Greener pastures 3 - Managing phosphorus in dairy pastures

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Managing phosphorus in dairy pastures
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Messages for farmers

- Soil testing for phosphorus (P) provides a reliable indication of when the level of phosphorus in a soil is likely to be adequate for pasture production in the next growing season.

- It is a waste of money to apply phosphorus fertiliser when soil testing indicates none is required, or to acidified soils, or to undergrazed pastures, or to pastures dominated by poorly productive species.

- Ryegrass-dominant pastures have a lower phosphorus requirement than clover-dominant pastures.

- Critical soil test P values are determined from the Phosphorus Buffering Index (PBI) for that soil type. Table 1 lists critical Colwell soil test values as determined for soils with different capacities to sorb P, ranked using PBI.

- No fertiliser phosphorus is required when soil test P is above the critical value for that soil. When soil test P is above the critical value for that soil, adding fertiliser phosphorus will have no effect on pasture production. It will also unnecessarily increase the already high phosphorus status of the soil, increasing the risk of phosphorus loss from the farm, contributing to eutrophication of adjacent waterbodies.
• When soil test P is above the critical value for that soil and no fertiliser phosphorus is applied, soil test P drops gradually. The rate of decline decreases as the PBI value of the soil increases. For most dairy soils in WA with relatively high PBI values, the rate of decline is slow and may take years to approach the critical soil test phosphorus value.

• Critical soil test phosphorus values for each pasture species do not change when nitrogen fertiliser is applied.
What did we learn about phosphorus in Greener Pastures?

We undertook two studies:

1. Between 1999 and 2009, soil testing was conducted in 48 dairy paddocks at Vasse Research Centre (VRC) in the south-west of Western Australia (WA). This study will be referred to as the VRC soil test study.

2. Phosphorus experiments were undertaken on partner farms of the Greener Pastures project to improve our knowledge of the phosphorus requirements of intensively grazed ryegrass pastures. These are the partner farm phosphorus experiments.

VRC soil test study

The soil sampling program

The study used 48 dairy paddocks at Vasse Research Centre which had been grazed intensively by dairy cows and their young stock over a period of 10 years, as part of the Vasse Milk Farmlets and Greener Pastures farming system projects. Pasture consisted of annual ryegrasses with some subterranean clover. Soils were 1-2 m sand to sandy loam over massive clay, known locally as Abba sand. For many soils in the region, including Abba sands, the topography is flat and the soils are waterlogged from June to early September in the typical May to November growing season.
Samples of the top 10 cm of soil were collected from each paddock in April 1999 and January-February 2000-2009, during the dry period before fertiliser was applied. These are the standard sampling depth and sampling time for soil sampling of dryland pastures in WA.

Soil samples were collected while walking on the same diagonal path across each paddock each year between two permanent markers located on fences. Samples were collected using 2.5 cm diameter metal tubes (10 cm long; known locally as pogos) that were pushed into the soil by foot every 2-3 m, with 50-100 samples collected per paddock, depending on the size of the paddock. The samples from each paddock were bulked, air dried and sieved through a 2 mm sieve to exclude coarse material. The samples were sent for analysis to CSBP Laboratories in Perth, WA. Soil test phosphorus was measured using the Colwell sodium bicarbonate soil test procedure, the standard procedure used in WA and much of Australia.

What did we find?

In the Vasse Milk Farmlet project, to ensure that pasture production was not limited by phosphorus supply, 49-55 kg P/ha was applied as fertiliser each year. In addition, phosphorus was also imported on to the farm in concentrates fed to the milkers. Consequently, soil test P increased significantly from 1999 to 2004 (Figure 1a).

During 2005-2009 in the Greener Pastures project, fertiliser phosphorus was only applied when soil test P was below the critical value for the sand to sandy loam soils. Most soil test P values were above the critical value, so few of the 48 paddocks were fertilised with phosphorus in these years. Mean soil test P declined gradually, but soil test values remained above critical values in most paddocks up to 2009 (Figure 1b).
This demonstrates that soils which have a reasonable capacity to hold onto P—those that have a high Phosphorus Buffering Index (PBI)—can accumulate a lot of plant-available phosphorus, as shown by high soil test values, and that these levels do not crash when no fertiliser phosphorus is applied.

