	0.04	13.4	0.12
17	No	NIA	N/A	N/A
18	No	0.15	3.6	0.39
19	No	0.08	6.7	0.22
Average[3]±SD		0.11±0.044[4]	5.7f3.1	0.30±0.10

1 See Smith er a/. (1990)

2 Lag time defined as time for 90% dissolution.

3 Excluding sites 13 (where some RPR may have been lost during irrigation), and 17 (samples not available at time of analysis).

4 Average rate constants for Mo adequate and inadequate sites are 0.08¨0.03 (SD) year-l and 0.13¨0.04 (SD) year-l, respectively.

Given the above, the available data from the National Series could be divided in 2 sets: 6 sites with low MO and 4 with adequate MO. For both sets ψ could be estimated by 2 independent methods: (a) based on DM results or (b) calculated by equation (2) from average values of the rate constant k determined for each site by measurement of residual RPR in the soil after 6 years.

It is more instructive to plot the data as ψ rather than $1/\psi$, because this represents the cumulative amount of dissolving P in a given year from RPR as a fraction of the total P applied annually. Since the dissolved P from RPR is assumed equivalent to that from triple superphosphate (TSP), then ψ cannot exceed unity. (This follows from equation (2) where fort = l/k, the time for complete dissolution, the value of $\psi = 1$.)

For the MO-adequate sites there is good agreement, as shown in Figure 3, between ψ calculated from soil RPR measurements and values calculated from DM production. Although the value for ψ in year 6 is slightly greater than 1 (1.05), it is within experimental error of the curve value (0.86). The data can therefore be explained on the assumptions made in deriving equation (2), including soluble P from RPR being equivalent to that from TSP. Also, it is apparent from Figure 3 that it takes 7 years before soluble P from RPR reaches 90% of that from TSP, with complete dissolution requiring 12.5 years (l/k).

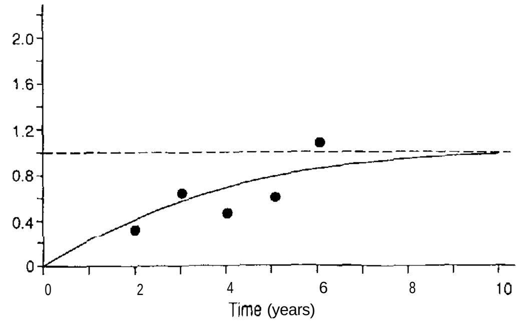

Figure 3 **Relationships between time and the substitution value (ψ). Values based on DM data from the Mo adequate sites of the National Series (0). The solid line represents the RPR dissolution model using the average rate constant from soil RPR residues from these trials.**

The molybdenum effect

For the MO-inadequate sites there is agreement (Figure 4) between ψ calculated from soil RPR residues and pasture DM production for only the first 2 years. Thereafter, the values for ψ from DM data continue linearly with time, with values considerably exceeding 1. The relationship based on soil RPR measurements suggests that, for this set of soils 4 years are required to reach 90% dissolution and total dissolution 7.5 years.

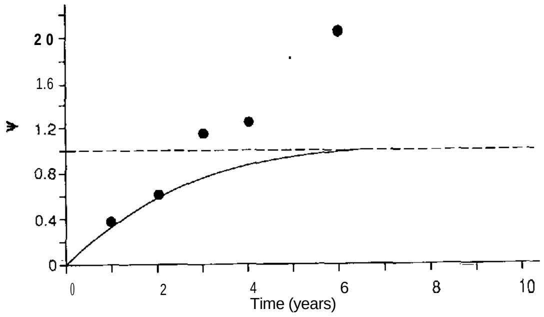

Figure 4 Relationship between time and the substitution **value** for the National Series **Mo** inadequate sites (see caption Figure 3).

