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Jottings on RPR (BAP)

The following notes are points extracted from over 500 pages of documents on RPR from a variety of sources. The intention is to provide talking points and demonstrate that there is a large body of international science and research on RPR. The notes are by no means exhaustive, however the notes demonstrate that RPR is a valid alternative to soluble phosphate most often in the form of Single Superphosphate (SSP) across a range of conditions.

ASSESSMENT OF SOIL PHOSPHORUS STATUS AND MANAGEMENT OF PHOSPHATIC FERTILISERS TO OPTIMISE CROP PRODUCTION – INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA (2002)

- Phosphorus (P) is an essential plant nutrient, and its deficiency in soils severely restricts crop yields. Tropical and subtropical soils are predominantly acidic and often extremely deficient in phosphorus. Moreover most of these soils possess a high phosphate sorption capacity. Strongly sorbed or fixed phosphate is unavailable for plant uptake. Therefore, substantial P inputs are required for optimum plant growth and adequate food and fibre production.
- Under certain soil and climatic conditions, direct application of phosphate rocks (PRs) is an agronomically and economically sound alternative to the use of expensive superphosphates
- It is well known that the phosphate rocks (PR) show different reactivity as a result of their extremely variable chemical and mineralogical composition. In addition to P, they also contain a wide range of chemical elements, some of which are beneficial (nutrient supply), while others have long term harmful effects.
- There is no single soil P test that can be universally used to estimate available P in soils amended with PR and water-soluble P fertilizers.
- In the short term, Cd availability to plants grown on soils amended with PR is lower than in soils amended with fertilizer products formed from PR acidulation. A continual application of reactive PRs to pastures in Australia resulted in fluoride accumulation in the top-layer of the soil, although the herbage F concentrations were not affected by fertilizer type or soil/site factors
- The relative agronomic effectiveness (RAE) was measured in terms of 4 response (dry matter, total P uptake or P derived from the fertilizer) with a standard fertilizer for comparison, usually triple superphosphate. The RAE of natural PR and modified PR products depends on the rate of P applied and crop species. Phosphate rocks were found to be more effective with crops having a long growth cycle, or subsequent crops of a rotation, nitrogen fixing crops, and crops with root systems that can release/exudate organic acids such as canola, lupin, etc.
- Greenhouse experiments were carried out with different soils, crops and P fertilizer treatments to evaluate the efficiency of locally available P fertilizer sources. No significant differences in the efficiency of superphosphate and reactive, finely-ground PR sources were found in acid soils, mostly Spodosols. In some countries, field experiments were either established or continued (long term trials) to compare different sources of P. Results similar to the greenhouse experiments were found.

STANDARD CHARACTERIZATION OF PHOSPHATE ROCK SAMPLES FROM THE FAO/IAEA PHOSPHATE PROJECT

- Phosphate rocks (PR) are phosphate-bearing minerals that vary widely in their inherent characteristics and consequently their agronomic potential
- A proper characterization of phosphate rock samples should provide the maximum of basic information that can be obtained in a cost-effective manner in normal chemical laboratories. Based on the results of this characterization, the following determinations are recommended: a description of the sample, major elemental (total P, Ca, Mg) composition, solubility in conventional reagents (neutral ammonium citrate, citric and formic acid) and particle size analysis.
- The unit cell is a dimension that is indicative of the degree of carbonate substitution for phosphate, decreasing as the mole ratio of CO3/PO4 increases. Thus, the axis is a key factor determining the chemical reactivity of the PR containing carbonate apatite
- The data on calculated indices of absolute solubility using the "a axis" of PR show that the most reactive PR products were Trinidad de Guedes from Cuba, followed by Algeria, Morocco 2, Tunisia 3, Tanzania, and Chile.
- In all segments of this series of analysis Algerian PR gave results that within the top 3% of the samples analysed.