Figure 1. Mean Colwell soil test P for the 48 paddocks in the Vasse Research Centre soil test study. During the Vasse Milk Farmlet project (1999-2004; Figure 1a) 49-55 kg P/ha was applied each year and linear regression indicated soil test P increased by 9.9 mg/kg per year. During the Greener Pastures project (2005-2009; Figure 1b) very little phosphorus fertiliser was applied. Linear regression indicated soil test P decreased by 4.7 mg/kg per year. Critical soil test phosphorus values are indicated by the dotted lines.
Partner farm phosphorus experiments

Phosphorus experiments were undertaken between May 2006 and June 2010 on intensively grazed ryegrass pastures on three leading commercial dairy farms in WA to evaluate the best method of applying fertiliser P.

The soils used had adequate soil P levels, the typical situation for most soils used for dairy production in WA.

Details on how the partner farm phosphorus experiments were undertaken, together with the results, discussion and conclusions, are provided in DAFWA Bulletin 4809. A summary of the study is reported here.

Brief details of the partner farm phosphorus experiments

Identical phosphorus experiments were established at three commercial dairy farms at Witchcliffe, North Jindong and Boyanup. The dryland pasture at each site consisted of annual ryegrasses with some subterranean clover, and was grazed intensively by dairy cows and their young stock.

The experiment comprised a nil treatment (no fertiliser phosphorus applied for the duration of the experiment), and three phosphorus levels (10, 20 and 30 kg P/ha per year) applied at three different timings in each growing season. These were all in autumn or half in autumn and half in spring or one sixth applied in autumn and after each of the first five grazings (there typically being at least five grazings in each growing season).
We expected to find the following:

1. No ryegrass production response to applied phosphorus when soil test P is above the critical value.

2. When no fertiliser phosphorus is applied, soil test P will decline gradually so phosphorus deficiency will take some time to develop.

What did we find?

No significant ryegrass production responses to applied fertiliser phosphorus were obtained, regardless of level or method of phosphorus application.

When no phosphorus was applied, soil test declined gradually, by between 4.4-7.1 mg/kg per year, and remained above the critical value for the soils at the Witchliffe and Jindong sites (Figures 2a and 2b). However, at the Boyanup site soil test declined below the critical value (Figure 2c).

Critical soil test P is located near the maximum yield plateau in the flat part of the relationship between yield and soil test, particularly when, as appropriate for dairy production, the critical value is for 95% of the maximum pasture dry matter yield.

Consequently, when no phosphorus is applied and soil test decreases, significant pasture yield decreases will only occur when the soil test approaches the steeper part of the relationship, which can take some time.

In addition, as occurs on farms, faeces deposited by cows while grazing supplied phosphorus to pasture, even when no fertiliser phosphorus was applied.
Figure 2. Colwell soil test phosphorus (P) for the nil-P treatment of 4 experiments conducted in the dairy region of Western Australia. Critical soil test phosphorus values for each site are indicated by the dotted lines.
Background Reading

Role of phosphorus in plants

Phosphorus is an essential component of cell membranes, genetic material, energy storage and transfer systems for chemical reactions in plant cells. Early plant growth is particularly dependent on phosphorus because of rapid cell division and expansion. The primordia for future stems, roots, leaves, flowers and seed are produced very early in the growth of annual plants so phosphorus deficiency during growth of germinating seedlings and plants can greatly reduce their yield potential.

Soil phosphorus

Phosphorus is derived from minerals in the rocks from which soils are formed. Western Australian soils are among the most ancient and highly weathered in the world. In their undeveloped state, most contained very low amounts of phosphorus and native plant species adapted to cope with this. However, few native plants were thought suitable for agriculture so they were cleared and introduced pasture and crop species were planted instead. These plants could not access enough phosphorus from the soil, so water-soluble phosphorus fertilisers, in which 80-90% of the total phosphorus is initially water-soluble, were applied.

Phosphorus fertilisers

For most soils, granulated fertilisers in which most of the phosphorus is water-soluble have been shown to be the most effective fertilisers for crop and pasture production in WA, although lower water soluble phosphorus fertilisers may have a place on some very sandy soils. Single Superphosphate was the first of the granulated phosphorus fertilisers. It contains about 9% phosphorus—80% of which is water-soluble—10% sulphur and 20% calcium.
Imported fertilisers include triple superphosphate, supplying phosphorus and calcium, and ammonium phosphate fertilisers, supplying mainly phosphorus and nitrogen. Triple superphosphate contains 20% phosphorus—80% being water-soluble—and 15% calcium. Imported ammonium phosphate fertilisers include MAP, containing 22% phosphorus and 11% nitrogen, and DAP, containing 20% phosphorus and 17.5% nitrogen, with 90% of the phosphorus in both fertilisers being water-soluble. Locally manufactured ammonium phosphates contain some sulphur in addition to phosphorus and nitrogen.

