Phosphorus

A whole of soil approach

Traditional agricultural phosphorus management has relied on soluble fertilisers such as superphosphate and Diammonium phosphate to supply P to crops and pastures. Although this has meant high yielding crop systems, it is an inefficient way to use P in the longer term due to much being locked up. The rising price of phosphate combined with the increasing soil quality issues that occur under conventional management means that a new approach to phosphorus use needs to be considered.

The goal of phosphorus management

The key outcome of using fertilisers to add phosphorus (P) to soils is to ensure that crops and pastures have an adequate supply of readily available P for growth. Insufficient levels of P will reduce yield potential in all crops.

P is not a very mobile nutrient and is taken up by plants in the soluble phosphate form. Therefore the key is to ensure that adequate levels of soluble P will be available in the soil solution at all times during the growing period. As P is cycled through different pools in the soil and as different soils cycle differently to each other depending on many factors, it is important to look at the whole soil system when managing P fertility.

The forms of P in the farm ecosystem

Phosphorus occurs in many forms in the soil and like all other elements that are needed for plant growth it is cycled through the farm ecosystem.

The two main pools of phosphorous in the soil include the mineral pool and the organic pool. The other pools include the phosphorous that is in plant biomass and the phosphorus that is in soil solution.

The mineral pool of phosphorous (P_i) is relatively immobile as it consists of phosphate ions bound to iron, aluminium or calcium. This form is not readily available to plants and is considered fixed.

The organic pool of phosphorous (Po) is the phosphorous that is in various forms of organic matter in the soil. This organic matter can be fresh plant and animal materials (manures), decomposing matter or stable humus. Phosphorus is also bound up in the bodies of the soil organisms. Some of this organic P is readily available while other forms are less easily mineralised.

A small fraction of P in the soil is in the soil solution as phosphate ions (Pw). This soluble form of P is the form that plant roots can take up. It is a very transitory pool of P with any phosphates very quickly being taken up by plant roots, taken up by soil organisms or bound to the minerals of the soil.

P cycling: the soil-plant system

The exchanges between Pi, Po, soluble phosphate ions and plant roots occurs through a range of chemical and biologically mediated reactions. These reactions are continuous and complex, occurring simultaneously throughout the soil.

Chemically the P that is bound to minerals can be desorbed from the mineral and so end up in solution. Reabsorption can also occur. It can also be dissolved from mineral precipitates.

Biologically P can be mineralised from both organic matter and from minerals by plants and soil micro-organisms such as bacteria and fungi.
Plants and soil organisms can release organic acids and enzymes (phosphatases) which allows them to access P from both the mineral and organic pools for their own nutritional requirements.

Furthermore the cycling of nutrients through the soil food web, as organisms eat both each other and the organic matter, results in excess P being mineralised and ending up in solution available for plants.

Influencing factors

A range factors determine the biological and chemical processes and the relative importance of the various pools in any particular soil. Every agricultural soil has a unique set of circumstances that need to be taken into account.

- **Soil minerals:** The type of minerals present in the soil directly determines how readily P will be fixed and in what forms. Indirectly the mineralogy shapes the fertility of the soil, the pH and the potential levels of organic matter.
- **Temperature and water:** These both influence the amount of chemical and biological activity in the soil and therefore directly influence the rate of P cycling. It is known for example that P availability early in the season is lower due to lower temperatures.
- **Soil organic matter:** The amount of organic matter will obviously influence the amount of P that is in an organic form. Soils that have lost organic matter will have very low P_o pools. In these soils the mineral and soluble pools are the most important. Furthermore soils with very high Carbon to Phosphorous ratios may have a low availability of P for plants as the soil micro-organisms compete with plant roots for any P that becomes available as it is relatively scarce.
- **Soil biological fertility:** Low functional diversity in a soil (where there is a reduced soil food web) will also led to less turn over of P. In these soils less P can be accessed by enzymes and organic acids. Therefore less P can be become available in the soil solution.
- **Previous P use**: The amount of P that has previously been applied to a soil as fertiliser will influence the chemistry of P exchange between the minerals and soil solution as well as the amount of enzyme and acid activity of plants and soil organisms. For example, when a high level of soluble P exists (often due to a high level of fertiliser use) then low enzyme activity occurs. The continued use of highly acidic forms of P fertilisers can also reduce the abundance of soil organisms.