EFFECT OF ACIDULATION OF HIGH CADMIUM CONTAINING PHOSPHATE ROCKS ON CADMIUM UPTAKE BY UPLAND RICE [USA]

- Potential cadmium (Cd) uptake by food crops from applied phosphate (P) fertilizers has become an important environmental issue because of the potential health hazards to human life from consuming foods that may contain a significant amount of Cd.
- Little information is available in the literature on Cd uptake by crops from either PR or partially acidulated PR (PAPR).
- Concentration of Cd in rice straw was higher with NC-PR than that with Togo-PR in Hiwassee soil. It should be pointed out that potential Cd toxicity to human health from Cd-contaminated food crops is based on Cd concentration in edible parts of crops rather than on total Cd uptake by crops. The experiment showed that both highly reactive NC-PR and low reactive Togo-PR resulted in the same quality of rice grains in terms of Cd contamination with respect to human health.

EFFECTIVENESS OF NORTH CAROLINA PHOSPHATE ROCK AND FERTILIZER TABLETS IN RECLAIMING DISTURBED LAND IN COPPER BASIN, TENNESSEE, USA

- Open smelting of copper ore about 100 years ago resulted in approximately 9,300 ha of disturbed land with severely eroded acidic soils at Copper Basin, Tennessee, USA. A field study was initiated in 1992 to compare revegetation from surface application of North Carolina phosphate rock (PR) and triple superphosphate (TSP)
- After 96 and 240 d, there was no difference between PR and TSP with respect to growth of loblolly pine. After 960 days, PR caused greater tree growth compared to TSP.
- Decreased soil acidity, increased growth of loblolly pines, and increased diversity of ground cover vegetation from PR application makes PR a suitable material for reclaiming extremely acidic soils.
- Legumes produce an acidic rhizosphere, which makes them well suited to utilize P in PR. The greater growth of legumes in the PR treatments was probably due to the acidic rhizosphere having a greater ability to solubilise apatite in PR compared to aluminium phosphates formed in soil with application

of TSP. Use of PR improved vegetative diversity of ground cover species by increasing legume growth. Since legumes can fix atmospheric nitrogen, the improved legume growth from PR addition has important long-term consequences for the developing ecosystem.

- Although PR may not increase pH greatly, the slight amount it does increase pH may be enough to reduce Al toxicity at very low soil pH levels.
- Use of PR in reclaiming extremely acidic soils provides several benefits that water-soluble P fertilizers cannot supply. Phosphate rock improves the growth of legumes due to the acidic rhizosphere of legumes solubilising apatite in PR and releasing P. Better legume growth in turn enhances the overall sustainability of vegetative growth due to the N input into the ecosystem via atmospheric N fixation. Phosphate rock also decreases soil acidity as observed with increases in soil pH and decreases in soluble Al. This is also confirmed by the increase in the molar ratio of Ca:Al in 0.01-M SrCl2 extracts with increased PR addition

AVAILABILITY OF P FROM PHOSPHATE ROCK, THERMOPHOSPHATE AND TRIPLE SUPERPHOSPHATE AFTER DIFFERENT INCUBATION PERIODS – BRAZIL

- The fastest way to reach the goal of high food production is by supplying adequate nutrients for maximizing plant growth and increasing yields. Supplying adequate phosphorus is problematic, not only for its low content in the soil, but also for its complex dynamics in the soil. Research carried out using ^{32}P labelled superphosphate showed that utilization efficiency of applied soluble P fertilizer to the soil is less than 10% in an annual crop, the rest being fixed in several forms of inorganic P

PLANT-AVAILABILITY AND FATE OF P FROM APPLIED PHOSPHATIC FERTILIZERS IN TWO LATOSOLS – BRAZIL

- Phosphate ions released by dissolution of soluble P fertilizers added to the soil do not remain stable. They are converted into less soluble forms through a series of reactions with the soil components. This phenomenon is known as P retention or fixation. P retention is the process by which phosphate ions react with aluminium, iron and calcium ions of soil solution resulting in new phases in the system. These reactions take place in two stages. The first stage is the surface adsorption that is rapid occurring in a matter of minutes or hours. The second stage is slower and involves the migration of P to subsurface layers of adsorbed P, resulting in its occlusion
- The complex dynamics of soil phosphorus fixation processes results in a reduction of the P fertilizer utilization by the plants. Therefore, knowledge of soil phosphate transformations is fundamental for establishing rational criteria and better management of phosphate fertilization
- Fertilizer P was recovered mostly as aluminium and iron bounded P. The contribution of other P fractions such as Ca bound P, Al and Fe occluded P, and water-soluble or weekly soluble P were very small. These results could be attributed to the predominance of iron and aluminium oxides with high affinity for phosphate ions in … acid soils.
- No significant differences in dry matter yield and P uptake of corn were found for the fluid and solid P fertilizer sources studied.