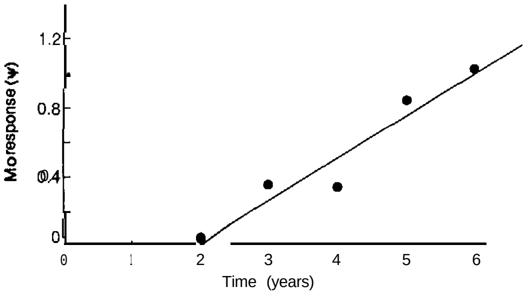

Figure **5** Relationship between time and the **Mo** response component of the Sechura RPR response (i.e. $[(\psi) \cdot 1 + (1-kt)3])$ see Figure 4.

The increasing positive deviation of ψ **based** on the DM data (low Mo sites) is best explained as aresponse to the Mo contained in the Sechura RPR but not in the TSP (Smith *et al.* 1990). This difference between ψ calculated from DM measurements and that calculated from soil RPR measurements is plotted in Figure 5. It suggests that theconfounding effect of **the Mo** impurity in the Sechura RPR on the low Mo sites does not become apparent until year 3 and increases linearly thereafter. This is consistent with an increasing Mo deficiency in the TSP-treated plots while adequate Mo was being applied to the Sechura RPR treated plots (Sinclair *et* al. 1990b). The DM responses to Sechura RPR on the MO-deficient soils can therefore be explained as a consequence of the dual correction of P deficiency and a developing Mo deficiency after 2 years. Molybdenum concentrations in clover and pasture are consistent with this (Sinclair *et al.* 1990b).

Rate constants

Rate constants (k) derived from the DM data can be determined from the slope of the relationship between $F(\psi)$ and time (equation 3) (Figure 6). For the sake of comparison the same function $F(\psi)$, based on direct measurement of RPR residues in the soil, is shown as the solid line. For the MO-adequate sites there is good agreement, noting that an estimate of ψ was not possible in year 1.

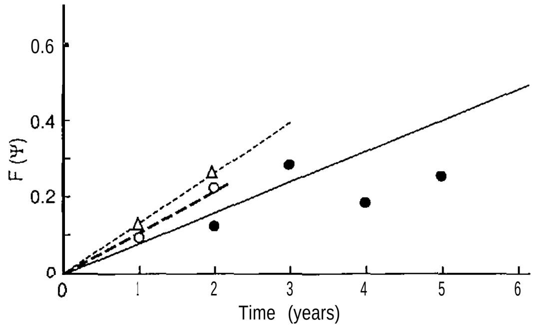

Figure 6 Relationship between **time and** the **function** $F(\psi) = [1-(1-\psi)1/3]$ (see text) based **on** dry matter data **from the** National Series for low **Mo sites** (6) (8) (years 1 and 2) and **Mo** adequate sites (4) (●). Values of $F(\psi)$ based on the RPR dissolution model using soil RPR measurements an shown as **(---) for** low Mo **sites** and **(——) for** the Mo adequate sites. Values represented as—are based on the DM data for all 19 sites for **years** 1 and2. **[RPR residues were not measured on all 19 sites. The dashed** line **represents** the line of best fit].

Similarly, for the MO-inadequate sites there is good agreement between $F(\psi)$ calculated from DM and RPR residues in years 1 and 2, during which time there was no Mo response (Figure 5).

For the sake of comparison $F(\psi)$ values derived from the substitution values published by Sinclair *et* al. (1990a) from ***all 19 sites*** for years 1 and 2 are also shown in Figure 6.

Thus, based on the DM data from the National Series, the rate constants (k, year-l) range from 0.06 (4 high Mo sites) to 0.13 (6 low Mo sites) with an average for all 19 trials of 0.10. These are in good agreement with the average rate constants based on soil RPR measurements from the same sites at 0.08 (high Mo) and 0.13 (low Mo) (Table 1).

The RPR dissolution model is therefore consistent both qualitatively (measuredpatternof RPR dissolution in soil) and quantitatively (same rate constant values) (Figure 6), with the agronomic data from the National

Series and with the independently measured rate constants from soil residues in the National Series trials.

