

## RIGHT P FERTILISER, RIGHT PLACE, RIGHT TIME

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### Abstract

This paper reviews reactive phosphate rock (RPR) research, past and present, to remind people what has and hasn't been researched. It identifies where RPR and superphosphate can be of value in improving phosphate uptake efficiency, and how RPR and superphosphate can be managed to assist in mitigating against nutrient loss. Economic considerations in P fertiliser choice are also presented.

Based on the edaphic parameters, identified in pasture trials, of soil pH<6.0 and mean annual rainfall >800 mm, the potentially suitable area of New Zealand for RPRs was estimated at 8 million hectares. However, slow release of P from RPR, which can be of benefit in maintenance situations, renders it less suitable for properties where development of soil P status is required. Although speed of dissolution can be improved by grinding to reduce particle size, difficulties in spreading are increased, as is the cost. The latter continues to be a factor in choice of P source, particularly if sulphur (S) is required, as it must be added to RPR.

The economic calculations associated with P source choice are complicated by the difference in S form and the availability of P and S within the budget year: purchasing RPR in one year when only some of the P applied will be available in that year 'frontloads' the expenditure.

Environmental impact calculations are also complex. The use of RPR has been shown to result in reduced P loss to waterways in some situations in comparison with superphosphate. However, following best practice for superphosphate application (e.g., avoiding application when heavy rain is forecast and tailoring applications to meet plant P uptake requirements) results in minimal losses.

Further reduction in P loss, which can occur through sediment and dung movement to surface water, might require a change in farm system; the changes will depend on individual farm physical, climatic and management factors whatever the source of P applied.

Best practice means checking the research and considering all aspects of the choices – production, protection and economics.

### Background

During the 1980s and 1990s there was considerable interest in the prospect for reactive phosphate rock (RPR) to replace superphosphate fertiliser. A comprehensive review (Bolan *et al.*, 1990) concluded that 'the potentially suitable area for RPRs on pasture in New Zealand is about 8 million ha'. This was based on the criteria of soil pH<6.0 and mean annual rainfall >800 mm, identified in pasture field trials. When these criteria were met, RPR's 'can be as effective as soluble P fertilisers, per kg of P applied'. However, the time taken to be 'as effective' can be significant.

## Effectiveness

Research comparing Sechura RPR with superphosphate in 19 field trials across New Zealand for 3-6 years concluded (Sinclair *et al.*, 1990) that in the first 2 years RPR was considerably less effective than superphosphate (applied annually at 4 rates), but that performance improved with time. In the final year, RPR out-yielded superphosphate on average over all trials, but with marked differences at different sites. The researchers noted that very high soil phosphate retention and a combination of low moisture and high pH appeared to be unfavourable for RPR performance. An effect of the molybdenum in the Sechura RPR on increasing clover performance was implicated in superior performance at some sites (thereby highlighting the importance of balancing nutrient input in research trials).

Factors affecting RPR dissolution in the field were investigated because of variability in performance, not only between different RPR sources, but also within one RPR.

Comparison of different RPR sources over 3 years at 2 different sites showed that Sechura phosphate rock and North Carolina phosphate rock produced approximately 88 and 86%, respectively, of the dry matter yield achieved with superphosphate, whereas at Te Kuiti the dry matter yield was approximately 53 and 50% for Sechura and North Carolina, respectively (Sinclair *et al.*, 1998). Egyptian, Arad and Zin phosphate rocks achieved between 25 and 50% of single superphosphate at the two sites.

In another trial involving 95 New Zealand pastoral sites, dissolution rates for Sechura phosphate rock averaged 31% but ranged between 0 and 70% per year (Perrott *et al.*, 1996). Using regression analysis, the researchers concluded that important soil and environmental factors affecting dissolution were soil type, soil pH, exchangeable soil Mg, rainfall and drainage (Perrott *et al.*, 1996).

The importance of pH was shown by Bolan and Hedley (1990) who reported that as pH decreased from 6.5 to 3.9 the dissolution of PRs increased from 29.3% to 83.5% for North Carolina phosphate rock, from 18.2% to 78.9% for Jordan phosphate rock, and from 12.5% to 60.3% for Nauru phosphate rock. However, the proportion of the dissolved P extracted from treated soils by 0.5 M NaHCO<sub>3</sub> (Olsen P) decreased from 38% to 5% and the proportion taken up by ryegrass plants decreased from 46% to 7%. Thus the amount of P taken up by plants was more closely related to the amount of NaHCO<sub>3</sub> extractable P (Olsen P) than to the amount of dissolved P present in the soil. The authors noted that the decrease in plant available P with decreasing pH corresponded to an increase in the soil adsorption of inorganic P with a decrease in pH.

The research involving 95 sites (Perrott *et al.*, 1996) supported the development of a simple RPR model (Perrott, 2001) recognising the importance of diffusion of Ca and P (the rate-limiting step) through the layer of soil surrounding the particle (Watkinson, 1994). Movement of the Ca and P is controlled by the concentration gradient across this layer of soil and is affected by both the solubility of the RPR and the thickness of the layer. This suggests that particle size, and speed of removal of Ca and P (e.g., rainfall and drainage as well as saturation of the cation exchange capacity and plant P uptake) are important. These factors were incorporated into the AgResearch Fertiliser Decision Support System (Perrott and Metherell, 1997; Metherell and Perrott, 2001).

