FERTILISER OPTIONS:

PHOSPHATE OPTIONS FOR HIGHER RAINFALL PASTURES

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Abstract. The range of pasture fertilisers now available on the market includes reactive phosphate rocks (RPRs) and products derived from them (PAPRs), as well as the traditional water soluble P (WSP) products. RPRs are attractive because they appear to be cheaper. However they require acidic soils and a relatively high rainfall to be effective, and losses in pasture production may occur for a number of years when a producer changes from annual applications of WSP to RPR fertiliser. Additional costs are also involved in adding sulphur to RPR, and sometimes with the ground-spreading of RPR. Potential benefits can occur from the 'lime-saving' effect of dissolving RPRs which consume soil acidity. This should reduce the rate of acidification that might be occurring in a pasture soil, providing that gypsum is the form of sulphur that is added to the RPR. PAPRs appear to be as effective as WSP fertilisers, and have some inherent advantages over both WSP and RPR products. Any expansion in their use in the future, apart from leaching environments, will depend on price advantages. Producers are advised to use RPR fertilisers cautiously until final results from the National RPR Project become available in 1995-96.

One of the key findings from pasture research in Victoria in recent years has been the strong re-affirmation of the need for adequate concentrations of plant-available phosphorus (P) in the soil, if high levels of animal production are to be achieved on heavily-stocked pastures containing productive grasses and legumes. The question as to *how much* P should be applied is very important. This paper addresses a second question, that is, *in what form the P should be applied?* This is a question that will be asked increasingly by pastoral producers in the high rainfall areas of southern and eastern Australia.

The cost of the traditional P fertiliser for pastures, single superphosphate (SSP), increased dramatically in the mid 1970s. Questions were then asked as to whether SSP was in fact the most efficient form of P and S fertiliser for pastures. One of the potential problems was considered to be the rate at which P is released from the granules. Release is far quicker than the rate at which the pasture plants require P from the soil. Another problem is that SSP only contains around 9% total P, due to its gypsum content (a by-product of the treatment of phosphate rock with sulphuric acid). This means that there are higher freight and spreading costs compared with the higher analysis products such as triple superphosphate.

Alternative fertilisers to SSP were evaluated in research programs in both Australia and New Zealand during the 1980s. Up until 1990 the differences between products in Australia were marginal, with minor variations in both price and agronomic effectiveness. In 1986, at the first annual conference of this society, I reported that the likely cost savings from ESPARP, an elemental sulphur - enriched partially acidulated rock phosphate which we were evaluating at the University of New England, were only in the order of 4% (Sale 1986). Such small gains did not warrant its manufacture and use. Savings of up to 15% were possible by using high analysis triple superphosphate (TSP), but then there was the need to add sulphur. We now know that when sulphur is added to TSP, the potential cost savings from high analysis P forms are practically eliminated.

Use of reactive phosphate rocks (RPRs) as pasture fertilisers

In 1986-87 pasture agronomists in New Zealand became quite excited because a new type of P fertiliser known as reactive phosphate rock (RPR) was performing quite well in field trials, after it had been re-applied for several years. Earlier work in New Zealand had shown that the phosphate rocks (PRs) used for manufacturing single superphosphate were *not* effective fertilisers when applied directly on to the pasture. These PRs dissolved too slowly to provide sufficient P to meet the pasture plant's requirements. However "reactive" PRs are those where a carbonate group (CO_3) has replaced a phosphate group (PO_4) in the crystal structure of the rock. The reactivity increases as the degree of carbonate substitution increases. Increasing the carbonate substitution increases the rate that the

PR will dissolve in the soil, and therefore its usefulness as a pasture fertiliser. The chemical formulae of a pure form of unreactive PR (fluroapatite) and the reactive Sechura PR (Hammond et al., 1986) can be written as:

$Ca_{10}(PO_4)_6F_2$ for unreactive PR, and

$Ca_{9.03}Na_{0.74}Mg_{0.13}(PO_4)_{4.88}(CO_3)_{1.12}F_{1.73}(OH)_{0.27}$
for Sechura PR

It can be seen that some of the phosphate has been replaced by carbonate while sodium (Na) and magnesium (Mg) have replaced some calcium (Ca), and hydroxyl groups (OH) have replaced some fluorine (F).