Apart from the inherent mineral type underlying the soil and the overall climatic factors, most of the conditions that influence P cycling in a farm soil can be modified by management practices. By taking a whole of soil approach and considering the biological aspects as well as the physical and chemical processes, new more efficient ways of P fertility can be achieved.

The current approach

The current approach to P fertility is to use soluble forms of phosphate fertilisers such as super phosphate and DAP. This ensures that adequate soluble phosphate is always available for plant uptake. However this approach has limitations that are becoming more apparent as soils start to function less effectively and as the cost of fertilisers increase rapidly.

Firstly, when applied, much soluble P is fixed to the minerals and this therefore becomes unavailable for plant growth. This means that most P applied is not used effectively and therefore financially it is a very inefficient way of applying P fertiliser. Estimates are that around 70-80% of the P applied in a soluble form are not available for plant use and become part of the mineral and organic pools. This P then requires chemical and biological reactions to make it available in the future.

In conventional farming systems over time, organic matter tends to decline and the soil biological fertility tends to decrease. This is due to a loss of carbon and the use of farm fertilisers and chemicals that adversely affect the soil ecosystem. Due to this decline less organic forms of P exist. Also, as the soil food web is reduced, the soil loses its ability to cycle P through the biological processes (less enzymes and acids are excreted to access P). This further reduces a soil's ability to access P from the mineral and organic pools.

In summary the current mainstream approach results in the loss of the organic P pool and a reduction in the potential of biological pathways for P cycling in the soil. To maintain P fertility it is therefore necessary to add soluble P regularly to ensure that adequate P is in the soil solution at all times. After some time the soil becomes over-saturated with P and at that point P will also be lost from the system through runoff or leaching. This further increases the inefficiency of P use as well as creating a number of environmental problems for water resources.

Taking a biological approach

The dimension of the soil system that is neglected in the conventional approach is the biological fertility and functioning of the soil. It has been known for some decades that the organic pool of P and the biological soil reactions are critical for the cycling of P.

The first step in taking a biological approach is to understand the critical importance of soil organic matter and biological fertility to soil health and to P fertility. Without organic matter and soil organisms many key functions of the soil are diminished. These include the ability of the soil to hold water, the ability of the soil to suppress disease and the ability of the soil to cycle nutrients to plants.

By building organic matter, encouraging soil organisms and ensuring healthy rhizosphere processes (the rhizosphere is the zone around the plant roots where maximum soil activity occurs and is critical for nutrient exchange) it is possible to build a balanced P cycle.

This cycle places more importance on the biological processes that affect P mineralisation rather than just the chemical ones. However it is possible to achieve adequate levels of soluble P in soils using this biological approach and so grow high yielding crops.

In addition to building soil biological fertility, the biological approach includes the use of P fertilisers that are not as highly soluble and do not acidify the soil greatly. These include the use of rock phosphates, composted rock phosphates, partially acidulated rock phosphates and biological inoculants that add P solubilizing micro-organisms to the soil. Each of these inputs when used correctly can result in adequate soluble P for plant growth.

The common denominator when using these inputs is to ensure that long term biological fertility is maintained when using them.

Finally in situations where historic use of P fertilisers has resulted in high amounts of unavailable P in the soil, the building of biological fertility will allow the availability of P to increase as the biologically mediated processes access P from the mineral pool. Research and farm results have demonstrated that in these situations P inputs can be eliminated.

Monitoring P fertility

The conventional approach to monitoring P fertility is to look at available P through a chemical extraction test which looks at the readily plant extractable P in the soil. Common tests include the Bray, Mehlich and Olsen tests.

These tests are generally seen as being correlated with the amount of P that is available in soils for plant uptake. When the levels of these P test results are low then P is added in the form of a fertiliser. It is important to remember that soil P is part of a dynamic cycle and that over time P tends to become fixed unless biological cycling releases it.

Under the mainstream approach fertilisers are assessed on how much water and citrate available P they have. Water extraction indicates the ease at which the fertiliser will be dissolved into water solution. A citrate extraction indicates the ease at which organic acids excreted by soil organisms and plant roots can access the fertiliser's P content.

Generally this monitoring approach does not allow for the assessment of how much of the soluble P will be fixed nor is an assessment of the biological processes and pools involved. Total Soil P which indicates how much P is already in a soil is also rarely assessed.

As a result, the focus of conventional testing is narrow and short term. The goal is to ensure adequate P in solution by considering a simple model of soluble P, available P and fertiliser. This leads to ongoing additions of P through the use of fertilisers year in and year out. No account is usually taken of the potential build up of P in mineral or organic pools and how to measure the potential of these pools to supply the soluble P pool for plant growth.