Speed of dissolution can be improved by reducing the particle size by grinding the RPR to a powder, but powder is difficult to apply by land or by air. Attempts have been made to granulate

or pelletise PRs to produce a commercially acceptable fertiliser. However, clumping particles reduces the rate of dissolution because the soil around the particles very quickly becomes saturated with respect to the PR component (Bolan et al., 1990).

In general, dissolution rate of RPR at a specific site can be estimated from the fertiliser properties of RPR solubility and particle size distribution (Perrott 2001).

### **Economics**

When the research was published in 1990 it was considered that the good performance of Sechura RPR and the relative cheapness of RPR indicated an important role for RPR on New Zealand pastures (Sinclair *et al.*, 1990), particularly where farms were distant from P fertiliser suppliers as the approximate 13% total P in RPRs meant less cartage and spreading costs.

Dr Sinclair investigated the economic aspect of the recommendation (Edmeades, 1999) and estimated that when superphosphate and RPR were approximately the same price, it would take more than 25 years for RPR to be more cost effective than superphosphate at a dissolution rate of 20% per year. At 30%, 40% or 50% a year, the RPR would be as cost effective as superphosphate in 10, 6 or 4 years, respectively. Dr Edmeades noted that Sechura rock phosphate was the most reactive PR tested at 30% dissolution a year. This indicated that the other rocks available would take longer than a decade to 'break even'. The impact of any delay in P availability is likely to be lower in maintenance situations, where the soil P concentration is adequate for pasture growth, than in situations where capital P fertiliser is required to improve productivity (Ballard, 1991, cited in Quin & Zaman, 2011).

Very low initial soil fertility and subsequent lack of response has resulted in farmers stopping using RPR in the past. Lack of price advantage has also influenced use (Zaman & Quin, 2011).

The challenge with the initial calculation for the farmer is that the budget is being 'frontloaded' – payment is being made for nutrients that won't be available for several years, which increases the apparent cost of the nutrient in the first year (Edmeades, 1999). An additional challenge is calculating the value of the sulphur that is in superphosphate but not in RPR. If sulphur is needed, it must be added to RPR, thereby increasing the cost of the final product. The dissolution profile of the sulphur must also be considered. Elemental sulphur (S) is permitted in organic systems, but is slow to become available. Fine grinding increases availability, as with RPR, but also increases difficulties in ground or air spreading. Elemental sulphur prills (e.g., Sulphur 90) overcome the dissolution rate problem, but are not ideal for blending with RPR because of differences in physical size. Sulphur super blends give an improved mix of P and S release rates and particle size.

Using the AgResearch RPR model (Metherell and Perrott, 2001), with February 2019 prices and no requirement for sulphur, in comparison to superphosphate an RPR with 30% dissolution per year (good quality RPR, in soils with low pH and with greater than 800mm rain per year) will be cost effective. At a dissolution rate of 20% per year, there is little difference in long term economics, unless transport costs are high which increases the competitiveness of RPR. If sulphur is required superphosphate will be more cost effective.

### **Environment**

For New Zealand, however, the main issues are not those of cost or efficacy, but environment (and now socio-political difficulties). It is important to recognise that some loss of P is indirect rather than directly from whatever fertiliser is applied, in pastures grazed by dairy cattle,

indirect losses of P from soil account for about 30-50% of total paddock losses (McDowell *et al.*, 2007). Where soils are potentially erosion prone, soil-P losses may account for more (i.e. nearer 50%) of paddock P losses compared to stable soils.

The potential for loss from any applied nutrient, whatever the source, is greatest soon after application, and declines exponentially with time as fertiliser-P is sorbed to the soil. Overall, the magnitude of loss will depend on the rate of application, but also on the form and solubility of the P fertiliser (McDowell, 2012).

RPR has been promoted as an environmentally-friendly solution for farmer needs. Being less soluble than superphosphate, it is thought to be less mobile in the environment. RPR has been shown to decrease P loss at a catchment scale by about a third compared to highly water-soluble superphosphate (McDowell *et al.*, 2010). The reduction was significant, though overall the loss of total phosphorus from the catchment in Southland was low (typical of a dry, hill country sheep farm catchment), whatever form of P was applied. Emerging technologies which coat soluble P fertiliser may well offer a similar benefit as RPR fertiliser in these environments

At Winchmore losses of P from overland flow were up to 5.40 mg/L total phosphate from superphosphate treatments, but only approximately 0.11 mg/L from the RPR treatments (and 0.02 mg/L from control plots). However, simulated rainfall events prior to fresh applications of fertiliser resulted in more P being lost from soils with RPR applied than superphosphate. Regression analysis suggested that the loss of P was elevated above the control for a period of 60 days following application. The research supported earlier studies indicating that risk of incidental P loss from soluble P fertilisers is greater than for RPR. The authors pointed out the potential environmental benefits from RPR fertilisation of soils 'at-risk' of P loss, i.e., where overland flow occurs such as in very wet soils and near stream channels. They also stated that adhering to good management practice (e.g., application timing and rate relative to expected runoff generation) would result in minimal differences in loss between superphosphate and RPR treated soils over a period of a year (McDowell *et al.*, 2003).

