Incitec Pivot Fertilisers

AGRITOPIC

August 2021

PHOSPHORUS

1. INTRODUCTION

Phosphorus (P) is one of the primary nutrients, along with nitrogen (N) and potassium (K). These nutrients, together with sulfur (S), calcium (Ca) and magnesium (Mg), are referred to as the macronutrients, as they are required in large quantities by plants.

Australian soils are characteristically low in phosphorus in their native state, with the exception of a few soils of basaltic origin and some alluvial soils. Productive crops and pastures deplete the soil of phosphorus. Even soils high in phosphorus when first farmed can reach a stage when phosphorus is necessary as fertiliser to maintain yields. Phosphorus is also important in animal nutrition, e.g. in the formation of bones and teeth, and milk production.

2. PHOSPHORUS IN THE SOIL

2.1 Forms and Availability

Most of the phosphorus in soils is associated with organic matter. Even in mineral soils, between 20% and 80% of the total phosphorus will be present in organic forms. This varies with land use, and the history of fertiliser application. In pastures, most of the phosphorus is in organic forms; while in arable soils, as little as 10 – 20 % may be organic. Of the total phosphorus present in the soil, only a small amount is present in plant-available forms. Its availability depends on the soil type, pH, organic matter content, the concentrations of other nutrients and the soil's phosphorus buffering capacity.

Phosphorus is most available for uptake by plants in the pH range 6.5 - 7.5. At pH below 5.5, slowly soluble oxides of iron, aluminium and manganese form, reducing phosphorus availability, while at pH above 7.0, slowly soluble calcium phosphate is formed.

Phosphorus in the soil is relatively immobile. Phosphorus applied as fertiliser rarely moves any great distance in the soil without some form of physical mixing, e.g. cultivation. The distance that the phosphorus front moves in the soil from fertiliser granules is rarely much more than 4 - 5 cm.

Soil phosphorus concentrations are generally higher in the top-soil than at depth, reflecting the higher organic matter content of the surface, and the application of fertiliser phosphorus which usually remains within the surface 10 to 20 cm.

2.2 Fixation

Phosphorus applied as fertiliser can be adsorbed or converted to insoluble forms in the soil, a process known as fixation. In general, fixation is greater in soils which:

- have a high clay content;
- are very acidic, and are high in iron and/or aluminium; or
- are very alkaline.

In phosphorus-responsive situations, higher rates of phosphorus will need to be applied on soils with a high fixation or buffering capacity. In soils that are high in phosphorus or where heavy applications of phosphorus fertilisers have been made in the past, fixation is less of a problem as the phosphorus-fixing capacity of the soils will have been largely met.

2.3 External Losses

As phosphate ions are attracted to clay and organic matter in the soil, and only a small fraction is present in water-soluble forms in the soil solution, very little phosphorus is lost through leaching in most agricultural soils, with the exception of deep sands in high rainfall areas. Some movement of recently applied phosphorus deeper into the soil may occur via pores and cracks on heavier textured soils when fertiliser granules dissolve on irrigating or when rain is received, e.g. after a period of dry weather.

As phosphorus concentrations are higher in the top-soil, phosphorus can be lost in run-off water if erosion occurs, especially where the soil is disturbed (cultivation) or ground cover is poor, e.g. over-grazed pastures. Freshly applied fertiliser phosphorus, and phosphorus in dung or manure, may also be lost in surface run-off following heavy rain. Such losses may be small in agronomic terms, but may be of concern in terms of water quality in surface water bodies and streams. The concentration of phosphorus in surface water that will support algal blooms is considerably less than that required in the soil for normal plant growth.

Phosphorus is also removed from farms in plant and animal products, e.g. grain, meat, milk, and the disposal of manure.

3. PHOSPHORUS IN THE PLANT

3.1 Uptake and Role of Phosphorus

Phosphorus is mostly taken up early in the life of plants, in the seedling stage of annuals and early regrowth of perennials. Very little phosphorus is taken up in the latter stages of growth in most crops. An exception is cotton, which takes up most of its phosphorus during the reproductive stage.

While phosphorus is not mobile in soils, i.e. it does not move far from where it is applied, it is one of the more mobile nutrients in plants, i.e. it is readily moved within the plant from old to young tissue during the growing season. Phosphorus is required for cell division at growing points, so is most abundant in growing tissue. It is particularly important in stimulating root development. Consequently, the best responses to phosphorus fertiliser are obtained if it is applied early, e.g. banded with or near the seed at planting in annual crops, and at the start of the main growing season in perennial crops and pastures.

In soils low in available phosphorus, emergence of most crops improves when phosphorus fertiliser is placed with or near the seed. This early advantage is manifested throughout the growing season. Fertilised plants produce a large, prolific and fast-growing root system; a more even and a vigorous stand results; and crops go on to produce more dry matter and higher yields.

Deep tap-rooted plants like cotton and soybean have less opportunity to absorb fertiliser phosphorus than small fibrous and shallow-rooted plants, e.g. vegetables, annual legumes and grasses. Perennial plants usually have a proliferation of surface-feeding roots. Plants with large fibrous root systems are the best phosphorus “scroungers”.

3.2 VAM

VAM (Vesicular arbuscular mycorrhiza) is a beneficial fungus that grows in association with plant roots and enhances the plant uptake of immobile nutrients such as phosphorus and zinc. Most agricultural crops are VAM dependent. Canola is an exception, in that VAM do not infect its roots. This is one reason why canola is more responsive to fertiliser than many other crops.