Thus, it is entirely appropriate, in our opinion, to use the mathematical dissolution model as the basis for evaluating the economics of RPR as a replacement for single super-phosphate (Sinclair et al. 1990c).

Substitution values

As discussed earlier, ψ is the ratio of the amount of soluble relative to RPR-P required to achieve the same yield. Given the average rate constant based on either the DM data (19 sites) or soil RPR measurements (10 sites) from the National Series (viz 0.10/year), the general relationship between $1/\psi$ and time can be described from equation (2) (Figure 7). This shows that in the typical situation about 3.5 times the amount of RPR-P is required in year 1 to achieve the same yield as soluble P. In year 2 about 2 times the amount is required and 1.5 times in year 3.

The typical situation also indicates (Figure 7) that about 5.5 years of annual RPR applications are required before RPR produces 90% of the yield achieved with soluble P applied at the same rate. The cumulative amount of P dissolving from RPR in a given year as a fraction of the total P applied annually is 27, 49, 66, 78, 88, 94% for years 1-6 respectively.

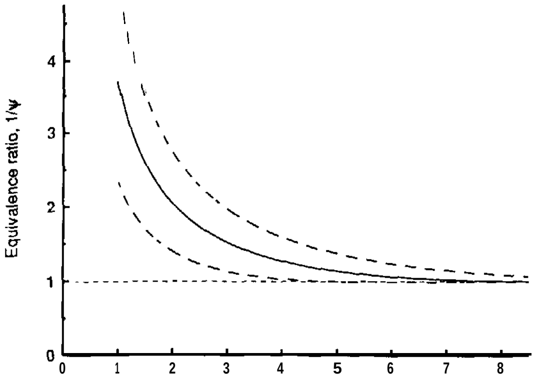

Figure 7 Effect of time on the equivalence ratio ($1/\psi$) for RPR relative to soluble P. Based on equation 2 using the average rate constant 0.10±0.04. The broken lines are based on the range in rate constant in Table 1.

RPR lag time

(a) Definitions

It is clear from both the RPR dissolution model and the yield data from the National Series that there is a lag effect when switching from the use of a soluble P fertiliser to RPR. This can be described in a number of different ways.

Pasture production (DM):

The lag effect is most frequently referred to and identified with an initial decrease in pasture production associated with a change to RPR use. It is important to note that the lag effect defined in this way may or may not be observed by the farmer, or measured in an experiment, depending on the initial P status of the site. At high soil P status no lag effect in terms of production will be *observed,* because soil P reserves will be sufficient to maintain production irrespective of the P-supplying power of the RPR. At low P status the lag effect will be apparent.

Amount of RPR dissolved:

Alternatively, the lag time can be defined as the time required to build up sufficient RPR residues in the soil such that the annual amount of total P applied as RPR is equal to the total amount of P dissolving and becoming available for plant uptake. This definition is independent of soil P status, except possibly where extremely high soil P levels inhibit RPR dissolution.

Substitution values:

Using substitution values based on the pasture production data from trials such as the National Series, the lag time can be defined as the time required such that the substitution value for RPR relative to soluble P is 1. The lag effect defined in this manner is identical to that derived from RPR dissolution considerations, as discussed earlier.

Economics:

The lag time can be defined in economic terms as the time required to reach a positive net present value with annual application of RPR relative to single superphosphate P fertiliser. Sinclair *et al.* (1990c) have calculated 'breakeven' times for a range of values of rate constants (k), discount rates and sulphur (S) to P ratios. Assuming no S is required and applying the average rate constant (k) listed in Table 1 and a discount rate of 10%, then the time required for RPR applications to be more economic than single superphosphate is about 5 years (range 3-7 years), based on current product costs. If S is required at the same rate as P then the breakeven time is 10 years (range 6-15 years). Once the breakeven time has been passed then RPRs are always more economic than single superphosphate assuming that the conditions for RPR use are met (see later).

(b) Lag **times**

Using the substitution value approach based on the National Series results (MO-adequate sites), it is apparent from Figure 3 that it takes about 7 years to reach a substitution value of 0.9 and about 12 years for ψ to equal 1.