### **Good Management Practice**

Good management practice has been the result of ongoing research and recent advances in technology, including precision application of any fertiliser, have allowed improvements in management of superphosphate fertiliser. McDowell *et al.* (2019) report that increased awareness of potential issues has resulted in a reduction in P losses to water. The authors identify strategies mitigating P loss from land, following of guidelines indicating which strategies were appropriate in which situations, and increased policies surrounding P management had been key in the reduction. They also reported that there was little evidence that the decrease in P in rivers was associated with a decrease in soil Olsen P concentrations or imported P (e.g. fertiliser), a change to low water-soluble P fertilisers, or that greater nitrate loads were assimilating P from groundwater or sediments.

Soil Olsen P should be maintained within the range of concentrations considered optimal for pasture production and not excessive for any given soil type. Since the magnitude of P losses from soil via overland or subsurface flow is proportional to soil P concentration (McDowell *et al.*, 2003), having an Olsen P concentration above optimum represents an unnecessary source of P loss and an unnecessary waste of the fertiliser P inputs. However, maintaining optimal soil Olsen P does not totally prevent P losses from occurring. Some soils can lose a lot of P at optimal Olsen P concentrations for pasture production e.g., soils with little Al and Fe oxides such as Podzols (McDowell and Condron, 2004). Furthermore, if a soil is already P-enriched

then it can take many years for Olsen P to decline unless soil is cultivated, perhaps during cropping or re-grassing, to remove surface enrichment and redistribute P within the plough layer (Sharpley, 2003). The risk of P loss from generating high soil Olsen P levels is greater on soils which have a lesser ability to retain fertiliser P additions. The ability of soils to retain P is measured by the anion storage capacity (ASC) laboratory test. There is less P lost in overland flow on soils with higher ASC values than those with lower ASC values at the equivalent Olsen P test level (Morton *et al.* 2003).

If good practice is followed, direct fertiliser P losses are relatively small i.e., less than 10% of total P lost from pastures (McDowell *et al.*, 2007a). For fertiliser P to be transported by overland flow into waterways, the soil has to be saturated and the rainfall intensity has to be high enough for runoff to occur before the fertiliser P has had the opportunity to be washed into the soil. Surface runoff travels only about 20m (Gilchrist and Gillingham, 1978) in a worst-case scenario (e.g., dry soil, heavy rain) and soil structure and type, pugging and pasture cover are important factors governing P loss via overland flow.

However, if good practice is not followed then P losses from fertilisers can account for the majority of P losses from a farm. For example, between 1.2 and 3.4 kg P/ha was lost from a 50 kg P/ha winter application (as superphosphate) on a pallic soil in either overland flow or soil drainage (Sharpley and Syers, 1979). Generally, the potential for soluble P fertilisers to be lost in either overland flow or drainage reduces quickly with time after application. Within 30-60 days the P lost from soil with soluble P fertiliser applied will equal the same as soil with no soluble P fertiliser applied (McDowell *et al.*, 2003). However, the potential soon after application is directly related to the solubility of the fertiliser applied, with the risk of direct P loss in the order superphosphate > serpentine super > reactive phosphate rock (McDowell and Condon, 2004; McDowell and Catto, 2005).

McDowell *et al.* (2003) indicated that within the first 60 days of superphosphate application, if a significant storm event occurs that causes overland flow, the concentration of dissolved P could be high enough to contribute to water quality problems from land closely adjoining streams. In this situation, the loss of P from RPR will be much lower and not significantly contribute to poor water quality, over the same time period (60 days). Over the longer term, P losses are likely to be the same regardless of fertiliser type. In some environments, storms occur only 3-4 times per year during predictable times. Where storms are more frequent, the timing is less easy to predict and for fertilised land in close proximity of a P-sensitive water body, then RPR application will reduce the risk of direct P loss from fertiliser over that first 60-day risk period. The alternative is to use placement verification technology and then establish a suitable buffer strip adjacent to receiving water bodies so no P fertiliser is applied in those areas.

## **Conclusions**

Although the long-term effectiveness of good quality RPR in an appropriate environment has been shown (e.g., at Winchmore), in many environments the delay in P availability, the additional need for sulphur resulting in increased price, and the overall lack of consistent price advantage between superphosphate and RPR, has mitigated against farmer uptake. Despite ongoing research and considerable marketing from some companies, superphosphate has remained the fertiliser of choice. Research on precision application of superphosphate fertiliser has reduced the potentially negative environmental impacts, thereby maintaining the use of a cost-effective source not only of P but also of S.

Good management practice can be encapsulated by the following: right product, right time, right rate and right place. After that the greatest losses of P will come from the farm system itself in terms of P loss caused by sediment and dung movement to surface water. To reduce these losses on farm may require greater or lesser farm system changes depending on individual farm physical, climatic and management factors

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