VAM populations in the soil decline when the soil is fallowed for an extended period, explaining why certain crops, if grown after a long follow, are more responsive to phosphorus fertiliser. Linseed, which is no longer widely grown, is particularly affected.

3.3 Phosphorus Deficiency Symptoms

Phosphorus, like nitrogen, is mobile in plants, so symptoms first appear in the older leaves. Unlike nitrogen deficiency, leaves of phosphorus deficient plants tend to become darker green.

Symptoms of phosphorus deficiency include:

- Poor legume growth, and loss of the legume component in the mixed pastures.
- Slow emergence and growth of annual crops.
- Off-green (often dark, not light green or yellowish) coloured foliage with purplish veins and purplish petioles.
- Plants look stunted and spindly; cereals tiller poorly. Crops have sparse foliage and grow slowly, often dropping leaves prematurely.
- In winter cereals, phosphorus deficient crops will be slow to mature. Where phosphorus is applied, winter cereals mature more quickly. Flowering may be advanced by up to 2 weeks, perhaps more. This contrasts with nitrogen where the

correction of deficiency in winter cereals delays maturity, i.e. nitrogen extends the vegetative stage.

- Low yields, e.g. of pasture, grain or fruit.

3.4 Excess Phosphorus

While not common, high concentrations of soil phosphorus, or the application of high rates of phosphorus fertiliser may restrict yields, by depressing the uptake of micronutrients such as iron or zinc.

3.5 Nutrient Removal

A large proportion of the phosphorus in mature plants is in the seed or fruit. Exceptions are root and tuber crops, e.g. potatoes.

Around 2 - 3 kg of phosphorus is contained in each tonne of grain for summer cereals (rice, sorghum, maize), 3 - 4 kg in winter cereals (wheat, barley), 5 kg in many legume grains (lupin, chickpea) and 6 - 7 kg in soybean and canola.

About 1 kg of phosphorus is present in each 1 000 L of milk.

4. CRITICAL LEVELS OF PHOSPHORUS

4.1 Soil Analysis

The total phosphorus content of soils is in the range of 200 - 1 500 mg/kg P (0.02 to 0.15% P). Most of this is not available for plant uptake.

Various tests are available to assess how much of this phosphorus is potentially available for plant uptake. Different tests have been found to be more useful in predicting where responses to phosphorus might be obtained in different soil types and for different plant species. It is best to use tests for which local research and interpretation data are available.

Tests used by the Incitec Pivot Laboratory depend on the location from where the sample was obtained, and which crop or pasture is to be grown. They include:

- Colwell
- BSES
- Olsen
- Bray 1
- DGT (Diffusive Gradient Thin Films)

In addition, a Phosphorus Buffer Index (PBI) test can be performed to characterize the buffering capacity of the soil. This can be performed periodically. It does not need to be done on a regular/annual basis.

4.2 Plant Tissue Analysis

Phosphorus is present in plants in smaller amounts than nitrogen or potassium, and in similar concentrations to sulfur.

In plant tissue samples from pasture and annual crops (grains, vegetables), a typical phosphorus concentration (dry weight basis) is 0.4% P. Higher phosphorus readings are found in the seedling stage. In tree crops, a typical value in the leaves is 0.2% P.

5. PHOSPHORUS FERTILISERS

5.1 A Brief History

Phosphorus was applied in early times as organic wastes, e.g. manure, crushed bones, guano, and then as phosphate rock. Responses were variable, with the best results being achieved on acid soils.

In 1842, John Lawes took out a patent in the United Kingdom for the manufacture of superphosphate, an event that is regarded as marking the birth of the modern fertiliser industry. The royalties he received were used to establish the Rothamsted Research Station, the oldest agricultural research station in the world and the site of many internationally recognised long-term experiments. The manufacturing process involves treating rock phosphate with sulfuric acid to increase the solubility of the phosphorus it contains, making it more available for plant uptake.

CSR (Colonial Sugar Refinery) is credited with being the first company to manufacture superphosphate in commercial quantities in Australia, in Victoria in 1876. Two early pioneers of the Australian fertiliser industry, to whom Incitec Pivot can trace its history, were James Cuming in Victoria and South Australia, and George Shirley in New South Wales and Queensland.

Superphosphate became and remained Australia's most important phosphorus fertiliser until the 1970s. Around this time, high analysis phosphorus fertilisers, such as DAP (Diammonium phosphate) and MAP (monoammonium phosphate), began to be manufactured in Australia, from imported phosphate rock.

High analysis phosphorus fertilisers have now largely replaced superphosphate in crops. Superphosphate remains popular on legume based pastures.

In the early 1970s, superphosphate was manufactured by Incitec Pivot's antecedent companies at numerous sites in South Australia, New South Wales and Queensland, all of which have now closed. Superphosphate continues to be manufactured at Geelong and Portland in Victoria, which are well placed to supply superphosphate for use on improved pastures in south east Australia, e.g. dairying. About two thirds of Australia's milk production comes from the State of Victoria.

High analysis phosphorus fertilisers continued to be manufactured in Australia from imported phosphate rock up until 1990, when the last of these plants closed, it having become more economical to import the finished product than to manufacture locally. The explanation for this lies in the analysis of the raw materials and the finished products.

