Residual values of Australian rock phosphates

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Residual values of

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For years superphosphate has been the cheapest, convenient and most efficient way of supplying phosphorus to newly cleared soils in Western Australia's South-West that are acutely deficient in phosphorus. However, its effectiveness as a phosphorus source falls markedly after application. Regular applications are needed to maintain profitable pastures and crops on these soils.

After a big jump in superphosphate prices in the mid 1970s, researchers tested the use of Australian rock phosphates as potentially cheaper alternative phosphorus fertilisers to superphosphate. On the non-leaching sands, as this article shows, none of the rock phosphates was as effective for plant growth as superphosphate in the year of application or in subsequent years.

Research is now concentrating on measuring the residual value of fertiliser phosphorus for pastures so that phosphorus fertiliser recommendations can be more finely tuned.

Choosing a fertiliser

Superphosphate is manufactured by adding sulphuric acid to apatite rock phosphates (calcium phosphates). About three million tonnes of superphosphate costing about $300 million are bought in Australia each year, of which about one-third is sold in Western Australia. In the South-West, fertilisers account for about 10 per cent of annual farm costs, and range from 5 to 30 per cent on individual farms.

Before 1974 superphosphate was applied liberally to pastures and crops. Granulated superphosphate is easy to cart, store and spread, and it contains other essential plant nutrients such as calcium, sulphur, zinc and copper. Other plant nutrients such as cobalt, manganese and potassium and extra copper and zinc can be added if needed.

Rock phosphates are more effective fertilisers when finely powdered. After application to the soil surface, the fertiliser should be mixed through the topsoil. Powders, however, are difficult to handle. On farms it may take many years before the powdered fertiliser is evenly mixed through the topsoil.

Australian rock phosphates also contain little sulphur. This and other essential nutrients have to be mixed with the powdered rock phosphate before application, or they must be applied separately.

Fertiliser phosphorus levels

In Western Australia the standard chemical reagents used to analyse phosphorus fertilisers are water (called water-soluble phosphorus), neutral ammonium citrate (citrate-soluble phosphorus) and strong acid (acid-soluble phosphorus). The percentages of each found in Australian rock phosphates are shown in the table.

Water-soluble plus citrate-soluble phosphorus is often labelled as 'available' phosphorus and it is inferred that all this phosphorus is available to plants. However, this can be misleading. Water-soluble phosphorus from fertilisers is highly effective for plant growth, but the effectiveness of citrate-soluble phosphorus varies and depends on the phosphorus compounds involved.

For example, between 50 and 70 per cent of the total phosphorus in Calciphos is citrate-soluble and very little is water-soluble. Similarly most of the phosphorus from dicalcium phosphate is citrate-soluble and only a small fraction is water-soluble. Pot trials have shown that phosphorus from Calciphos is only one-tenth as effective as water-soluble phosphorus from superphosphate, whereas phosphorus from dicalcium phosphate is equally as effective as water-soluble phosphorus from superphosphate.
Measuring fertiliser effectiveness

While plants use a small amount of fertiliser phosphorus in the year of application, some of the remaining or residual phosphorus is available for use in subsequent years. This residual phosphorus comes from the fertiliser granule or powder, from the products resulting from the chemical reactions of fertiliser phosphorus with the soil and, in time, from soil organic matter. Both the initial and residual value of applied fertiliser phosphorus must be considered when determining the costs of these fertilisers.

Although there are several relatively rapid laboratory and glasshouse pot methods to measure the effectiveness of fertiliser phosphorus, they are only a guide to this effectiveness. The best method of measuring the effectiveness of fertiliser phosphorus is to use plants grown in the field.

Soil tests

To calculate the amount of superphosphate to apply on farms each year, the Colwell sodium-bicarbonate soil test method is used in this State to determine the soil's current phosphorus status. Soil samples are collected in summer, and the results are used to help calculate the amount of superphosphate to apply in the next winter growing season for profitable crops and pastures. Various versions of the 'Decide' computer model are used to determine fertiliser advice.