Similarly, applying an average rate constant of 0.10 (from 19 sites, Figure 6) to the RPR dissolution model gives a lag time of about 5-6 years (for 90% dissolution) (Figure 7) and an economic breakeven time of 5 years. (Assuming no S required and a discount rate of 10% - see Sinclair et *al.* 1990c.)

Bearing in mind the range of the rate constants from the 12 National Series trials running 6 years (viz. 0.04 to 0.17. Table 1), and applying these to the dissolution model, indicates the general situation, with lag times being about 4-6 years (Table 1) and economic breakeven times of 3-7 years (Sinclair *et al.* 1990c).

Site and climate factors

As stated earlier the primary objective of the National Series was to determine the impact of soil and climate factors on the agronomic effectiveness of RPR.

Regression analysis (results not given) indicate that none of the factors (rainfall, soil pH, soil phosphate retention) either singly or in combination, account for the measured site-to-site differences in RPR effectiveness as measured by the rate constants. However, this result must be seen in context. Of the 19 trials only 12 were continued for 6 years. It was only from these trials that rate constants were calculated based on RPR residues present after 6 years. The range in soil pH of these 12 trials was 5.1 to 6.3 and 10 had soil pH values in the range 5.5 to 6.0 inclusive (Smith *et al.* 1990). Thus, the range in soil pH across these trials was small. Similarly individual site annual rainfall ranged from about 700 to 1800 mm with all but 2 of the sites in the rainfall range 1 000- 1800 mm (Smith *et* al. 1990). Soil phosphate retentions ranged from 13 to 98. The lack of any meaningful relationships between rate of RPR dissolution and soil and climate factors may, in this instance, be a consequence of the narrow range in two of the site factors.

Currently RPR applications are not recommended in New Zealand if the annual rainfall is less than 800 *mm* and the soil pH is >6.0 (Quin et al. 1987). The only basis at present for applying these boundary conditions is the poor performance of RPR on the non-irrigated Winchmore site (site 14, Smith *et* al. 1990) measured either agronomically (Smith et al. 1990) or in terms of the dissolution rate constant (Table 1). However, there is evidence from Rajan *et* al. (1991) which supports the need for an upper limit on soil pH with respect to RPR use. Their results (Figure 8) indicate that the performance of RPR relative to soluble P fertiliser decreases exponentially with increasing pH, the absolute increase in $1/\psi$ being especially great as soil pH values increase above 5.5. At the opposite extreme, field trials on acid (pH 4.5) tussock grassland soils in Otago show that North Carolina RPR was at least as good as single super-phosphate where response to applied P were obtained. in each of 3 years. Recent uncompleted trials in Northland show that at pH <5.0 RPR is as effective as soluble P in year 1. From this combined information the following relationship between soil pH and RPR lag time is tentatively suggested.

Soil pH range	**Lag time (years)**
> 6.0	(RPR not recommended)
5.5 • 6.0	4 - 6
5.0 • 5.5	1 - 3
< 5.0	0 - 1

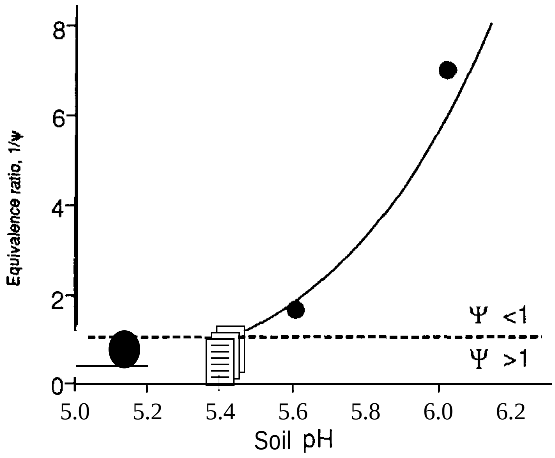

Figure 8 Effect of soil pH on the equivalence ratio ($1/\psi$) for Sechura RPR relative to Ibex on a yellow-brown loam (after Rajan *et al.* 1991).