Phosphate rock contains 13 – 17 % phosphorus (P). Incitec Pivot SuPerfect (single superphosphate) contains 8.8 % P. To minimize freight, it is best to import the phosphate rock, and manufacture superphosphate locally, close to the markets in which it will be used, provided competitively priced sulfuric acid is available.

On the other hand, it is best to manufacture concentrated high analysis phosphorus fertilisers, such as DAP (18% N 20% P) close to where the phosphate rock is mined, and to export the finished product. This is what is done at the Incitec Pivot manufacturing facility at Phosphate Hill in north-west Queensland, where DAP and MAP are manufactured.

The Duchess deposit was discovered in 1966. It was mined for a while in the 1970s and early 1980s, with phosphate rock being railed east for export through the Port of Townsville. The mine then remained idle until December 1999, when the ammonium phosphate fertiliser plant at Phosphate Hill was commissioned. This plant has the capacity to produce around one million tonne of high analysis phosphorus fertiliser per annum, which is used both in Australia and exported overseas through the Port of Townsville.

5.2 Analyses and Composition of Incitec Pivot Phosphorus Fertilisers

The analyses of Incitec Pivot's phosphorus fertilisers are shown in the following table.

Analyses of Incitec Pivot phosphorus fertilisers.

Product	Common Names	Analysis			
		%N	%P	%S	%Ca
DAP	Diammonium Phosphate	18	20	1.6	-
MAP	Monoammonium Phosphate	10	21.9	1.5	-
SuPerfect	Single Superphosphate (SSP)	-	8.8	11	19

The ammonium phosphate fertilisers (DAP and MAP) are manufactured by reacting ammonia with phosphoric acid, and have the chemical formulae of:

- DAP Diammonium phosphate $(NH_4)_2HPO_4$
- MAP Monoammonium phosphate $NH_4H_2PO_4$

DAP and MAP are used in cropping, to meet the crops phosphorus requirement, and supply part of the nitrogen. The balance of the nitrogen can be applied as another product, e.g.

urea, either in a blend with DAP or MAP, or at a different time. Plants typically take up about ten times more nitrogen than phosphorus.

The high analysis of DAP and MAP helps save on transport and distribution costs, and speeds up fertilising operations, as there are less stoppages to fill fertiliser bins. DAP and MAP are compatible in blends with most other fertilisers including urea, the world's most commonly used nitrogen fertiliser. Urea should not be blended with superphosphate.

SuPerfect, Incitec Pivot's product name for single superphosphate, is comprised of approximately one-third monocalcium phosphate and two-thirds gypsum (calcium sulfate). SuPerfect is ideally suited for use in legume-based pastures, in which nitrogen is not normally required (legumes fix their own nitrogen), and phosphorus and sulfur are both required. Plants take up about equal amounts of phosphorus and sulfur.

DAP and MAP are low in sulfur.

5.3 Solubility

On fertiliser labels, the analyses of phosphorus fertilisers is broken down into the following components:

- Water Soluble – dissolves in water
- Citrate Soluble (as determined in ammonium citrate) – dissolves in weak acid (citric acid)
- Citrate Insoluble

Together, the water soluble and citrate soluble fractions are referred to as the Available Phosphorus. The citrate insoluble fraction is only soluble in strong (concentrated) acids, and is regarded as being unavailable for plant root uptake.

Phosphorus compounds vary in their solubility, as shown in the following table.

Solubility of Various Phosphorus Compounds in Water.

Chemical	Formula	Solubility kg/100 L at 20^{O} C
Diammonium phosphate (DAP)	$(NH_4)_2HPO_4$	70
Monoammonium phosphate (MAP)	$NH_4H_2PO_4$	37
Monopotassium phosphate (MKP)	KH_2PO_4	23
Monocalcium phosphate (MCP)	$Ca(H_2PO_4)_2.H_2O$	2
Dicalcium phosphate (DCP)	$CaHPO_4.2H_2O$	0.02

The fertiliser most commonly used to apply phosphorus in solution, i.e. in fertigation programs and foliar sprays, is technical (soluble solid or solution) grade MAP.

DAP is more soluble, but it also more hygroscopic, meaning it is more likely to absorb atmospheric moisture and set in storage. MAP stores better.

Monocalcium phosphate (MCP) does not have high enough solubility to use in the preparation of fertiliser solutions, but is sufficiently soluble to dissolve in soil moisture and maintain an adequate phosphorus concentration in the soil solution to meet crop and pasture demands.

Dicalcium phosphate (DCP) is 100 times less soluble than MCP.

SuPerfect contains:

- 7.0% Water Soluble Phosphorus (P)
- 1.6% Citrate Soluble Phosphorus (P)
- 0.2% Citrate Insoluble Phosphorus (P)
- 8.8% Total Phosphorus (P)

The water-soluble phosphorus is present as monocalcium phosphate (MCP), and the citrate soluble phosphorus is dicalcium phosphate (DCP). The remainder (0.2% citrate insoluble phosphorus) is residual unreacted phosphate rock.

6. FERTILISER PRODUCTS

6.1 DAP

DAP is the most widely used and traded phosphorus fertilisers in the world. It is usually the most economical source of phosphorus where both nitrogen and phosphorus are required. DAP can be applied on its own or used in blends.

It is commonly used in crops such as maize, in planting fertilisers for vegetable crops, and as the phosphorus source for NPK fertiliser blends for use in tree and plantation crops, sugarcane and nitrogen fertilised grass pastures.