PHOSPHATE FERTILIZERS WITH VARYING WATER-SOLUBILITIES APPLIED TO AMAZONIAN SOILS: AGRONOMIC EFFICIENCY OF P SOURCES

- The effects of P fertilization on successive crops are well known; usually water-soluble P sources provide better results in the first crop and reduced residual effect with time whereas the reverse occurs with less soluble P sources with higher residual effects in subsequent crops compared with P soluble sources.
- For the first crop (cowpea), the best results for dry matter yield and P uptake were obtained with TSP application. For the second crop (rice), no differences among the sources were found.

EVALUATION OF PHOSPHORUS UPTAKE FROM MINJINGU PHOSPHATE ROCK, GROWTH AND NODULATION OF AGROFORESTRY TREE SPECIES ON AN ACID SOIL FROM KENYA

- A series of studies were carried out to study the effect of P application on fast growing multi-purpose trees.
- The relative availability of Minjingu phosphate rock (MPR) at 3 months after transplanting showed that *L. leucocephala* and *G. sepium* derived 2.93 and 1.06 times more P from Minjingu PR than from TSP respectively.
- In this work it was clearly established that MPR was as readily available as TSP to tree seedlings growing in the acid soils of Kenya. It was also shown that patterns of utilization of P differ between the tree species studied.
- The high efficiency of Minjingu PR in P tree seedling nutrition when compared to TSP in several instances shows that Minjingu PR can be used as substitute to TSP in nursery potting media preparation as well as a cheap source of P for faster establishment of agroforestry tree species

APPLICATIONS OF ISOTOPE TECHNIQUES FOR THE ASSESSMENT OF SOIL PHOSPHORUS STATUS AND EVALUATION OF ROCK PHOSPHATES AS PHOSPHORUS SOURCES FOR PLANTS IN SUBTROPICAL CHINA

- With long-term application of phosphate fertilizers in southern China, P has accumulated in some soils and the effectiveness of P fertilizers has decreased accordingly. With this new situation, fertilizer formulae that provide some soluble phosphorus for immediate use by the plant and some slowly released P that sustains a long-term supply would be ideal for maintaining soil P fertility. Apparently, rock phosphate-based fertilizers can satisfy this requirement.
- Chien et al. demonstrated in pot experiments that there existed a positive interaction between rock phosphate and soluble phosphate in promoting plant uptake of phosphorus.

FIELD ASSESSMENT OF THE RELATIVE AGRONOMIC EFFECTIVENESS OF PHOSPHATE ROCK MATERIALS IN A SOYBEAN — MAIZE CROP ROTATION USING ^{32}P ISOTOPE TECHNIQUES [THAILAND]

- Grain yield of soybean variety Nakorn Sawan 1 in the second year (1996) was higher than in the first year (1995). There was no response of P from TSP in terms of grain yield. North Carolina phosphate rock had a very good agronomic effectiveness for soybean.
- Yield of maize variety Suwas 3504 (hybrid) in the second year was lower than in the first year (1995). The %Pdff did not have any change from the first year in both flowering and maturity stages. The fertilizer phosphorus utilization (%FPU) in both stages was higher than in the first year. Algerian phosphate rock showed the highest %RAE among all represented phosphate rocks.