Two questions were put to the New Zealanders, "Did you have to grind the RPR finely to make it effective?", (because fine grinding was essential to make unreactive PRs more effective) and, "Could it be effectively applied by ground-spreader or by air ?" The answers were that it could be spread without any further grinding, and that there were no major problems in spreading the material "as received", although most of the research was done with aerial spreading. Furthermore, there were major cost savings being obtained in New Zealand, in the order of 30-40% of the cost of applying the same amount of P as single superphosphate.

In 1990, a consignment of 5,000 tonnes of RPR from Egypt was unloaded in Geelong. It was placed on the market, ex-Geelong, at a price per unit of P that was 24% cheaper than SSP. Although the price of RPR per tonne was similar to that of SSP the higher P concentration in RPR (around 13% instead of 9% in super) meant that the unit cost of P in RPR was much less. Within 12 months, a North American RPR was available in Geelong from another company with a cost saving of 29% over the cost of super. Today, the North American RPR is still available in Geelong and the cost saving, per unit of P ex-Geelong is now around 37%. The question is whether these sort of cost savings can be obtained in the pasture paddock, say on the Tablelands of NSW ?

The purpose of this paper is to explore the different issues that are involved with the cost-effectiveness of RPR. I am proud to report that we are increasingly able to comment on these issues. In 1990, the three pasture-based R&D Corporations (DRDC, AWRPO and MRC), together with the companies CSBP, Incitec, Pivot and EZ Fertilizers, and Quinphos (Aust.) agreed to provide support for a large collaborative research project, known as the National RPR Project. The aims of this five-year project are to identify the pasture environments in temperate and tropical Australia where RPRs can be used as cost-effective, alternative P fertilisers to the superphosphates. We now have results for two growing seasons from some 27 sites across Australia. Some of the preliminary trends that are appearing will be referred to in this paper. However, New Zealand experience suggests that it might take up to four years in relatively favourable environments for repeated applications of RPR to become as effective as those for superphosphate, so it is still too early to give a full report on this work.

Key issues relating to RPR use

Will RPRs work ?

RPRs are effective fertilisers if they dissolve rapidly in the soil such that their rate of P release and P supply is able to match the P demand by pasture plants. For this to happen, soil conditions must exist that favour the rapid disappearance of the products of RPR dissolution away from the surface of the dissolving RPR particles. The dissolution process involves the insoluble molecule of RPR breaking up into soluble ionic forms:

Reactive PR $\Leftrightarrow$ CATIONS $(Ca^{2+}.Na^+.Mg^{2+})$ + ANIONS $(PO_4{3-}.CO_3{-}.F^-.OH^-)$

The driving forces for making the RPR dissolve are the spontaneous neutralisation reactions between the acidic H^+ ions in the soil solution and the anions that are produced at the dissolving surface of the RPR particle. These reactions produce plant-available phosphate (H_2PO_4- ions), and water (H_2O), carbon dioxide (CO_2), and hydrogen fluoride (HF) respectively. So it is the supply of acidic H^+ ions that is essential for RPRs to dissolve rapidly and be effective pasture fertilizers. *The soils therefore need to be acidic with a low pH.* The other products that need to be removed from the soil solution surrounding the dissolving RPR particle are calcium (Ca^{2+}) and phosphate (H_2PO_4-) ions. The latter tend to be removed naturally by reacting with the solid phases of the soil, while calcium ions can be removed by becoming adsorbed on to clay or organic matter particles.

The second major environmental requirement for RPRs to dissolve rapidly is soil moisture. *RPRs do not dissolve in dry soils.* Moisture films surrounding the RPR particle are required to enable the products of dissolution such as calcium ions to diffuse away from the dissolving surface and to permit the the inwards diffusion of the acidic H^+ ions towards the surface to facilitate their associated neutralisation reactions with the anions that are released from the RPR.