**Uptake of phosphorus from soil**

Plant roots take up water-soluble phosphorus from the soil solution. Phosphorus is not chemically stable in the water-soluble form, and readily reacts with iron and aluminium exposed at the surface of soil constituents (clays, oxides and organic matter) to form sparingly soluble compounds. This is the process of sorption (retention, fixation, binding) of phosphorus by soil. A consequence of sorption is that the concentration of phosphorus in soil solution can be very low.

Plant roots intercept water-soluble phosphorus as they grow through moist soil, with many fine roots produced when water-soluble phosphorus is encountered (known as root proliferation).

**Effect of pasture species and nitrogen fertiliser on uptake of phosphorus**

Annual and Italian ryegrasses and subterranean clover are the most profitable pasture species in terms of quantity and quality for animal production in the high rainfall (>600 mm) region.
of south west WA. Ryegrass is better able to use the phosphorus taken up from soil and accumulated into herbage to produce dry matter than clover, so ryegrass has a lower requirement for phosphorus fertiliser than clover. As critical soil test values have been developed for clover-dominant pastures (for further discussion, see below), these will be more than adequate for ryegrass-dominant pastures.

Critical soil test phosphorus values for ryegrass have been found to be unaffected by application of nitrogen fertiliser after grazing. The same applies to clover. Both clover and ryegrass plants respond to the nitrogen by growing bigger leaves and stems. However, in pastures treated with nitrogen after each grazing, ryegrass plants grow over the top of, and shade out clover, which can rapidly disappear from such pasture. Where use (or lack of use) of nitrogen fertiliser leads to a change in the proportion of ryegrass vs. clover over time, it may change the critical soil test phosphorus value for the pasture owing to differences in phosphorus requirements for these two species.

**Residual value of phosphorus fertilisers**

Phosphorus fertilisers supply phosphorus for plant uptake in the year of application as well as in following years—they have a residual value. Fertilisers have a residual value because plant roots can acquire phosphorus which has been previously sorbed by soil, and from the 10 to 20% of sparingly soluble phosphorus still present from previously applied fertiliser. In addition, phosphorus taken up by plants and organisms growing in the soil is returned to the soil as organic matter. Animals grazing pasture return phosphorus to soil in faeces. Soil organisms (insects, including dung beetles, earthworms, fungi, algae, protozoa and
bacteria) physically and chemically process soil organic matter and faeces to release nutrients, including phosphorus, into soil solution for plant uptake. This is the process of mineralisation. Mineralised phosphorus can be taken up by soil organisms, but can also be sorbed by soil if it contains iron and aluminium exposed at the surfaces of soil constituents. Therefore, regular application of fertiliser increases the phosphorus status of the soil. Over time, most or all of the phosphorus crops and pastures require comes from phosphorus stored in the soil so little or no fertiliser phosphorus needs be applied. This could occur in under 10 years for soils with low phosphorus sorption—for example, Banksia sands—or more than 25 years for soils with high phosphorus sorption—for example, Karri loams.

Decline in phosphorus soil test when no fertiliser is applied

Soils with a high PBI (greater than 70) which have been heavily fertilised over many years usually have a phosphorus soil test well above the critical value. If no phosphorus fertiliser is applied, phosphorus soil test values generally decline—they do not crash. Clearly, phosphorus soil tests in sandy soils with a very low PBI may fall more quickly than those with a high PBI. An example for a nil-phosphorus treatment is shown in Figure 2d (see earlier). In this case the critical value for soil test phosphorus was 34 mg/kg, owing to a PBI value of 132. Although soil test phosphorus levels were declining year after year, in all years the soil test values were above the critical value. There was no effect of declining soil phosphorus status on pasture production, which was 9.3, 12.3, 9.6 and 11.2 t DM per ha for the years 2001-2004 respectively.
Similarly, there was no pasture yield response to applied phosphorus. The nil-phosphorus plots yielded as much as the highest rate of phosphorus in every year of the experiment. Further details are provided in DAFWA Bulletin 4809.