DIRECT USE OF PHOSPHATE ROCK TO IMPROVE CROP PRODUCTION IN INDONESIA

- According to Hammond et al, the direct application of phosphate rock (PR) may be more cost effective than the use of water-soluble phosphate fertilizer such as SSP (single superphosphate) or TSP (triple superphosphate). An additional benefit of PR is its residual effect, which could improve the status of soil P. It is also reported that PR was significantly superior to SSP in building the residual P status in certain soils.
- In pot experiments, PR application did not show significant crop yield increases. In the field experiments, PR applied at high rates had the same effectiveness as TSP to increase crop yield. The residual effect of PR applied from 2 previous crops was clearly shown for the third crop

EFFECT OF FERTILIZER TYPE ON CADMIUM AND FLUORINE CONCENTRATIONS IN CLOVER HERBAGE [AUSTRALIA]

- There were no significant differences between F in herbage from plots fertilized with single superphosphate, partially acidulated phosphate rock or North Carolina phosphate rock, or between sites. Concentrations of F in herbage were low, generally less than 10 mg F /kg.
- However, there were large differences in Cd concentrations in herbage between sites, while differences between fertilizer treatments were small in comparison.
- The treatments sampled represented the upper end of the fertilizer rates commonly used by most grazers (up to 8 times maintenance), yet only small differences in Cd concentrations in clover herbage resulted. Hence it can be concluded that a switch from SSP, containing approximately 150 mg Cd/kg P, to NCPR or PAPR (which contain twice this Cd concentration), will only have a small impact on clover Cd concentrations in the short and medium term. In the long-term however, the higher Cd fertilizers will obviously allow Cd concentrations in soil to increase more rapidly with time with an associated greater risk of increasing Cd concentrations in the herbage and in grazing animals.

THE EFFECT OF ROCK PHOSPHATES ON THE CONTENT OF MINERAL PHOSPHATE FORMS IN SOD-PODZOLIC SOILS [RUSSIA]

- Thirty days after phosphate rock application to soil, up to 59.2% of all phosphates were in the form of sparingly soluble Ca phosphates. After 200 days, only 36.5% of local RP remained in the original form. The process of P conversion from RP was accompanied by the formation of Ca, Mg, Fe, and Al phosphates
- When a phosphate fertilizer is applied to a soil, fertilizer phosphorus is converted to different chemical compounds unequally available to plants, which significantly influence the effectiveness of phosphorus fertilizers. The most available form of P to plants in acid soils is Ca phosphate followed by Al phosphates and to a lesser extent Fe phosphates

EVALUATION OF THE AGRONOMIC EFFECTIVENESS OF ROCK PHOSPHATES FROM THE POLPINO DEPOSIT IN THE RUSSIAN FEDERATION AND THEIR POTENTIAL TO REDUCE ^{137}CS ACCUMULATION IN PLANTS

- The uptake of P by plants was increased with the increase in the rates of the fertilizers applied, but the percent of P fertilizer utilization decreased. The amount of P used by plants from fertilizers depended on the type and rates of P fertilizers. With the increase in SSP rates from 21.8 to 87.2 mg/kg soil, the P utilisation of SSP by plants decreased from 32.6 to 21.9%. For the local Polpino RP, the decrease was less pronounced, from 14 to 10.4%
- At a rate of 21.8 mg P/kg soil, the differences in ^{137}Cs accumulation between grain and straw were insignificant compared to the control.

CONDITIONS PROMOTING AND RESTRAINING AGRONOMIC EFFECTIVENESS OF WATER-INSOLUBLE PHOSPHATE SOURCES, IN PARTICULAR PHOSPHATE ROCK [ROMANIA]

- In all … aspects the authors have arrived at sound conclusions and recommendations of practical interest, which certainly may support the use of reactive PR as sources of P for field crops on about one-third of the arable land in Romania.

LIMING EFFECT ON P AVAILABILITY FROM MAARDU PHOSPHATE ROCK [LITHUANIA]