In the trials, bicarbonate-extractable soil phosphorus levels were determined for soil samples collected in summer. When these measurements were related to plant yields obtained in the following spring for a given soil test value, they did not always predict the same yield for the different phosphorus fertilisers. This indicates that separate soil tests are needed for each fertiliser because existing tests would result in large errors.

Earlier research

During the early 1940s and in the 1960s the Department of Agriculture tested the use of rock phosphates as alternative phosphorus fertilisers to superphosphate. Trials in the South-West showed that in the year of application on all but the most acid peaty soils, rock phosphates were inferior to superphosphate as phosphorus fertilisers, and were not as profitable to use. Most of these trials, however, did not measure the longer term or residual effectiveness of phosphorus from rock phosphates compared to superphosphate.

By 1974 most agricultural soils had received large total applications of superphosphate. Rather than continuing to use superphosphate to maintain soil phosphorus levels and profitable plant production, many people argued it might be less costly to use Christmas Island C-grade ore, Calciphos or Queensland rock phosphate. (See 'Rock phosphate sources', page 54.)

Residual phosphorus trials

In 1975 a large field research programme was started on non-leaching soils in the South-West. The aim was to measure the initial and residual
Superphosphate is still one of the cheapest and most convenient forms of phosphorus to apply on farm land.

Superphosphate
Duchess rock phosphate

Phosphorus (g/ha) applied

Subterranean clover yields after the application of superphosphate and Duchess rock phosphate, Mt Barker Research Station, 1977.

• Superphosphate is still one of the cheapest and most convenient forms of phosphorus to apply on farm land.

Effectiveness of phosphorus from Christmas Island C-grade ore, Calciphos, Duchess rock phosphate from Queensland and superphosphate. The research was funded by the Wheat Industries Research Council of Australia and the Department of Agriculture.

The trials were located on old and new land and on both sandy (low phosphorus-fixing) and gravelly (high phosphorus-fixing) soils in Esperance, Newdegate, Mt Barker, Yallingup, Chittering, New Norcia and Wongan Hills.

Pasture and cereal crop yields and the amount of phosphorus extracted from the soil by sodium bicarbonate were used as indicators of fertiliser effectiveness.

Results and discussion

Despite the application of massive amounts of rock phosphates, none supported the same maximum crop and pasture yields as superphosphate (Figure 1).

Superphosphate was the most effective phosphorus fertiliser in the year of application and in subsequent years (Figure 2). If plant yield is measured (Figure 2a), the effectiveness of superphosphate fell markedly by between 30 and 60 per cent, depending on location, from years 1 to 2. In the following years the decrease was more gradual.

Australia’s traditional sources of apatitic rock phosphate are Nauru Island in the Pacific Ocean and Christmas Island in the Indian Ocean. All possess high quality apatite suitable for the manufacture of good quality superphosphate.

However reserves are running out. The apatite reserves on Christmas Island, an Australian territory in which no royalties are paid for the rock phosphate, will be exhausted in about five years, as will be the reserves on Nauru Island. Rock phosphate reserves from another source, Ocean Island in the Pacific, are depleted.

Queensland rock phosphate

Australia has very large deposits of apatite rock phosphate in north-western Queensland. About one-third of the Duchess deposit contains about 13 per cent phosphorus and can be used to manufacture superphosphate. It is called ‘direct shipping’ grade ore because it only needs to be ground for use in manufacturing superphosphate.

The remainder of the Queensland deposits contain only about 7.4 per cent phosphorus. They must be upgraded to about 15.7 per cent phosphorus to manufacture superphosphate. The ground rock is suspended in water and the finer material floating near the surface and containing much more phosphorus is removed.

During the manufacture of phosphatic fertilisers, the apatite is ground. The ore from Nauru, Ocean and Christmas Islands is relatively soft and easy to grind. Queensland rock phosphate, however, contains a form of silica called chert which is very hard.

