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Rock phosphates are poor fertilizers for non-leaching soils in south-western Australia

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Field experiments conducted on our non-leaching soils from 1975 to 1988 have consistently shown that rock phosphates, compared with freshly applied superphosphate each year, are a relatively ineffective fertilizer in the year of application and in the years after application.

Between 3 and 1,000 times as much rock phosphate phosphorus is required to produce the same yield as that from superphosphate phosphorus freshly applied each year. The effectiveness of each addition (that is, each increment) of rock phosphate also decreased as more was applied.

At low levels of application about 3 to 10 times as much rock phosphate phosphorus was needed to produce the same increment in yield as that from freshly applied superphosphate, while 1,000 times as much rock phosphate was required for higher levels of application (Figure 1).

Field experiments have also shown that rock phosphates generally do not support the same maximum yield as freshly applied superphosphate. Thus use of rock phosphate instead of superphosphate may frequently mean forfeiting yield.

Water soluble phosphorus in freshly applied superphosphate only needs moisture to dissolve. Rock phosphates need moisture and react with the soil to dissolve.

Background

There are two types of rock phosphates, both of which contain almost no water-soluble phosphorus.

- Calcium phosphates, mostly apatite rock phosphates, such as those from Nauru and Queensland (Duchess) rock phosphates, which can be used to make fertilizers such as superphosphate and diammonium phosphate (DAP).
- Calcium iron-aluminium rock phosphates, mostly crandallite-millisite rock phosphates, such as the C-grade ore on Christmas Island, which cannot be used to make fertilizers such as superphosphate or DAP, but are heated (calcined) at about 500°C to produce fertilizers, for example, Calciphos from Christmas Island, or Phospal from Senegal in West Africa. Calcining changes the mineralogy of the ore, making the phosphate more readily available to plants.

Plants absorb phosphorus in the water-soluble form through their roots from soil solution. The higher the water-soluble phosphorus content the more effective the phosphorus fertilizers are for plant growth.

High quality apatite rock phosphates can be converted to soluble forms during manufacturing. Strong acid is added to the rock phosphate which converts most of the phosphorus to water-soluble mono-calcium phosphate in superphosphate fertilizers (single or ordinary superphosphates, double superphosphate, triple superphosphate) or to ammonium phosphate in nitrogen-phosphate fertilizers (mono-ammonium phosphate or MAP, diammonium phosphate or DAP).
Phosphate fertilizers are usually drilled with the seed whilst sowing crops or topdressed onto pastures. The water-soluble phosphorus compounds in the fertilizer granules strongly absorb water in or on wet soil and quickly dissolve in the soil water. Once in the soil, these compounds react rapidly with the clay, oxides, silt and organic matter to form compounds that are sparingly water-soluble. Over time these compounds continue to react to form other compounds that are increasingly less soluble in water and which are thus also increasingly less effective for supplying phosphorus to plants for growth.

Rock phosphates as direct application fertilizers

Hydrogen ions (that is, acidity) and wet soil are needed

The water-soluble phosphates present in fertilizers such as superphosphate or DAP dissolve in wet soil regardless of the pH of the soil or how much is applied. Thus provided the soil is wet, the phosphorus will dissolve in both acidic or alkaline soils. However, rock phosphates not only need a wet soil to dissolve in, but also need hydrogen ions (acidity), which are provided by the soil.

Figure 1. Relationship between dry matter yield of Gamenya wheat tops and the amount of superphosphate or rock phosphate (RP) applied measured in the year of application (1977) on 'Neddale' near Neiv Narcia.

To produce 4 t/ha dry matter required about 25 times more phosphorus from Duchess RP than phosphorus from superphosphate and about 35 times more phosphorus from Calciphos. That is, the RPs were only 3 to 4 per cent as effective as superphosphate. Note that the maximum yield for superphosphate was greater than that for either of the RP fertilizers.

Relative to the effectiveness of superphosphate freshly applied each year, the residual value of the RP fertilizers remained approximately constant for up to four years after application in the experiment.

Similar results were obtained for many other field experiments in the south-west.
The quantity of hydrogen ions in a soil is measured by the amount of alkali (for example, sodium hydroxide) required to consume (that is, remove) the hydrogen ions, and is a direct measurement of the ability of the soil to dissolve rock phosphate. Soil pH is an indirect measure of the quantity of hydrogen ions in the soil.

Most soils in the south-west of Western Australia dry out between rains, and do not possess an adequate supply of hydrogen ions to dissolve much rock phosphate. The exceptions are the peaty sandy soils near the west and south coast, that do remain wet, and which possess a large quantity of hydrogen ions. Rock phosphates do dissolve in these soils and are 60 to 80 per cent as effective as superphosphate.

Another example is soils in the tropics. The soils are wet all the time, and they possess a large quantity of hydrogen ions, so that rock phosphates dissolve to a greater extent in these soils. In some cases rock phosphates have been reported to be 80 to 100 per cent as effective as superphosphate in some of these soils.

Hydrogen ions are used up as the rock phosphate dissolves. For it to continue dissolving more hydrogen ions must move towards the rock phosphate particles from adjacent soil constituents.

Rock phosphate fertilizers are not effective on alkaline and calcareous soils because there are not enough hydrogen ions to dissolve them.