Results from the National RPR Project are confirming the fact that soil acidity and soil moisture are key requirements for the RPR dissolution process. Other soil, climate, and pasture factors are probably also important but these have yet to be accurately de-
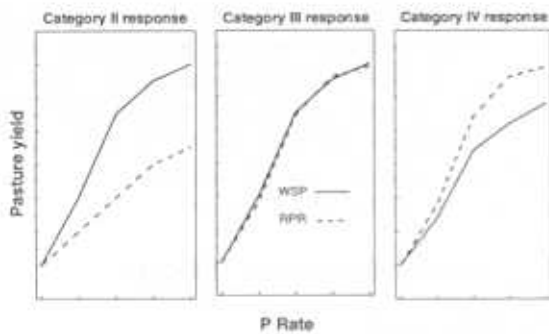
Figure 1. Schematic representations of category II, III and IV responses used to describe the different dry matter responses resulting from water soluble phosphate (WSP) fertilisers and reactive phosphate rocks (RPRs) in the National RPR Project.

fined. The high rainfall, acid soil sites are the ones where RPRs are performing very effectively in the first and second seasons. We have categorised the different types of P responses to water soluble fertilisers such as single or triple superphosphate (WSPs) and RPRs as either category II (where the WSPs are clearly superior), category III (where the WSPs and RPRs are equivalent in effectiveness) and category IV (where the RPRs are superior to the WSPs). These three types of response are illustrated by the pasture dry matter yield responses in Figure 1.

It is interesting to note that the Tully site in North Queensland, which has a soil $pH_{(CaCl2)}$ of 4.4 and an annual rainfall of over 4000 mm had a category III response in the first growing season. RPRs are very effective on these acidic soils on the wet tropical coast of Queensland. A more acidic soil site (pH_{CaCl2} of 4.1) in the eastern part of the southern Tablelands of NSW (near Tarago, annual rainfall of around 700 mm) produced a category II response in the first year, but this changed to a category III response in the second growing season.

One site in north west Tasmania had a category IV response in the first year. The soil at this site was an acidic, peaty sand with a soil pH_{CaCl2} of 4.1 and an annual rainfall of 1100 mm. The reason why the WSPs performed so poorly is attributed to the leaching of plant-available P from this sandy soil over the wet winter and spring. The RPRs, on the other hand, were able to maintain a steady release of plant-available P from continuing dissolution during the growing season. Perhaps one of the key findings from the National Project has been the superior performances of RPR-based products on these high rainfall, leaching soils in Western Australia, South Australia and Tasmania.

How long will it take for RPRs to work ?
New Zealand field research indicates that RPR dissolution is a continuing process over time and that it

might take up to three to four years for it to dissolve completely if soil conditions are suitable (Quin *et al.*, 1987). A useful rule of thumb for a three year dissolution time-frame, would be that a third of the RPR would dissolve in the first year, another third in the second year and then the final third in year three. These rates would depend on existing soil and climatic conditions. If a producer, who is applying annual fertiliser, decides to switch from a WSP fertiliser to an RPR form he/she might experience a fall in pasture production in the first year after switching fertilisers, as only a portion of the P applied as RPR is released into the soil solution. This would be the case if pasture productivity was being restricted by low P supply. This loss will be less in the second year, because the P supply will be increased by the dissolution of the RPR from the current application together with that from the previous year's application. By the third year the cumulative effect of the continuing dissolution of three successive applications of RPR means that the P supply should be equivalent to that from a regularly applied WSP fertiliser such as superphosphate. The time delay before the annual RPR fertiliser strategy results in equivalent pasture production to that from annual WSP additions is known as the "lag phase". This lag phase is illustrated in Figure 2.

Thus, in the early years of a strategy of changing from a WSP fertiliser to RPR, a yield reduction may occur. The duration of the lag phase and the severity of the production loss before equivalence in response is reached will have a vital role on the economics of RPR use. Balanced against this potential production loss will be the cost savings associated with the RPR. The National RPR Project aims to define the duration of this lag phase for different permanent pasture environments across Australia. It is too early yet in the Project to make definitive comments about different lag phases, apart from saying that the lag phase at the majority of sites would appear to be at least three years in duration.
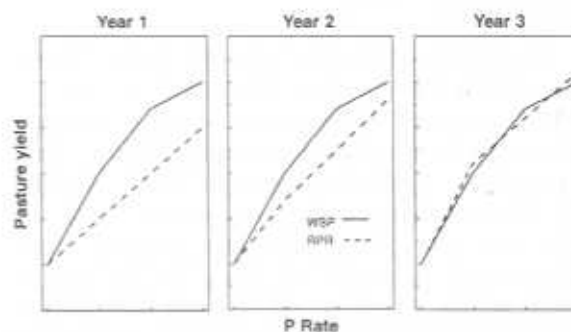

Figure 2. Schematic representation of pasture response curves for a three year lag phase, before annual applications of RPR produce similar yield responses to those from a WSP fertiliser.