The ammonium phosphate fertilisers (DAP and MAP) are ideal planting fertilisers. They provide starter nitrogen and phosphorus. In responsive situations, i.e. where both nitrogen and phosphorus are required, the combination of positively charged ammonium ions (NH_4^+) nitrogen with negatively charged phosphate ions (HPO_4^{2-} and $H_2PO_4^-$) in DAP and MAP promotes root uptake of both nutrients. In contrast, negatively charged nitrate ions (NO_3^-) can compete with phosphate ions for plant root uptake.

6.2 MAP

MAP is a popular planting fertiliser in grain and cotton. MAP (10% N) is lower in nitrogen than DAP (18% N). This is advantageous under the following circumstances:

- MAP is less hygroscopic than DAP, which means it is less likely to absorb atmospheric moisture and set in storage. This is of particular importance where fertiliser is to be stored on farm in a silo in advance of planting. MAP may be placed in a silo for a limited period, whereas it is recommended that DAP not be placed in silos. The incidence of application difficulties through precision application equipment, such as air-seeders, is also likely to be lower with MAP than DAP.

- MAP is less likely to harm germinating seeds and emerging seedlings when the seed and fertiliser are placed in direct contact with each other, e.g. winter cereals.

MAP is also used as a planting fertiliser for legume grain and forage crops. It provides starter nitrogen, which can be beneficial in meeting the crop's nitrogen requirements in the first few weeks of growth, up to the time the root system is properly nodulated, and can satisfy its own demand for nitrogen.

6.3 SuPerfect

SuPerfect is the name given to the granulated single superphosphate manufactured by Incitec Pivot at Geelong and Portland in Victoria. SuPerfect is an ideal fertiliser for top-dressing legume based pasture, where sulfur is likely to be required as well as phosphorus, and the nitrogen in MAP and DAP is not of importance.

The main reserve of sulfur in most soils is the soil organic matter. Where the soil is cultivated, sufficient sulfur is likely to be mineralized to meet crop demands. This is unlikely to occur in permanent pasture.

Molybdenum fortified grades of SuPerfect are available for periodic use where molybdenum needs to be applied.

A selected grade known as Air Seeder SuPerfect is available in some markets for use in grain crops.

6.4 Triple Superphosphate

Triple superphosphate is manufactured by reacting phosphate rock with phosphoric acid, rather than sulfuric acid, as used in the manufacture of single superphosphate. The resultant product has a higher phosphorus content than single superphosphate, but contains very little sulfur.

Triple superphosphate consists mainly of monocalcium phosphate, whereas single superphosphate contains monocalcium phosphate and calcium sulfate (gypsum). Triple Superphosphate contains around 20% P.

Incitec Pivot no longer markets triple superphosphate, due to low demand. MAP had become a more economical source of phosphorus, without placing any value on its nitrogen content.

In recent years, the use of triple superphosphate has been largely confined to grain crops planted at wide row spacings, in which the fertiliser and seed are applied through the same delivery hose and placed in direct contact with each other in the soil.

If MAP was used in this situation, it could affect germination and emergence.

The suggested maximum rate at which MAP should be used at planting in direct contact with the seed under good moisture conditions in crops such as sorghum planted at one metre rows is 50 kg/ha. This rate should be reduced on loams.

The risk of fertiliser burn is avoided if the MAP is applied through a separate delivery hose and is banded to the side of and below the seed.

6.5 Ammonium Polyphosphate Solution

Ammonium polyphosphate is manufactured by reacting superphosphoric acid, ammonia and water. It is the main source of phosphorus used in fertiliser solutions, e.g. in mixtures with UAN (Urea Ammonium Nitrate Solution).

Incitec Pivot does not market ammonium polyphosphate. Little use is made of the product in Australia.

6.6 Soluble Fine (Solution Grade) Phosphorus Fertilisers

The granular phosphorus fertilisers marketed by Incitec Pivot, i.e. DAP, MAP and SuPerfect, are intended for dry application to the soil.

They are not recommended for application in solution, on account of their large particle size, the presence of insolubles, the use of granulation or conditioning agents during their manufacture, and in the case of SuPerfect, its low solubility.

High purity soluble solid phosphorus fertilisers are available for application in solution (dissolved in water) through water injection equipment at planting in row crops such as sorghum and cotton, fertigation systems or as a foliar spray:

The most commonly used fertilisers to apply phosphorus in solution are monoammonium phosphate (MAP) and monopotassium phosphate (MKP).

Typical analyses for soluble solid solution grades of these products are shown in the following table.

Analyses of Soluble Solid Phosphorus Fertilisers

Product	Chemical name	% N	% P	% K
MAP	Monoammonium phosphate	12	26	
MKP	Monopotassium phosphate		22.5	28

6.7 Phosphate Rock

Apart from its use in organic farming systems, there is little demand for phosphate rock in Australia. It use as a conventional fertiliser is largely confined to pasture. Having low solubility, phosphate rock is not recommended where a quick response to phosphorus is required, e.g. at planting in annual crops.

Phosphate rock is only effective in acid soils, in which it reacts slowly to release phosphorus in more water-soluble forms for plant root uptake. It is relatively ineffective in neutral and alkaline soils.

A fine particle size is essential with most phosphate rocks, in order for them to react in the soil. They need to be applied as a powder or dust.

6.8 Reactive Phosphate Rock

Reactive Phosphate Rock (RPR) is phosphate rock that has undergone some natural chemical modification. Reactive Phosphate Rocks are more chemically reactive and have a greater ability to dissolve than unreactive phosphate rock when applied to the soil.