- Field experiments with fodder beets and barley were carried out to evaluate the P availability of granulated superphosphate and Maardu phosphate rock. The comparison was made at three acidity levels: a) unlimed acid soil with a high content of Al (pH 4.3-4.4, b) soil limed with 0.5n rate $CaCO_3$ powder limestone based on hydrolytic acidity, and c) soil limed with 1.0n rate $CaCO_3$.
- In the unlimed soil the yield (of fodder beet) was low, the effect of superphosphate was better than that of phosphate rock. A good fodder beet yield of 32 to 35 t/ha was obtained and the effect of phosphate rock was better than that of superphosphate at 0.5n $CaCO_3$) rate. When liming with at the high rate (1.0n $CaCO_3$ rate according to hydrolytic acidity) the action of phosphate rock declined, and a better yield was obtained with superphosphate.
- Although yield differences due to different phosphorus fertilizers were small, a significant yield increase through phosphate rock application was obtained in the soil limed with a 0.5n $CaCO_3$ rate, as compared with superphosphate
- No significant effects on the chemical indicators of fodder beets and spring barley were found between plants fertilized with phosphate rock and superphosphate.

LONG TERM FIELD EVALUATION OF PHOSPHATE ROCK AND SUPERPHOSPHATE IN ACID SOILS OF HUNGARY: INCUBATION AND POT EXPERIMENTS

- A series of experiments was conducted to compare the agronomic effectiveness of phosphate rock (from Algeria) and of single superphosphate (from Russia, Kola)
- Initial soil pH decreased on average by 0.5 units in the superphosphate treatments. Phosphate rock slightly increased the pH of the slightly acidic chernozem brown forest soil. The increase in the moderately acidic pseudogley brown forest soil was greater, but no ”liming effect” could be observed.
- On the average of incubation and P forms, the highest P treatment increased the P concentration of winter rape significantly in comparison to the lowest P dose.

SUPER, RPR AND LIQUIDS – OBSERVATIONS ON 40 YEARS OF SCIENCE AND SEMANTICS, ZEALOTRY AND BIGOTRY, REGULATION Vs DEREGULATION, CONS OR COMMERCE, FACT OR MYTH, INTERPRETATION OR MISINTERPRETATION – Bert Quin [NZ]

- The author tried to immerse himself in the MAF"s soil fertility philosophy. Tried but mostly failed. The author came to the conclusion that some major issues were not even being identified, let alone understood, because they were essentially chemical in nature, not "agronomic", and partly because of an attitude that it "wasn't our job" to get involved in anything that could be seen as questioning the dominance and behaviour of New Zealand's 75-year-old single superphosphate industry.
- During the 1960s, a combination of cost and incentive circumstances, supported by an industry-wide belief that "super is super" led to increasing use of cheap, high Al and Fe, Christmas "B" grade rock for manufacture
- One of the unfortunate side-effects of this lengthy and variable decline in quality was a diminishment in value of fertiliser comparison work by earlier researchers such as John Grigg and Nelson Cullen. To avoid this problem in the "National Series" of RPR vs. superphosphate trials that the author designed with Chris Dyson, and had oversight of from 1981-6, the standard product used for the response curve at each site was TSP (with elemental S) from the USA. Ironically, if commercial super from 1981 had been used, RPR would have looked exceedingly good!
- The greater issue of what benefits – environmental and residual performance in particular –that RPR could potentially bring to NZ pastoral agriculture has been to a large degree hidden in a smokescreen of argument over (a) how many years do they really take to equal the performance of (good quality) superphosphate, and (b) how do you define an RPR anyway?
- RPR vs. SSP comparisons – playing with numbers [RPR National Series]
    - If you look at the full data from all 19 sites, the full data released to Quinphos by order of the Ombudsman … showed that, averaged over all rates of application, RPR produced 3.1% less growth in Year 1 than TSP (compared to 5% for the no P controls), 1.4% less in Year 2, 1.1% more year 3, 0.7% less in year 4, 1.0% more in year 5 and 2.7% more in year 6. In subsequent research, RPR also showed much better residual performance in the years following cessation of P application.
    - However, on the way to scientific publication of the full trial data by staff from what was by now AgResearch, several sites were dropped, for a variety of reasons
    - A classic example of questionable data interpretation is RPR. We now know it offers considerable benefits in terms of reduced P runoff, and stronger residual performance, but many farmers have been scared off being prepared to "risk" trying out by greatly exaggerated short-term agronomic limitations. There is a real need to revisit the data with an open mind, including all data on partially-acidulated products and RPR/soluble P mixes.
    - Finally, there are many, many farmers out there who have been using RPR as their major P input for up to 25 years. It obviously works for them; otherwise they would not still be in business! There is a great deal that could be learned from interviewing these farmers and studying their environment, farm management and production.