Agronomic effectiveness of RPR-P

An important assumption in the economic analysis of Sinclair *et al.* (1990c) is that the P released from RPR has the same agronomic effectiveness as P from soluble P fertiliser. This assumption has not been specifically tested but there is compelling circumstantial evidence in support.

1. The fact that the DM production data from the National Series can be adequately described by the

RPR dissolution model, with numerical values for the rate constants in agreement with measured values, implies that the rate of dissolution of P from RPR and its agronomic equivalence with soluble P over 12 months are the major factors determining pasture yield. If the P released from RPR were used more efficiently (i.e. more DM for a given amount of soluble P over the growth period) then one would expect to fiid positive deviations from the linear relationship (Figures 3 and 4), and values for $\psi > 1$ after a few years. This in fact is true for the Mo-deficient sites (Figures 4 and 5). However, this response is to the Mo in Sechura RPR and not to a greater efficiency of P from Sechura RPR since the effect is absent in the Mo-adequate sites (Figure 3).

2. A more common way of evaluating the data is to compare the efficiency of producing DM per unit of soluble P applied, at a given rate, for the two fertilisers. Using the DM data from Smith *et al.* (1991a) and amounts of RPR-P dissolved per year from Table 1, from the Mo adequate sites running for 6 years (sites 1, 6, 7, 13), calculations show that the 2 forms of P fertiliser are equivalent in terms of kg DM/kg soluble P in each of the 6 years at both 0.75 x and 2 x maintenance. For example, at 0.75 x maintenance, Sechura RPR efficiency (kg DM/kg P) = -2.8 + 1.05 TSP efficiency (kg DM/kg P) ($r^2 = 0.98$, range 15 to 92). This regression is not significantly different from one passing through the origin with a slope of unity.
3. Both mixed herbage P concentrations and P uptake were determined on most of the National Series trials (Smith et al. 1991a). One of the conclusions reached from examination of these data was that “in general, herbage P concentration and P uptake data followed the same trends as the DM production data”.

Examination of the relationships between mean P uptake and DM yield for all sites for the RPR and TSP treatments reveals a linear relationship. There is no suggestion that for a given P uptake plots receiving RPR produced more DM (Figure 9 and Figure 10). The same picture emerges looking at individual sites although there are some exceptions, but among these there are no consistent patterns. The data of Rajan et *al.* (1991) suggest a higher DM per unit of P uptake with decreasing pH and/or increasing amount of RPR dissolved.

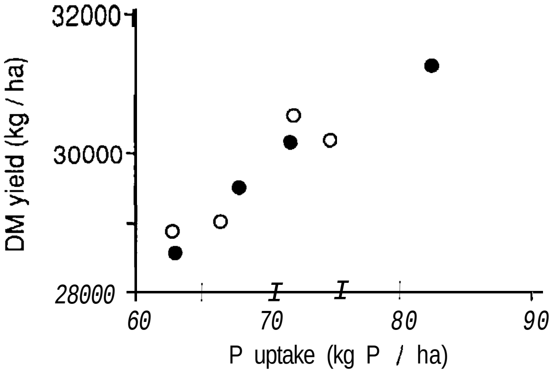

Figure 9 Relationship between pasture production (DM) and pasture P uptake from the ‘National Series’ trials (values are means of all trials over years 1-4. see Smith et al. 1991a). (○ TSP, ● RPR).