A more positive aspect of this lag phase phenomenon is that if fertiliser topdressing was stopped after many years of applying RPR, the suggestion is that the continuing dissolution of successive recent applications should maintain pasture production longer with RPR, than would be the case if a WSP source had been used (Ledgard and Jones, 1990). This needs to be clearly demonstrated by field research.

Does S need to be added, and what will be the effect on cost savings ?

Sulphur (S) does need to be added with RPR - sooner or later - because RPRs do not contain any appreciable amounts of S. It may be that pastures will not respond to added S if they have been receiving regular maintenance applications of single superphosphate (Sale, 1986). However, the reality is that pasture plants require almost as much S as they do P, and that inevitable losses of S occur from a grazed pasture system. So there will always be the eventual risk of S deficiency for producers who switch from annual single superphosphate to annual RPR (minus S) applications. For example, with the four experimental sites in Tablelands NSW within the National RPR Project, two responded to S in the first growing season, and all four responded to S by the second season. The attitude among producers and agronomists is to take the view that *S needs to be added with the RPR*, perhaps at a lower rate than exists in single superphosphate. The problem is that adding S is expensive, so the magnitude of any cost savings associated with RPRs is reduced when S is added to the RPR. For example, the cost savings per unit of P (over than for WSP) of around 29% with an RPR ex-Portland in Victoria is reduced to around 20% when elemental S is added to the RPR to produce a P:S ratio of around 1.2:1.

There are two forms of S that are currently being added to RPR. The first is gypsum which is a low analysis form of S (23% S). Adding gypsum will provide a readily-available S source but the P concentration of the fertiliser will be less, resulting in higher freight and spreading costs. Also it is important that the gypsum is well mixed with the RPR and that suppliers do not take too many short-cuts with the mixing process.

The second form of S that is being added to RPR is elemental S which is a high analysis (100% S) form. The advantage with elemental S is that the P concentration in the RPR/S mixture is not greatly reduced because of the high analysis of the elemental S. However elemental S must be in a finely ground form to be agronomically effective. Research findings (McCaskill and Blair, 1989) suggest that a sizeable proportion of the elemental S must be very fine (less than 0.15 mm in diameter). This will oxidise to plant available S in the first season, while larger particles will take longer to oxidise and become available. Research is required to determine what proportion should be less than 0.15 mm in diameter, and what the particle size configuration of the remaining portion should be. Any producer who purchases RPR/elemental S mixtures should ensure that the elemental S is fine enough and that the elemental S is evenly mixed with the RPR as it is spread over the surface of the paddock.

Sulphur is the vital issue with any decision on RPR. Such decisions will depend on the extent that S can be added in an agronomically effective form to RPR, without an excessive erosion of the RPR cost savings. This will determine how much RPR will be used in this country. We need to know what the required P:S ratio should be. Suggestions from New Zealand indicate that the P:S ratio in SSP (1:1.2) is supplying more S than is necessary. It may be that P:S ratios as high as 2:1, where twice as much P as S is being supplied, are closer to the optimum because S tends to be recycled more efficiently in a grazed pasture than P. Further research is required to determine what the ratio should be. If this high P:S ratio is effective then the cost penalties associated with adding S to RPR will be less.

Are there extra costs in spreading RPR ?

The dissolution of phosphate rocks is a surface reaction that occurs at the surface of the particle. It is necessary that the particles of RPR are sufficiently fine so that there is an adequate surface area of PR exposed to the soil, as this will result in an adequate rate of P release from the PR. The bottom line is that RPR particles are small, resulting in the material having a consistency of a medium-fine sand. Such material does not spread well with a ground spreader. Whereas the mixed particles of SSP might cover a swath width of 25 m, the swath width for an even distribution of RPR that will avoid 'banding' would be considerably less. This means that spreading contractors might charge more to spread RPR than the better granulated WSP fertilisers. Experience in Victoria has shown that some ground-spreading contractors do, and some do not, charge more to spread RPR than to spread SSP.