All Australian fertiliser manufacturers are equipped to handle the soft Island ores, but when this equipment is used to grind Queensland rock phosphate, it is rapidly worn out. The manufacturers can re-equip their plants with appropriate machinery, but it is not yet economical to do so.

Queensland rock phosphate also contains about 3 per cent fluorine, which causes pollution problems during the manufacture of phosphatic fertilisers. This problem can be overcome by using suitable emission controls.

With Australia’s traditional sources of apatite ore fast running out, Queensland rock phosphate is an assured, cheap source of high grade apatite. This is highly important to Australian agriculture. Although world reserves of high quality apatite are large, the big demand for phosphorus fertilisers means these reserves will become increasingly scarce and expensive.
As calculated from yield, the effectiveness of rock phosphates was low and remained fairly constant over time. Christmas Island C-grade ore, Calciphos and Duchess rock phosphate were respectively 3 per cent, 13 per cent and 7 per cent as effective as freshly applied superphosphate.

It is unlikely that these fertilisers will cost only 3 per cent, 13 per cent and 7 per cent of the price of superphosphate. There are also the additional costs of applying the rock phosphates as fine powders, incorporating the powdered fertilisers into the topsoil and the need to apply larger amounts.

None of the rock phosphates studied, therefore, are economical alternative phosphorus fertilisers to superphosphate in the short or long term for non-leaching soils in the South-West. These soils make up the bulk of the agricultural soils in this area.

Both calcium and the phosphate form of phosphorus dissolve together from rock phosphates into the soil solution. Only a fixed amount of these nutrients can remain in soil solution, depending on their solubilities and on their removal by adsorption on to the surfaces of soil constituents, absorption by plant roots, and by leaching. At the same time further calcium and phosphate dissolve from the rock phosphate to replenish the soil solution.

Christmas Island C-grade ore
Christmas Island has two types of rock phosphate deposits. They are apatite rock phosphate (called A-grade ore) which has been mined since the early 1900s for superphosphate manufacture, and a calcium-aluminium phosphate called C-grade ore. This material contains about 11 per cent phosphorus. It also has high levels of iron and aluminium which make it unsuitable for the conventional manufacture of superphosphate.

C-grade ore, which is usually found on top of the A-grade ore, has already been mined and about 150 million tonnes are stockpiled on Christmas Island. It represents a potentially cheap and abundant phosphorus fertiliser for the South-West.

When C-grade ore is heated to about 500°C, the mineralogy of the ore changes and the phosphorus becomes more rapidly available to plants. The product, called Calciphos, has been used in Indonesia as a fertiliser for rubber trees; about 10 000 tonnes being used each year. Little Calciphos has been used elsewhere.

A product called Phospal, which is produced by heating a similar calcium-aluminium rock phosphate from Senegal, is widely used in France as a phosphorus fertiliser for pastures.

Little calcium and phosphate is leached from most South-West soils.
Calcium is usually adsorbed on to cation (positively charged) exchange sites on the surfaces of soil constituents. Most South-West soils have a poor cation exchange capacity and thus remove little calcium from the soil solution. The areas of non-leaching soils also adsorb phosphate, particularly the lateritic soils in the Darling Range and the karri loams near Manjimup and Walpole. These soils have large capacities to adsorb phosphorus.

The absorption of phosphorus by plant roots depends on roots intercepting rock phosphate particles and soil water content because roots cannot absorb nutrients from a dry soil. The mixing of finely powdered rock phosphate through the topsoil improves root interception, and places some of the rock phosphate below the soil surface where moisture helps to dissolve phosphate from the fertiliser and its absorption by plant roots.