RPR REVISITED (1): RESEARCH, RECOMMENDATIONS, PROMOTION AND USE IN NEW ZEALAND - B. F. QUIN and M. ZAMAN

- Reviewing all data from the 'National; Series' Sinclair *et al* demonstrated that overall, RPR was inferior to TSP in Year 1, but attained equivalence with TSP in the third or fourth year of use, and exceeded TSP by year 6

- ***MAF RPR Recommendations for Farmers (Ballard 1991)***
    - Do not use RPR if pH is greater than 6.0 or there is less than 800 mm rain plus irrigation per year.
    - For a rapid increase in soil P status (1–2 years) use a soluble P fertiliser. For a more gradual increase, RPR will be effective.
    - To maintain an adequate soil P status (for the desired stocking rate) if the current P status is more than adequate, either use no P fertiliser or apply a light application of RPR; perhaps half maintenance.
    - Use RPR or superphosphate at full maintenance rates when the soil P status approaches the desired range.
    - If the soil P status is currently in the desired range, use RPR or superphosphate. The RPR may produce slightly less dry matter in the first 1–2 years. This decline is unpredictable but it is likely to be less than the seasonal fluctuations normally experienced in pasture production. After 1–2 years of using RPR, the residual effects of early applications should remove any yield differences between RPR and soluble P fertilisers. The decline in production in the first 1–2 years following a change to RPR is likely to be of practical importance only if stocking rates and pasture utilisation are already near maximum.
    - If RPR has already been used regularly for 3 or more years there is unlikely to be any benefit from returning to superphosphate.
    - Where superphosphate and RPR are equally effective, the choice should be based on considerations such as cost, the need for sulphur, or organic farming practices.
- McBride (1992) reported the results of a 10-year comparison of pasture production with RPR/S and SSP on an irrigated, shallow soil in Canterbury with low P retention. Despite the site being very low fertility to start, having had no fertiliser for many years, and a relatively high pH of 6.0, a modest capital application of 71 kg P/ha was sufficient for production with RPR to equal that of SSP in only 2 years, and thereafter to at least equal it with maintenance applications. This compares to a median annual difference of -2.9% under grazing
- In the last decade, research with RPR has been focused on comparing losses of P in surface run-off from RPR and SSP. RPR has invariably shown significantly lower P runoff losses, particularly as dissolved reactive phosphate (DRP). This provides a real opportunity for both farmers and regional councils in P-sensitive catchments. Farmers in P-sensitive catchments should be given the opportunity to consider changing to RPR as a P run-off mitigation strategy, rather than be subjected to P caps that ignore the form of P being used.

RPR REVISITED (2): LONG-TERM FARMER EXPERIENCE HELPS DEFINE THE ROLE OF RPR IN GRAZED PASTURES [NEW ZEALAND] - M. ZAMAN AND B. F. QUIN