RPR can be applied as is, without further grinding to achieve a fine particle size. As a fertiliser, it is less effective that superphosphate in most situations, and it does not supply sulfur.

RPR is most effective on heavier textured acid spoils, i.e. those that are acid, and are buffered to resist changes in pH, and in higher rainfall areas where the growing season extends over the greater part of the year.

RPR is less effective on sandy soils, neutral and alkaline soils, and in low rainfall areas.

RPR can be considered where the following criteria are met:

i) The rainfall exceeds 600 mm (New Zealand experience indicates that RPR is less effective where the rainfall is less than 800 mm, and where there is a pronounced dry season);

ii) The soil pH is less than 5.5, or possibly 6.0 at the highest;

iii) Soil phosphorus is at moderate levels, e.g. greater than 15 mg/kg P (Colwell) and maintenance applications of phosphorus are required. RPR is not recommended where a quick response to phosphorus is required, e.g. during pasture establishment.

6.9 Partially Acidulated Phosphate Rock

In the manufacture of water-soluble phosphorus fertilisers such as single superphosphate (SuPerfect), phosphate rock is fully acidulated with sulfuric acid.

Partially acidulated phosphate rock (PARP) is manufactured by adding sufficient acid to solubilise part but not all of the phosphorus in phosphate rock. It is an in-between product, containing some phosphorus in the same forms as present in superphosphate, and the remainder in the forms present in un-acidulated phosphate rock.

Note. Incitec Pivot Fertilisers no longer markets RPR or PARP. The demand for these products did not warrant their retention on the company's Product Range.

7. PHOSPHORUS FERTILISATION

7.1 Variation between Species

Plant species vary in their phosphorus requirements, and responsiveness to phosphorus fertiliser. The native vegetation provides a guide to soil fertility, e.g. soils that support Brigalow and Belah are more fertile than those that carry Box. Likewise, pasture species also indicates how fertile the soil is. Blady grass and Bracken are symptomatic of soils low in phosphorus. The more productive native grasses, and introduced grasses, do not flourish as well on soils low in phosphorus.

Higher soil phosphorus levels are required to support legumes than grasses. Legumes have a higher demand for phosphorus (it is typically present at higher concentrations in the foliage and seed), and their root systems do not exploit the soil for phosphorus (and other nutrients) as well as grasses.

In grass legume pastures, legume growth is often determined by the soil's phosphorus status. Grasses persist at lower soil phosphorus concentrations that are inadequate for legumes, but their growth and productivity are limited by nitrogen deficiency if legume growth, and nitrogen fixation, are poor.

Pastures and perennial tree crops are able to respond to surface applied phosphorus fertilisers as their roots proliferate at or near the soil surface.

Some crops respond to fertility rather than fertiliser. They do well on fertile soils, in which all the roots have access to an adequate supply of phosphorus. They respond to fertiliser when grown on infertile soils, but do not yield as well as might be expected, i.e. they do not reach their full yield potential.

Cereal crops, with their fibrous root systems, tend to respond better to phosphorus applied at planting than crops with a deep taproot, such as cotton.

The ammonium phosphate fertilisers, e.g. MAP, which combine high water solubility with starter nitrogen in the ammonium form, are likely to be the most effective phosphorus planting fertilisers in crops with a deep tap root, such as cotton.

Potatoes are another crop whose root system is relatively inefficient at taking up phosphorus, and other nutrients, from the soil. Potatoes have a relatively small and shallow root system. In addition, root hairs, which are so critical for phosphorus uptake, make up about 20% of the root mass in potatoes, compared with 30 – 60% in other crops. Consequently, higher rates of phosphorus are required, and responses to phosphorus are obtained at higher soil test levels in potatoes, than in other crops.

High rates of phosphorus are applied in potatoes when grown on red volcanic or basaltic soils (also known as Ferrosols or Krasnozems). These soils are found in locations such as northern Tasmania, the Victorian Gippsland, Robertson and Dorrigo in New South Wales, and the Atherton Tableland in Queensland. They have a high phosphorus fixation capacity.

On red basalts, potatoes fertilised with superphosphate tend to out yield those fertilised with other phosphorus fertilisers, such as DAP. Various explanations have been proposed, including:

i) As red volcanic soils have a high phosphorus fixation capacity, the high water solubility of DAP (70 kg/100 L) may be a disadvantage, compared to MCP, the phosphorus source in superphosphate, which has a solubility of 2 kg/100 L. DAP will dissolve more quickly in the soil and be more rapidly fixed, whereas superphosphate may maintain soil solution phosphorus concentrations at a satisfactory level for a longer period of time.

ii) The calcium in the superphosphate granules dissolving and moving in the soil away from the fertiliser band, complexing aluminium and decreasing the exchangeable aluminium and percent aluminium saturation. This in itself could reduce phosphorus fixation, and create a greater volume of soil of favourable fertility for roots to proliferate.

iii) A response to calcium. Plant uptake of calcium is not as efficient as for other plant nutrients, occurring just behind the root tip. Calcium is required for cell elongation and cell division.