The situation with aerial topdressing is less of a problem, as the finer RPR particles tend to spread effectively as they fall from the plane. New Zealand experience suggests that there would be no major cost penalty with RPR, compared with the WSP fertilisers, if aeroplanes were used to apply the fertilisers.

Does RPR have a liming effect ?

The dissolution of RPR consumes some soil acidity. The acidic H^+ ions in the soil solution react spontaneously with the anions produced at the dissolving

surface of the RPR particle. However, because RPR is only applied at low rates (in the order of say 10-20 kg P/ha), and the fact that soil acid is only consumed as the RPR dissolves (which might take a number of years to complete), the impact on soil pH would be expected to be minimal.

Calculations reveal that the rate of annual acidification for an annual pasture in N.E. Victoria might be in the vicinity of 80 to 100 kg of lime equivalents (Ridley, 1990). That is, 80 to 100 kg of lime would be required to neutralise the acid produced each year in the pasture soil. Were the landowner to apply 10 kg P/ha as RPR, then the soil acid consumed by the complete dissolution of this fertilizer would amount to around 40 kg of lime equivalents per ha (M. McLaughlin, *pers. comm.*). By introducing acid-tolerant perennial grasses, which might reduce acidification rates by say 20 to 40 kg lime equivalents per ha, and by using RPR fertilisers, the producer could go a long way towards minimising the acidification rate in that pasture soil. However if the RPR is spread with elemental S, then the gains from the consumption of soil acidity by RPR dissolution will be substantially offset by the acid production from the oxidation of elemental S to the plant-available sulphate form.

It is misleading to say that RPR has a "liming" action. This suggests that RPR acts like lime such that when you add it to the soil it will reduce soil acidity and increase the soil pH. Producers would not be adding the high rates of RPR (tonnes/ha) necessary to increase soil pH, because it is too expensive, and furthermore it is likely that large applications would require considerable time to dissolve. Perhaps the more appropriate term is the "lime-saving" effect of regular applications of RPR, which consume soil acid as they dissolve over time, and thereby reduce the rate of acidification that might be occurring in the pasture soil.

Future use of RPRs on high rainfall pastures in Australia

The two key fundamentals in the RPR equation are:

- the *duration of the lag phase*; and,

- the *relative costs*, between RPRs and the WSP fertilisers, for each unit of effective P applied on a pasture with adequate amounts of effective S.

It remains to be seen how long the lag phase will be on our acidic (soil pH_{CaCl_2} less than 4.5), higher rainfall (greater than 600 mm) pasture soils in southern and eastern Australia. Already there are indications that it could be only two years for some very acidic soils in the south. On leaching soils such as the acidic, peaty sands and on the acidic soils of the very wet tropical coast of north Queensland, there will be no lag phase. So it is fair to say that there will be quite a large area of high rainfall Australia where RPRs will be effective P fertilisers for permanent pastures without a lengthy lag phase.

The relative costs of RPRs and WSPs look promising from the RPR perspective. A comparison of the per unit P savings for straight RPR at Australian ports indicates cost savings of between 22% to 37%. These savings are based on small (part-shipload) consignments of RPR being shipped to Australian ports. A full shipload of RPR should be cheaper than part shiploads. So again it comes down to the question of S. There are major advantages in adding finely-ground elemental S to the RPR in order to maintain a high P concentration in the RPR+S fertiliser. Given that elemental S really is quite cheap in the US - huge reserves are located beside natural gas processing sites, resulting in low prices of around $US 40 per tonne at those sites (J. Glendinning, *pers. comm.*) - it should be possible to add this form of S to the RPR cost-effectively. It is true that finely-ground elemental S can be explosive, so there are some technical difficulties. Given that these can be overcome, then cost savings at Australian ports in the order of 20% plus, per unit of P in an RPR+S product, over that for WSP sources, might be achievable. Cost savings of 20% did exist in April 1994 in Portland, Victoria, although the fineness of the elemental S that was being added to the RPR was not given. Additional costs in spreading this material should be compensated for by the savings in the cost of freight to the farm.

The prospect of cost savings of around 20% per unit of applied P for pasture country with a lag phase of 2-3 years, must be an attractive proposition. For this to happen there must adequate competition in the market place. Such competition will develop if there is sufficient demand.