- Given the length of time RPR has been commercially available in New Zealand, and the increasing attention being drawn to the proven lower P run-off losses associated with RPR, it was decided to interview a number of farmers who have continued to use RPR based fertiliser as their predominant (>75% on a P basis) P input long-term.
- Fifty four farms over the whole spread of NZ agriculture were included.
- **Discussion on answers to individual formal questions**
- ***Q.2 "What made you try RPR in the first place?"***
    - This question was posed to throw some light on what were the primary factors influencing a farmer to change the type of fertiliser being used. The answers to this question show a mix of farmer interests, willingness to try something new, concerns with costs and other aspects of their previous fertiliser, environmental awareness and concerns, relationships with company field staff and confidence in their recommendations, and trust in RPR suppliers.
- ***Q.3 "Did you notice any change in pasture production after changing to RPR?"***
    - This question was posed to compare the significance of the small but scientifically proven (at least in mown plot trials) lag-phase with farmer experience. Fully 74% of farmers answered "good from the start", "no change" or "not really any change" to this question. Only 13% noted or implied a small decline initially. This was matched by a similar percentage who noted a steady improvement from the start (relative to previous type of fertiliser used, with no lag-phase), and noted benefits such as higher clover content in the sward, and "hanging on better in hard times". These answers could reflect in part the relatively low year-to-year responses to fertiliser P under maintenance P regimes. Dairy farmers are generally able to assess much smaller changes in production *via* milk production, but the percentage of dairy farmers in the no change bracket was 72%, only slightly less than the 79% of sheep and beef farmers. Likewise, soil P fertility had no obvious effect on the farmer's likelihood of discerning the presence of a lag phase. In the Waikato, which had a lower average Olsen P than Taranaki and a much higher standard deviation, farmers who noted a slight initial decline were less represented than they were in Taranaki, which provided 70% of the total farmers in the survey who noted a lag-phase. This may reflect the higher (and more consistent) P retention in Taranaki farms surveyed (80%, compared to 76% in the Waikato). Quin & Zaman (2012) concluded that the lag-phase was most pronounced on very high (>80%) P retention soils.
- ***Q.4 "Have you noticed any change in stock health?"***
    - This question was asked because of persistent anecdotal comments of improvements in stock health over the past 20 years. Over 25% said yes, and the answers suggest significant benefits are occurring on many farms. The benefits most commonly cited included less bloat on dairy farms, and less diarrhoea on sheep and beef farms. These may reflect less variability in seasonal plant nutrient content with a slow-release source of P.
- ***Q.5 "Are you happy with the use of RPR, and do you intend to keep using it?"***
    - Not surprisingly, given that all farmers interviewed were already long-term users of RPR, all expressed satisfaction, and all except one the intention to keep using it. The only "No" was because of its perceived increasing relative cost in recent years. Many of the comments were highly positive, perhaps not a common finding in farmer surveys of any nature.
- ***Q.6 "Do you know any farmers who have stopped using RPR and why?"***
    - This question was asked in order to get what would possibly be more objective answers than having farmers who had stopped using it, who might feel that they were being targeted for doing this, if asked why. Surprisingly, only 14% of farmers surveyed either knew someone or

had heard of some who had used RPR then stopped. Reasons why some had stopped (as assessed by the farmer-users interviewed) included very low initial soil fertility and subsequent lack of response to RPR, reduction in the original cost advantage of RPR compared to SSP, and stopping all fertiliser application due to drought.

- ***Q.7 "What advice would you give to a farmer interested in switching to RPR"***
    - This question had the same basic motivation as Question 5. It needs to be kept in mind that the farmers in this survey who made the decision to use RPR all did so in a period when the efficacy of RPR in general, the extent of the lag-phase, and the relative performance of different RPRs were the subject of intense debate in the farming press. By far the most common response to this question was "Just give it a go!" (61%) or "Give it time" (20%) or words to that effect. Most added a supportive comment to their answer.
- The results of this survey have indicated that RPR based fertiliser is being continuously and successfully used on pasture across a typical New Zealand range of locations, soil types, soil factors and climates. The study confirms the results of extensive trial work conducted, especially since 1980, showing very similar levels of production to soluble P from the third year of use, and supports indications of a smaller lag-phase under real-life grazing situations, rather than in mown plot conditions.

USE OF PHOSPHATE ROCKS FOR SUSTAINABLE AGRICULTURE – FOOD AND AGRICULTURE ORGANISATION OF THE UNITED NATIONS, ROME [2004]