The better growth responses are not confined to comparisons with the ammonium phosphates. Single superphosphate is usually more effective than triple superphosphate. Possible explanations are:

i) Single superphosphate is comprised of approximately two parts gypsum to one-part monocalcium phosphate, whereas triple superphosphate consists mostly of monocalcium phosphate. Gypsum, which has a solubility in water of 0.26 kg/100L, is eight times less soluble than monocalcium phosphate (2 kg/100 L), so its presence will slow down the dissolution (and fixation) of phosphorus from the fertiliser granules.

ii) At the same rate of phosphorus, single superphosphate (8.8% P, 19% Ca) will supply three times as much calcium as triple superphosphate (20.1% P, 13.5% Ca). This may be of importance if calcium is complexing aluminium, and providing a more favourable medium for root growth, or the calcium itself is stimulating root growth and development.

iii) Single superphosphate has a lower phosphorus analysis, and therefore has to be applied at a higher rate. There will be more point sources, and a greater volume of phosphorus (and calcium) enriched soil for the crop's roots to exploit, compared to where the higher analysis fertilisers, e.g. DAP and triple superphosphate, are used.

It is not certain which, if any of these factors may be in play, explaining the better responses often obtained with single superphosphate compared to high analysis phosphorus fertilisers in potatoes when grown on red basaltic soils.

Responses have not been obtained to pre-plant applications of lime in potatoes grown with planting fertilisers based on single superphosphate in trials on the Atherton Tablelands in north Queensland.

7.2 Soil Application

The keys to efficient phosphorus fertilisation are timing and placement.

Timing

Because phosphorus is required for early root development and is mobile in plants, it is best applied early.

For annual crops, it needs to be applied at planting, so that the fertiliser is accessible by plant roots soon after germination or transplanting.

For clover-based pastures in southern Australia (winter - dominant rainfall areas) on soils with low phosphorus levels, phosphorus is best applied in the autumn. Where phosphorus soil test levels are higher, i.e. non-responsive situations, and a maintenance dressing of phosphorus is being made, timing is less critical, and phosphorus is often applied in the spring, particularly on soils with a high phosphorus fixing capacity which become water-logged during the winter. Iron and manganese become more available in the soil in these circumstances, and react with phosphate ions in solution to produce less soluble phosphorus compounds.

For most tree crops, phosphorus can be applied at the start of the main growing season, i.e. in the spring.

Because phosphorus does not leach readily, there is usually no need to apply it more frequently than each time a crop is planted, or once per year in perennial tree crops and pastures.

However, as nitrogen and potassium are required in tree and plantation crops on a more regular basis, phosphorus is usually applied in combination with these nutrients as a NPK fertiliser.

Placement

Phosphorus is immobile in soils. It needs to be placed where the roots are, or the area they will grow into. Banding the phosphorus in the soil, so it is exposed to less fixation sites, reduces fixation and improves utilization. Phosphorus fertiliser is least effective if it is broadcast on the soil surface, and then incorporated into the soil.

In annual crops, phosphorus is best banded with or near the seed or transplants at planting. In crops planted at narrow row spacings, e.g. winter cereals such as wheat, the fertiliser is applied through the same delivery hose as the seed.

In crops planted at wider row spacings, e.g. cotton, vegetables and sugarcane, the fertiliser is normally applied through separate hoses, and placed in two bands 5 cm to either side of and 5 cm below the seed or planting material.

In vegetables, the basal fertiliser can also be applied in a broad band along the intended position of the crop row, and then be incorporated into the soil.

Side or top dressing with phosphorus in annual crops is not recommended. It is too late, and can leave the fertiliser at the soil surface, where it is not fully exploited by crop roots.

In tree crops, while phosphorus can be broadcast over the entire floor area, it is normally recommended that it be directed in a broad band around the edge of the canopy (or along the drip line), where most of the roots will be actively foraging.

In pasture, phosphorus is top-dressed (broadcast on the soil surface).

7.3 Seed Safety

There are limits to how much fertiliser, particularly those containing nitrogen and potassium, can be applied safely with the seed at planting in crops in which the fertiliser and seed are applied through the same delivery hose.

This can influence the choice of planting fertilisers in winter cereals. Some row crop planters are also not set up to place the fertiliser and seed apart in the soil.

Phosphorus is sorbed onto soil colloids and does not contribute greatly to salt or osmotic effects on germinating seed and plant roots. It is the rate at which companion nutrients such as nitrogen, is applied, that generally dictates how much fertiliser can be safely applied at planting in direct contact with the seed.

Of the ammonium phosphate fertilisers, MAP is a safer product to use, as it has a lower nitrogen content, 10% compared to 18% in DAP.

In winter cereals and forage crops planted at narrow row spacings, it is unlikely that the safe rates at which nitrogen can be applied will be exceeded where MAP is used as the planting fertiliser.

In row crops planted in one metre rows, the suggested maximum rate at which MAP is used at planting in direct contact with the seed under good moisture conditions is 50 kg/ha. This rate should be reduced on loams.

Small seeded crops are the most sensitive to fertiliser burn. It is recommended that no more than 10 kg/ha P (50 kg/ha of MAP) be applied in direct contact with the seed of canola.

For comparative purposes, the Salt Indices of commonly used nitrogen, phosphorus and potassium fertilisers are shown in the following table.

Salt Indices of Commonly Used Fertilisers

Product	Salt Index
Urea	75
Gran-am (Sulfate of Ammonia)	69
SuPerfect (Single Superphosphate)	8
MAP	30
DAP	34
Muriate of Potash	114

The Salt Index compares the increase in osmotic potential brought about by the use of a fertiliser compared to sodium nitrate, which is given a value of 100. The Salt Index provides a guide to, but is not the sole determinant of the likelihood that a fertiliser will burn plant roots.