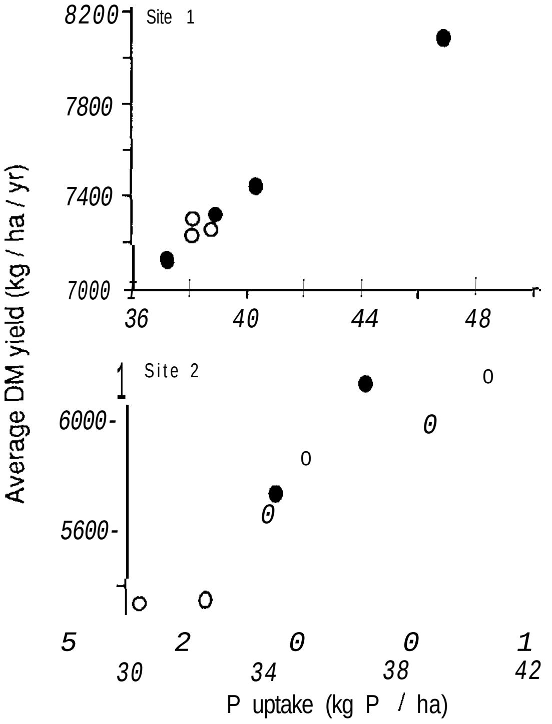

Figure 10 Relationships between pasture production (DM) and pasture P uptake for Site 1 (high Mo) and 2 (low Mo) from the ‘National Series’ (values are means over years 1-4, see Smith *et al.* 1991a). (○ TSP, ● RPR).

4. Results from the National Series (Smith *et al.* 1991b) show that the soil pH of plots treated with RPR is not significantly different (nor are there any trends), from that of soluble P treated plots, indicating that RPRs do not have a liming action or that, if it occurs, it is not measurable by the methods used. Thus it is unlikely that the utilisation of RPR-P is enhanced by a self-liming effect. In any case this suggestion is contradicted by the well-known decrease in effectiveness of RPR with increasing soil pH (Figure 8).
5. It is possible that, because RPRs maintain a lower soil soluble P concentration than soluble P fertilisers, RPR-P, once released into the soil solution, will not be subject to the same detrimental chemical reactions such as P-fixation and immobilisation. While this may be so initially, after 6 years of annual application

the amount of P solubilised annually from the accumulated RPR residues is approximately equal to the amount of soluble P applied. Both sources will then contribute the same amount of soluble P annually. The only difference is that soluble P fertilisers dissolve immediately while the RPR-P dissolves over the course of the year. This slow-release effect may exist at $pH < 5.5$ (Rajan *et* al. 1991), where, from Figure 8, ψ is significantly ($P < 0.05$) greater than unity. Since most National Series trials and most NZ pastoral soils have $pH > 5.5$ this effect would be uncommon.

Implications for longlife and PAPRS

Longlife superphosphate is manufactured by adding RPR (typically at a level of 30%) to single superphosphate during manufacture. This type of product is now manufactured only by Ravensdown Fertiliser Co-op Ltd and Southland Co-operative Phosphate Co Ltd. However, both Farmers Fertiliser Ltd and BOP Fertiliser Coop Ltd manufacture a sulphuric acid PAPR (marketed under the trade names Parrphos-18 and Longlife Supreme, respectively). These products are intermediate between superphosphates and RPR in terms of their P solubility. (For a more detailed discussion on the chemistry of these products see Goh *et* al. 1990).

MAF have conducted 13 field trials examining the agronomic effectiveness of Longlife-type products relative to soluble and slow release P fertilisers. The general conclusion from these trials is that Longlife behaves agronomically as a mixture of RPR and single superphosphate and that there is no chemical interaction between these 2 components. It follows then that:

(a) Longlife is not agronomically identical to single super-phosphate, and
(b) The boundary conditions of pH and rainfall which currently apply to RPR should also apply to Longlife.

It also follows that unlike single superphosphate there will be a lag effect associated with Longlife use because of its RPR component but that the magnitude of this lag effect (but not the time) will be smaller than that observed for straight RPR.

This is demonstrated by the results in Figure 11, which show that in year 1 Longlife was agronomically inferior to single superphosphate but superior to RPR when applied at the same rate. By year three the difference in agronomic performance between these products was small.