- Because of their extremely variable and complex chemical composition, PRs are sources of several nutrients other than P. They are usually applied to replenish the soil P status, but upon dissolution they also provide other nutrients present in the PR. Application of medium and highly reactive PRs to highly weathered tropical acid soils has a potential trigger effect on plant growth and crop yields as a result not only of P release but also of their effects on increasing exchangeable calcium (Ca) and reducing Al saturation. The resulting harvest products and residues have a better nutritional quality (higher P content than unfertilized plants). The incorporation of such organic residues enhances biological activity and soil carbon (C) accumulation, leading to improved soil physical and chemical properties. Thus, PRs have an important role in contributing to improving soil fertility and soil degradation control, in particular nutrient mining (depletion).
- Pastoral farming based on ryegrass/white-clover permanent pastures constitutes about 90 percent of agriculture in New Zealand for the production of dairy, sheep, beef and deer products.
- Currently (2004), one kilogram of P in RPR costs US$0.87, whereas it costs US$1.07 as SSP if the soil does not require S. Thus, RPR phosphate is 20 percent cheaper. A promising strategy is to encourage application of RPR with soluble P, which is likely to result in the same level of agronomic effectiveness as the application of soluble P. The savings on using RPR will be less if the value of S in the fertilizers is accounted for. Thus, the cost-effectiveness of RPR relative to soluble fertilizers will depend on the S requirement of soils in addition to environmental and management factors. A specific incentive for RPR use in New Zealand is its permissibility for use in organic farming.
- Research by the International Fertilizer Development Center (IFDC) has shown that the application of medium to highly reactive PRs with low free-carbonate contents can result in significant liming effects on acid soils. Although the increase in pH is generally less than 0.5 units, the decrease in exchangeable Al can be significant where the soil pH is less than 5.5
- Use of phosphate solubilising micro-organisms

- A group of heterotrophic micro-organisms have been reported to solubilise inorganic forms of P. This is achieved by excreting organic acids that dissolve phosphatic minerals and/or chelate cationic partners of the P ion directly, releasing P into solution. Some important micro-organisms include the bacteria *Bacillus megaterium, B. circulans, B. subtilis, B. polymyxa and Pseudomonas straita*. Fungal micro-organisms include *Aspergillus awamori, Penicillum bilaii, P. digitatum and Trichoderma sp*. Analyses of culture filtrates have identified a number of organic acids such as lactic, glycolic, citric, 2-ketogluconic, malic, oxalic, malonic, tartaric and succinic acids, all of which have chelating properties.
- Field trials in India and the then USSR have shown that the use of phosphate solubilising micro-organisms (PSMs) can increase crop yields by up to 70 percent. The crops include oats, mustard, sugar beets, cabbage, tomato, barley, Egyptian clover, maize, potato, red gram, rice, chickpea, soybean and groundnut. In vitro studies have demonstrated the dissolution of PR by PSMs. Results from greenhouse trials have indicated a greater response of wheat and onion to PR application when seeds or seedlings are inoculated with PSMs. The increase in growth is greater with VAM fungi and PSMs in combination than when these organisms are used singly. It is likely that PSMs dissolve sparingly soluble P, which is taken up by VAM mycelia, by more than one process, including the release of organic acids and the solubilisation of calcium phosphates.

- Numerous studies have shown that the agronomic effectiveness of PRs can be improved when they are applied after admixing or co-granulating with sulphur (S).
- The principle behind the use of phosphate rock elemental sulphur assemblages (PR/S) is that the inoculated or native population of soil bacteria oxidizes S to H_2SO_4 when the product is applied to the soil. This acid in turn reacts with the PR particles that are in close proximity to S and forms monocalcium and dicalcium phosphates. Thus, the dissolution of PRs in soil is assisted by localized acidulation, in addition to that caused by ambient soil acidity.
- On long-term crops such as permanent pastures, PR/Ss prepared at a PR:S ratio of 14:1 can be agronomically as effective as superphosphate.
- It is now known that effective PR sources provide not only P for plant growth but that they may also supply secondary nutrients, such as calcium and magnesium, and micronutrients, such as zinc and molybdenum, depending on the chemical and mineralogical composition of PR. Reactive PRs or PRs containing free carbonates (calcite and dolomite) can also raise soil pH to partially reduce aluminium (Al) saturation of acid soils and decrease Al toxicity to plant growth, although their liming effect is generally lower than lime. One environmental issue regarding PR applications has been the potential uptake by plants of elements that are harmful to human health. Limited studies suggest that the uptake of toxic heavy metals, notably Cd, by plants from PR is significantly lower than that from water-soluble P fertilizers produced from the same PR
- In addition to PR reactivity and Cd content, Cd uptake by plants also depends on soil properties, especially soil pH, and crop species.

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