7.4 Application Rates

Application rates for phosphorus are variable, depending on the soil type (higher rates are used on red-brown earths), crop or pasture species, and expected yields. Higher rates of fertiliser are applied under irrigation and in areas favoured with high rainfall, as yield expectations are higher, and more nutrient is removed in farm produce.

- In rain-grown pastures, 10 - 20 kg/ha P is normally applied.

- In irrigated pastures, and where rainfall is favourable, 20 - 50 kg/ha P may be required. Higher rates are used on soils with a high phosphorus fixation capacity, and where the pasture is intensively grazed and nutrient removal is high.

- Grain and cotton crops often receive 10 - 20 kg/ha P. Lower rates are used in sorghum, e.g. 5 – 10 kg/ha P.

- In sugarcane, plant crops often receive 30 kg/ha P or more. Ratoon crops receive lower rates, e.g. 15 - 25 kg/ha P.

- Vegetable crops may receive 40 kg/ha P or more.

- Potatoes, when grown on red volcanic soils which readily fix phosphorus (attributable to their high iron content) can receive phosphorus at rates of 150 kg/ha P or higher.

- Tree crops typically receive 20 – 40 kg/ha P per annum.

When new land that is low in phosphorus is being bought into production for sugarcane and horticulture, it can be worthwhile applying 100 kg/ha P as an initial broadcast application, and incorporating it into the plough layer, so as to raise the soils phosphorus status to a more productive level.

Similarly, in new pastures, it is often recommended that 100 kg/ha P be applied cumulatively over the first three years, so as to raise the soil phosphorus levels as quickly as possible.

This allows a more rapid transfer or progress from legume dominant pastures with a high bloat risk, to well-balanced productive grass legume pastures.

7.5 Water Injection

Water Injection equipment is used to improve germination and emergence in grain crops planted at wide row spacings. Fertilisers, e.g. trace elements such as zinc, or inoculum for legumes, may be applied simultaneously.

Water injection equipment can be used to apply low rates of starter phosphorus in crops such as cotton and sorghum where soil phosphorus levels are moderate, and a response to phosphorus is not certain.

Sorghum is efficient at extracting phosphorus from the soil, so it is less responsive to fertiliser phosphorus than winter cereals such as wheat. Sometimes, there is an early response to phosphorus, but this can disappear as the root system and mycorrhizae (VAM) develop.

Phosphorus is not recommended in sorghum at soil test levels where it would be in other crops, i.e. the critical values are lower.

Responses to phosphorus in sorghum are more likely in early season plantings when soil temperatures are low.

Where soil phosphorus levels are marginal for sorghum, e.g. 15 – 30 mg/kg Colwell P, phosphorus can be applied at a low rate through water injection, using a Soluble/Solution grade of MAP as the phosphorus source. These products are two to three times more costly than the granular grades, so would not be used where soil phosphorus levels are low, and phosphorus needs to be applied at high rates.

Where soil phosphorus levels are low, dry granular phosphorus fertilisers, e.g. Incitec Pivot MAP, can be used at planting.

7.6 Fertigation

Fertigation can provide a convenient and labour-saving means of applying fertiliser, particularly where there is a need to apply nutrients on a regular basis during the growing season.

Phosphorus is not commonly used in fertigation programs in annual crops, in which an adequate supply of phosphorus is required from germination. Phosphorus plays an important role in stimulating early root development, so it is best applied in the basal fertiliser. Application after planting, particularly if applied to the soil surface, is much less effective.

Phosphorus is more likely to be used, in combination with nitrogen and potassium, in fertigation programs in perennial crops, e.g. trees and vines.

In crops grown under plastic mulch, e.g. strawberry, fertigation through underground emitters placed in the soil is the only practical way of maintaining the soil's fertility and replacing nutrients removed in the harvested produce.

Soluble/Solution grades of MAP and MKP may be used to apply phosphorus in fertigation programs. Seasonal phosphorus rates with fertigation will be similar to where fertilisers are applied dry to the soil.

7.7 Foliar Sprays

Foliar sprays can be used to supplement, but not replace soil applications of phosphorus fertiliser. Soluble/Solution grades of MAP and MKP may be used for this purpose

There are limits to how much fertiliser can be foliar-applied without burning the foliage.

Suggested foliar application rates for MAP and MKP in **vegetables** are:-

- On young foliage, and in sensitive crops, apply up to 500 g/100 L (0.5 % w/v).

- On mature leaves, and in tolerant crops, apply up to 1 kg/100 L (1 % w/v).

Lower concentrations are recommended in **tree crops**, in which higher spray volumes are used than in vegetables. As a guide, apply MAP or MKP at 250 g/100 L (0.25 % w/v).

7.8 Compatibility in Solution

Soluble phosphorus fertilisers, such as MAP and MKP, are compatible in solution with urea, ammonium nitrate, ammonium sulfate, potassium fertilisers (potassium chloride or Muriate of Potash, potassium sulfate and potassium nitrate), soluble boron fertilisers, sodium molybdate and metallic chelates.

Do not mix MAP and MKP in solution with calcium or magnesium salts, e.g. calcium nitrate or magnesium sulfate, or metallic sulfates, e.g. zinc sulfate, as insoluble precipitate will form.

8. CADMIUM

Cadmium occurs naturally in the soil. It is also present as an impurity in phosphorus fertilisers, being derived from the phosphate rock from which the fertiliser is made.