Although phosphoric acid PAPRs have been available in New Zealand and have been extensively investigated (Smith *et* al. 1990) they are currently not commercially available. In addition to the lag effect described in this paper, there would also be a prior delay to the start of dissolution of the RPR component in these products of at least 3 months, caused by the soluble P present being of greater concentration than the solubility of RPR (Rajan 1987).

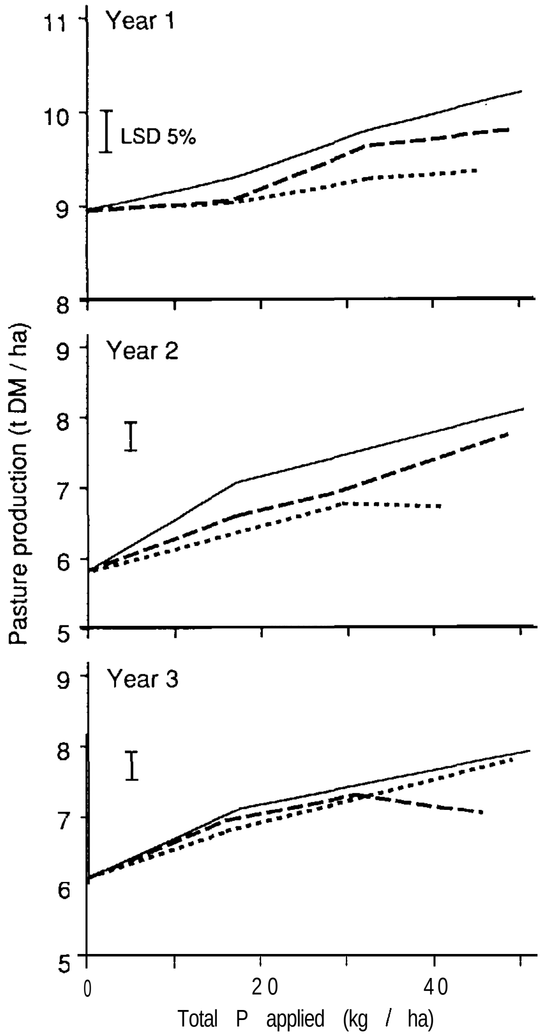

Figure 11 Effects of single superphosphate (——), North Carolina RPR (......) and Longlife (- - -) on pasture production on a yellow-brown loam (values are means of 2 trials).

Sulphuric PAPRs have been manufactured in New Zealand only recently. Consequently only a limited amount of agronomic data are available. Pot trial results and the initial results (1 year) from 1 field trial indicate that this type of product is almost as good as single superphosphate initially. Further work, now in progress, is required before definitive conclusions on the agronomic performance of these products can be made. Of particular importance is the need to ascertain whether soil pH and rainfall restrictions should apply to these products as they do for Longlife and RPR.

Conclusions

1. RPRs release P slowly and on average the rate of release of P is about 30% within the year of application, 23% in year 2 and progressively less in subsequent years. The total P released from current and earlier applications therefore increases with time to a constant value equal to that of the application rate. Consequently, a lag effect is associated with their use.
2. The pasture production data from the National Series of trials are consistent with, and can be described quantitatively by, the RPR dissolution model.
3. The lag time associated with RPR use is about 4-6 years on average based on both the National Series pasture production data and on the RPR dissolution model.
4. Based on the National Series the site-to-site differences in the rate of dissolution of RPR and hence the agronomic performance of RPR are not associated with soil pH, total annual rainfall or soil phosphate retention, noting the narrow range of the former two parameters.
5. Available evidence suggests that the RPR-P dissolved over 12 months has the same agronomic effectiveness as annual P applications from soluble P fertiliser, for soils of pH 5.5 to 6.0.
6. In economic terms based on current prices, the time required for RPR to be more cost effective than soluble P is about 3-7 years, assuming no S is required.
7. The lag time associated with Longlife-type products has two components: the first applies to the RPR component alone which is in proportion to their RPR content. There is also a delay to the start of RPR dissolution which is probably related to the RPR solubility.

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