Rock phosphates often contain small quantities of free lime as an impurity. The application of a large amount of rock phosphate to soils with low levels of hydrogen ions increases the soil pH because hydrogen ions are removed by the lime. This in turn reduces the amount of rock phosphate which dissolves and may reduce the crop yield produced by rock phosphate compared with that from freshly applied superphosphate.

Other factors

Other factors affect the amount of rock phosphate which dissolves in the soil.

Climate

The soil must remain wet at all times for rock phosphates to dissolve.

Movement of hydrogen ions toward rock phosphate and movement of the dissolved products away from rock phosphate particles

For rock phosphate to dissolve there must be a steady movement of hydrogen ions towards rock phosphate particles in the soil and a corresponding steady movement away from the fertilizer of the dissolved fertilizer constituents. These movements occur most rapidly when the soil is wet to field capacity (that is, the soil is saturated with water).

Fine powders and incorporation in the soil

Rock phosphates are poorly soluble in water so they must be applied as fine powders rather than as granules and thoroughly mixed (incorporated) through the top 10 cm of soil. Applying a fine powder to the soil results in a large number of tiny rock phosphate particles being scattered through the same volume of soil which increases the amount of rock phosphate which dissolves. It does this by:
• Making it easier for hydrogen ions to move toward the fertilizer particles and for the dissolved products to move away from the fertilizer particles; they simply have less distance to move.

• Improving contact between plant roots and water-soluble phosphorus in the soil solution that has dissolved from the fertilizer particles.

• Incorporating the fertilizer at about 10 cm depth in the soil increases the chance that the fertilizer particles remain in wet soil for longer periods of time, because the soil near the surface dries out more rapidly.

Thus, incorporating finely powdered rock phosphate particles through the soil is more effective than topdressing onto the soil surface.

Level of application

Field and laboratory studies have shown that the effectiveness of rock phosphate decreases as more is applied. More of the rock phosphate is dissolved at the lower levels of application and the fertilizer is more effective for supplying phosphorus to plants.

For example, in a field experiment at New Norcia, about 350 kg/ha of phosphorus as Queensland rock phosphate and 20 kg/ha of phosphorus as superphosphate were required to produce 33 per cent of the maximum grain yield of wheat, but 1,190 kg/ha of phosphorus as Queensland rock phosphate and 40 kg/ha of phosphorus as superphosphate were needed to support 66 per cent of the maximum yield.

Thus the relative value of the two fertilizers had changed from 1:18 to 1:30 (superphosphate:rock phosphate) for this increment in yield. The maximum yield produced by rock phosphate is often less than the maximum yield produced by superphosphate. This may be simply caused by the soil not being able to dissolve enough rock phosphate to achieve maximum crop yield.

Previous phosphorus fertilizer history

A history of high levels of phosphorus fertilizer use over many years means that as the soil wets up in autumn, mineralized organic matter and sparingly water-soluble phosphorus compounds derived from the previously applied phosphorus add to concentration of phosphorus in the soil solution. These high concentrations of phosphorus in soil solution may slow down the rate at which freshly applied and previously applied (residual) rock phosphate dissolve and so reduce its effectiveness.
Therefore rock phosphates are not expected to be suitable fertilizers for some ‘old land’ situations. Plants are much more likely to respond to the initially very high concentrations of phosphorus in soil solution provided by water-soluble fertilizers.

Type of rock phosphate

Rock phosphates differ in physical, chemical and mineralogical properties and thus differ in their effectiveness for supplying phosphorus to plants. The most effective rock phosphates are the so called ‘reactive’ apatite rock phosphates, such as North Carolina rock phosphate.

Pattern of release of phosphorus from rock phosphates

Most of the phosphorus that will dissolve from rock phosphates in wet soils does so within a few days. This is a similar pattern to the release of phosphorus from freshly applied superphosphate granules. However, compared with superphosphate, the amount of phosphorus dissolved from rock phosphates is much smaller per unit of fertilizer, and levels of phosphorus in soil solution are much lower for rock phosphates. Thus rock phosphates cannot be regarded as fertilizers that provide a nearly constant rate of release of phosphorus to the soil over time.

In the south-west, agricultural production is achieved largely by growing annual plants in a strongly seasonal environment (that is, a cool, wet winter growing season of five to seven months followed by a hot, dry summer). Water-soluble phosphorus fertilizers are usually applied with the seed of crops or topdressed onto pastures near the start of the growing season. Thus the young germinating seedlings have access to comparatively high concentrations of phosphorus in solution derived from freshly applied superphosphate. This phosphorus is readily taken up by plants, and probably provides them with much of their phosphorus requirements for the rest of the growing season (that is, it is diluted within the plant as it grows).

Rock phosphates also add phosphorus to the soil as soon as the soil is wet near the start of the growing season, but the amount is comparatively small and concentrations of phosphorus in soil solution much lower. Therefore the plants may not obtain enough phosphorus for maximum growth during the early growth stages and this may limit yield later on in the season. This may be one of the reasons why rock phosphates do not support the same maximum yield as freshly applied superphosphate.

Cost

The cost per unit of phosphate supplied from rock phosphate or superphosphate is about the same, but the cost of applied rock phosphates would need to be about one-fifth that of superphosphate for it to be an effective substitute. In Western Australia in 1989, each unit of phosphorus in superphosphate cost about $16 per tonne, compared with about $12 per tonne for ground rock phosphate so that there is no economical advantage in using rock phosphate instead of superphosphate for most broadscale agriculture in south-western Australia.

Acknowledgements


References


Further reading