The PAPR option

Fertilisers that contain some undissolved RPR (slow-releasing P) and some water soluble P (rapidly-releasing P) are now on the market. In many cases these products also contain some rapidly-releasing S in the sulphate form, and some slowly-oxidising elemental S. They are therefore particularly suitable for use in leaching environments. They commonly are made by mixing WSP forms with RPR and adding extra S. They can also be made by adding insufficient acid to fully acidulate the RPR, resulting in only a portion of the RPR being converted to water soluble P. This gives rise to the name of partially acidulated phosphate rock (PAPR). Generally the per unit cost of P in these PAPR formulations is more expensive that in WSP fertilisers. For example in Portland, Victoria, the cost
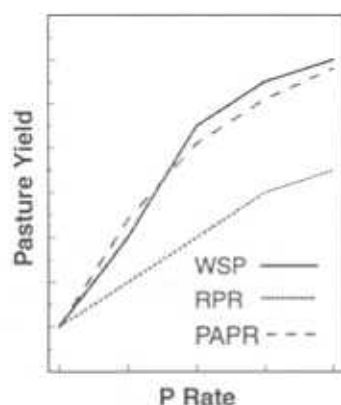
Figure 3. Schematic representation of pasture yield responses to added WSP, PAPR and RPR fertilizers at Category II sites in the National RPR Project during the first two growing seasons.

of P in a PAPR marketed as Pro-long/SR-15 is about 9% more expensive than that in SSP. Similarly in Goulburn NSW, the per unit cost of P in Greenleaf Longlife (a PAPR) is about 21% more expensive than Greenleaf SSP.

One of the interesting observations from the early results of the National RPR Project was the finding that the PAPR, produced by the 50% acidulation of an RPR (half the sulphuric acid, required for complete conversion of the P to WSP) performed exceptionally well. At practically all of the category II sites in the first two growing seasons, where the WSP fertilisers were clearly superior in performance to the RPRs, the PAPR resulted in similar yield responses to the WSP product (Figure 3). Thus there are no short-term yield penalties involved when a producer changes from a WSP to a PAPR fertiliser.

So, under what conditions might PAPR-type fertilisers be used for topdressing pastures in the future? Perceived advantages are that:

1. they are generally equivalent in agronomic effectiveness to WSP fertilisers under non-leaching conditions, yet superior under leaching regimes, especially if they contain elemental S;

2. they have similar granulation properties to the superphosphates, so they do not experience the ground spreading difficulties of the RPRs;

3. there is scope to adjust both the P:S ratio of the fertiliser and the amount of added elemental S (which would depend on the leaching conditions that will be encountered);

4. they generally have a higher P concentration than that in SSP with possible freight and spreading savings; and,

5. the presence of the slow-releasing RPR compo-

nent might increase the residual effect of the added P over time. It seems that there are a number of advantages with the PAPR, so its future use in non-leaching environments will depend on price. To date there is no price advantage in favour of PAPRs in Australia.

In New Zealand, the PAPR-type products, with a P:S ratio of 1 to 1 are generally around 10% cheaper than single superphosphate which has a P:S ratio of 1 to 1.2. If less S is added with the P then there is an opportunity to supply cheaper P. This is also fundamental to the PAPR option.

Conclusions

The evaluation of the RPRs and PAPR is now occurring at pasture sites across the higher rainfall regions of Australia and information is coming to hand as to where these fertilisers may become cost-effective alternatives to the superphosphates. The first question is whether RPR will be effective as a P fertiliser and how long it will take for this to happen. A relatively high rainfall and an acidic soil both appear to be important here. Then the question becomes one of cost - whether the extra costs associated with adding sulphur (and perhaps topdressing) are significantly less than the savings from the cheaper unit cost of P and cheaper freight costs to the farm. PAPR-type fertilisers appear to have definite advantages but their use will again depend on price considerations.

Producers should not yet embark on the widespread use of RPR products until the current National RPR Project has been completed. We need to be able to predict what the duration of the lag phase will be for different pasture environments. Other questions relate to the effectiveness of autumn-applied RPRs in increasing winter growth rates of pastures, and their effectiveness as a P source for heavily grazed, higher input pastures.

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