The biological approach is to look at soil biological fertility indicators in conjunction with total P and available P. This allows the whole soil system to be understood and a more accurate and efficient fertiliser approach to be undertaken.

Assessing organic matter levels and trends in total and available P can allow the biological system to be assessed. A critical aspect of biological P monitoring is to test plant levels and calibrate this to soil levels. Plant nutrition is the end result of the soil ecosystem at work so if plant levels are adequate then it is a general indication that the complex soil P cycle is effectively supplying P to a crop.

The assessment of fertilisers is also different under a biological approach with the citrate and water solubility of fertiliser products becoming secondary to an assessment of the suitability of a product to the soil under consideration.

For example, in soils that are biologically active and have a high level of organic matter, rock phosphates are a more suitable form of fertiliser. In soils that have less biological function the use of organic forms of P fertilisers (composted rock phosphates and composts) may be more suitable. The use of highly soluble fertilisers need to be minimised and then eliminated under a biological approach as the soil ecosystem begins to cycle and supply P to plants through the biological pathways.

References:

Abbott, K & Murphy D, 2003, *Soil Biological Fertility*, Kluwer Academic Publishers, The Netherlands.

Bardgett R, 2005, *The Biology of Soil: A community and ecosystem approach*, Oxford University Press, London.

Babana A.H., Antoun H, 2006, Effect of Tilemsi phosphate rock solubilizing microorgansisms on phosphorus uptake and yield of field grown wheat (Trticum aestivum L.) in Mali, in *Plant and Soil* 287, P 51-58.

Bolland M.D.A. & Gilkes R.J., 1997, The agronomic effectiveness of reactive phosphate rocks – effect of phosphate rock reactivity, *Australian Journal of Experimental Agriculture* 37, p 921-936.

Chen Y.P., Rekha P.D., Arun A.B., Shen F.T., Lai W.A. & Young C.C., 2006, Phosphate solubilizing bacteria from subtropical soil and their tricalcium phosphate solubilizing abilities, in *Applied Soil Ecology* 34 (1), p 33-41.

Clements D & Shrestha A, 2004, *New Dimensions in Agroecology*, Food Products Press.

Loomis R & Connor D, 1992, *Crop Ecology*, Cambridge University Press.

Mittal V, Singh O, Nayyar H, Kaur J, Twerai R, 2008, Stimulatory effect of phosphate solubilzing fungal strains (Aspergillus awamori and Penisillum citrinum) on the yield of chickpea (Cicer arietinum L.cv GPF2), in *Soil biology and Biochemistry* 40 (3), 718-727.

Oehl F, Frossard, E, Fliessbach A., Dubois D. & Oberson A, 2004, Basal organic phosphorous mineralization in soils under different farming systems, *Soil biology and biochemistry* 36 (4), p 667-675.

Ouahmane L, Thioulouse J, Hafidi M., Prin Y, Ducousso M, Galinan A, Plenchette C, Kisa M & Duponnis R, 2007, Soil functional diversity and P solubilization from rock phosphate after inoculation with native or allochtonous arbuscular mychorrizal fungi, in *Forest Ecology and Management* 241 (1-3), p 200-208.

Rao NS, 1999, *Soil Microbiology*, Science Publishers inc, USA.

Richardson A.E, Soil Microorganisms and Phosphorous availability, in *Soil Biota: Management in sustainable farming systems*, CSIRO, Australia.

Richardson A.E., Habdobas P.A. & Hayes J.E., 2000, Acid phosphomonoesterase and phytase activities of wheat (Triticum aestivum) roots and utilization of organic phosphorous substrates by seedlings grown in sterile culture, in *Plant cell and Environment* 23, 397-405

Schonning P, Elmholt S & Christensen BT, 2004, *Managing Soil Quality: Challenges in Modern Agriculture*, CAB International, UK.

Sparks, D, 2003, *Environmental Soil Chemistry*, Academic Press, USA.

Sale P.W.G, Simpson P.G, Lewis D.C, Gilkes R.J, Bolland M.D.A., Rtakwosky D.A., Gilbert M.A., Garden D.L., Cayley J.W.D. & Johnson D., 1997, The agronomic effectiveness of reactive phosphate rocks – effect of the pasture environment, *Australian Journal of Experimental Agriculture* 37, p 921-936.