Dry spells during the growing season in the South-West, particularly in autumn and spring, can cause dry surface soils which can reduce the rate at which phosphorus is dissolved from rock phosphates. This limits their value as phosphorus fertilisers. It may also restrict the maximum yield achieved for rock phosphate compared with water-soluble phosphorus from freshly applied superphosphate.
Plant yield is the most direct and best method for measuring the residual value of fertilisers. However soil tests are widely used to determine the current value of past superphosphate dressings. This is because farmers' records of past superphosphate applications are often incomplete. A soil test is a rapid and convenient method of determining the current phosphorus status of soils, and forecasting phosphorus requirements.

The standard sodium bicarbonate soil test method used in Western Australia was also used to determine the residual value of the fertilisers applied. For this method, the effectiveness of superphosphate fell more uniformly by 50 to 79 per cent from year 2 to year 7 (Figure 2b). As measured by the soil test, the effectiveness of the rock phosphates relative to superphosphate applied in the first year was always low and similar to values determined using plant yield.

Value of rock phosphates
Research by the Department of Agriculture has demonstrated the advantages of using slow release phosphorus fertilisers on the leaching sands in high rainfall areas of the South-West, both for agriculture and for overcoming pollution problems caused by phosphorus leaching into rivers and estuarine systems.

These soils adsorb little phosphorus. The water-soluble phosphorus from superphosphate granules rapidly moves out into the moist soil and leaches down the soil profile, out of reach of plant roots, and accumulates in drainage systems. This can cause algal pollution problems such as in the Peel-Harvey estuarine system near Mandurah south of Perth.

Slow release fertilisers, such as rock phosphates, are more effective phosphorus fertilisers than superphosphates for these soils because the phosphorus dissolves more slowly in water and maintains a supply near plant roots. Unlike superphosphate, these fertilisers do not release large amounts of phosphorus into the soil shortly after it becomes moist.

A new phosphorus fertiliser called New Coastal Superphosphate, which is less soluble than ordinary superphosphate and contains elemental sulphur, has been produced for use on these leaching soils. Only 28 per cent of its total phosphorus is water-soluble, compared with 75 per cent for ordinary superphosphate.

Effects of cultivation
Cultivation has different effects on the availability of phosphorus from superphosphate or powdered rock phosphate.

If pastures are killed during cultivation before sowing the crop, mixing of previously applied superphosphate through the topsoil usually reduces the effectiveness of the phosphorus for plants. The phosphorus is mixed with more soil and chemically reacts with more of it to form compounds which do not readily release phosphorus to plants.

However cultivation usually increases the effectiveness of powdered rock phosphate, probably because the plant's roots intercept more powder when it is more thoroughly mixed through the soil.

Cultivation also encourages the organic matter near the soil surface to break down more quickly, releasing its phosphorus to be used by plants.

Future research
In the developing countries of Africa, South America and Asia rock phosphates are used as 'direct application' fertilisers. They need only be ground and applied, thus avoiding the costs of setting up factories to manufacture sulphuric acid and superphosphate. However, the physical, chemical and mineralogical properties of rock phosphates vary markedly, as does their effectiveness for plants.

Research in developing countries has concentrated on determining the effectiveness of phosphorus from local rock phosphate deposits to find rock phosphate fertilisers suitable for direct application. In some apatite rock phosphates, carbonate has been substituted for phosphate in the crystal structure. These highly carbonate substituted apatites or reactive apatites have proved to be as effective, or almost as effective, as superphosphate on high phosphorus-fixing, acid tropical soils in high rainfall areas of South America and South-East Asia.

Field trials have started in Western Australia's South-West to determine the effectiveness of these apatites.

The Department of Agriculture and the Department of Soil Science and Plant Nutrition at the School of Agriculture, University of Western Australia have started a joint research programme to measure the residual value of fertiliser phosphorus for pastures.

The aim is to improve the effectiveness of fertiliser advice using the 'Decide' computer model. This joint research project is funded by the Australian Wool Research Trust Fund, the Reserve Bank of Australia and the Department of Agriculture.