As the cadmium concentrations in phosphorus fertilisers are higher than those typically present in most agricultural soils, the regular use of phosphorus fertilisers may cause soil cadmium concentrations to gradually increase.

In some crops, e.g. potatoes and peanuts, violation of food standards (Maximum Levels or MLs) for cadmium occasionally occur, particularly on sandy soils and where poor quality irrigation water is used.

It is therefore advisable to choose low cadmium fertilisers where phosphorus is applied at high rates, so as to contain increases in soil cadmium; and in crops known to take up cadmium in large amounts.

It is recommended that fertilisers containing no more than 150 mg Cd/kg P be chosen for vegetable production. Fertilisers containing less than 100 mg Cd/kg P should be used where repeated high applications of phosphorus (that is greater than 100 kg/ha P per crop) are made.

The maximum cadmium concentration in Incitec Pivot fertiliser products is shown on the product label, which forms part of the packaging or is shown on the bag tag that is attached to 25 kg packs, is inserted into the pouch on Bulk Bags, or is attached to the Delivery Advice for bulk deliveries.

Incitec Pivot DAP and MAP typically contain less than 50 mg Cd/kg P.

Incitec Pivot SuPerfect contains up to 300 mg Cd/kg P, the maximum allowed in Australia. SuPerfect is mainly used on pasture.

SuPerfect should not be used as the sole source of phosphorus in NPK planting fertilisers for vegetables, and in other risk situations.

Note. The cadmium concentration in phosphorus fertilisers can be expressed in two ways:

- mg/kg Cd - milligrams of cadmium (Cd) per kilogram (or parts per million) in the product;
- mg Cd/kg P - the cadmium concentration per kilogram of phosphorus (P) in the product. Expressing the cadmium concentration this way allows easier comparisons to be made between fertilisers with different phosphorus contents.

9. PHOSPHORUS IN ANIMALS

Phosphorus makes up more than 20% of the body's mineral ash, being second to calcium. Nearly 80% of the phosphorus (P) in animals is found in bones and teeth. Pregnant and lactating animals have a high phosphorus requirement.

Phosphorus supplements are used where the diet is low in phosphorus, and for high producing animals, e.g. lactating dairy cattle.

Phosphorus deficiency in grazing animals is most likely to occur in unfertilised native pastures on soils with a low phosphorus status, e.g. spear grass country in central and northern Qld, and in high producing dairy cattle.

Affected animals lack thrift, live weight gains are poor or animals lose condition, calving and lambing percentages are depressed. Bones become brittle and break easily. Badly affected cattle will chew old bones.

For beef cattle on unfertilised phosphorus (P) deficient country in Queensland, the recommended supplementation rate is 5 grams P per head per day for dry cattle and 10 grams P for lactating breeders.

In North Queensland, the recommended time of year to feed phosphorus supplements is during the wet season (summer) when pastures are at their best and cattle are gaining weight.

Lactating dairy cattle may also require supplementation. Supplementation rates will depend on the quality of the feed on offer, and what other supplements are being fed in the bails. The advice of an animal nutritionist or Dairy Husbandry Officer should be sought.

Lot fed cattle on high grain diets do not require phosphorus supplements, as most grains are high in phosphorus.

The most commonly used phosphorus supplements are dicalcium phosphate (DCP) and monocalcium phosphate (MCP).

DCP typically contains 17 – 18% P and 25 – 26% Ca, and MCP 22% P and 16% Ca. These products have low solubility, and are mixed in dry with the feed. MCP is the more soluble of the two, and therefore more readily available for absorption by the animal.

High purity technical (Solution) grades of monoammonium phosphate (MAP) may be used in the preparation of licks for use in roller drums.

The granular phosphorus fertilisers marketed by Incitec Pivot fertilisers, i.e. DAP, MAP and SuPerfect, must not be used as mineral supplements for livestock. These products contain around 2% fluorine (F). Their use in animal feeds and stock licks is likely to result in fluorosis (fluorine poisoning).

10. THE ENVIRONMENT

Phosphorus has the potential to impact on aquatic environments if lost during storage and transit, or from the fields to which it is applied. Low concentrations in surface waters can stimulate weed and algal growth.

Applying phosphorus into the soil, rather than to the soil surface, virtually eliminates losses of fertiliser dissolved in surface run-off. This is not practical in pasture and tree crops. In these situations, phosphorus is usually applied in advance of or at the start of the main growing season. Application when peak rainfall events, e.g. summer storms, are likely, should be avoided.

In flood irrigated pastures, SuPerfect should be applied as soon as practical after an irrigation, rather than just before irrigating. Once in the soil, the main way in which phosphorus is lost is through soil erosion, attached to eroded soil particles.

Soil testing is encouraged, to ensure phosphorus is applied at appropriate rates. Properly nourished crops and pasture provide better ground cover, and protection against erosion. Soil testing also allows soils that are high in phosphorus to be identified, avoiding the over application of phosphorus. This not only is costly (unnecessary expenditure), it can also add to phosphorus concentrations in surface water where erosion occurs.

FURTHER READING

Agritopics on “Cadmium in Vegetables”, “Fertigation”, “Foliar Fertilisers” and “Mineral Supplements for Ruminants” are available, in which these topics are discussed in more detail.

WARNING

The information contained in this publication is for use as a guide only. The use of fertilisers is not the only factors involved in producing top yielding crops and pasture. Local soil, climatic and other conditions should also be taken into account, as these could affect pasture or crop responses to applied fertiliser.

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