**When is it sensible to apply fertiliser phosphorus?**

It is not profitable to apply fertiliser phosphorus to pasture if the pasture does not need it. Soil and tissue testing are used to indicate the likelihood of phosphorus deficiency and therefore whether or not it is likely the pasture will respond to phosphorus fertiliser.

However, three other factors may need attention before considering application of phosphorus fertiliser to pasture:

1. Grazing management.
2. Amelioration of soil acidity.
3. Renovating pastures that have deteriorated.

**Grazing management**

It is a waste of money to apply fertiliser to undergrazed pasture to grow more unused pasture.

Undergrazing results in pastures becoming dominated by poorly producing species and it is usually not profitable to fertilise these species. It is often more profitable to improve grazing management to use more paddock-grown pasture than to apply more fertiliser.

**Soil acidity**

Agricultural production acidifies soils. As a soil becomes more acid (pH in calcium chloride less than 5.5), most nutrients, including phosphorus, become less available for plant uptake. As soil pH falls below 5.0, dissolution of aluminium increases. The concentration of aluminium in soil solution eventually becomes toxic to plant roots, reducing root function and growth and interfering with their ability to explore the soil to take up water and nutrients.
Soil acidification is ameliorated by applying sufficient lime to raise the pH of the top 10 cm of soil to 5.5 or greater.

When first cleared for agriculture, many west coast soils had pH values of 5.5 to 6.0. Unfortunately these soils were allowed to acidify until pH values of 4.0 or less were common. Several applications of lime over several years are required to ameliorate these highly acidified, poorly productive soils.

As soils acidify, subterranean clover and ryegrass are replaced by inferior species. Therefore, subterranean clover and ryegrass may need to be re-established in the pasture, once soil pH has been corrected by liming. Once soil acidification has been corrected, monitor soil pH regularly (preferably yearly) and re-apply lime to maintain soil pH at 5.5 or greater. Smaller amounts of lime are required to maintain pH near the target value. Don’t wait until low soil pH values re-occur, which would then require another major liming program over several years to rectify.

Renovate pastures

Undergrazed and acidified pastures become dominated by poorly producing species. It is often profitable to renovate these pastures to re-establish annual ryegrasses and subterranean clover as the dominant productive pasture species.

However, renovation will be a waste of time and money unless the factors which caused the pasture to deteriorate in the first place are identified and corrected. Otherwise, poorly producing species will soon again dominate the pasture.

Best time to apply phosphorus fertiliser

The best time to apply phosphorus fertiliser to a deficient soil is three weeks after pasture has emerged at the start of the growing season, except on soils with very high PBI when it should be applied close to germination.
This ensures there is adequate phosphorus for pasture production during the whole growing season and that the fertiliser is applied when pasture plants have developed sufficient roots to take up nutrients. It should also reduce leaching of phosphorus below plant roots in very sandy soil, and runoff in water flowing over soil when rainfall is intense.

Soil testing for phosphorus

Soil testing provides a reliable indication of when phosphorus is likely to be required. Samples are collected before the start of the growing season, usually in January-March. Only apply phosphorus fertiliser when the soil test is below the critical value for that soil.

Soil test values are measured using a sodium bicarbonate procedure by one of two methods, known as the Colwell or Olsen tests. The Olsen method was developed in the early 1950s in the United States of America and is used in Victoria, Tasmania and New Zealand. All other states of Australia, including WA, use the Colwell method developed in the early 1960s in New South Wales, which is a modified version of the Olsen procedure.

Capacity of soils to sorb phosphorus

Soil test calibrations are strongly influenced by the capacity of the soil to sorb phosphorus from soil solution, particularly when the Colwell procedure is used.

Phosphorus is sorbed by iron and aluminium exposed at the surfaces of soil constituents (clays, oxides, organic mater, and sandy soils coated with various amounts of iron and aluminium oxides). Soils have different capacities to sorb phosphorus so have different soil test calibrations.
When measuring soil test values in the laboratory, the capacity of the soil to sorb phosphorus can be ranked using a variety of procedures.

The first procedure used in WA was reactive iron, which is the amount of iron extracted from soil by ammonium oxalate. However, reactive iron is an indirect measure of phosphorus sorption. Subsequently, phosphorus sorption was measured directly by adding one level of phosphorus to soil, which was known as the Phosphorus Retention Index (PRI).

More recently, the PBI has been developed to quantify the capacity of soil to sorb phosphorus. This has now become the national standard procedure used throughout Australia.

Critical soil test values

The critical soil test value for a soil is the value which produces a pasture yield of 95 per cent of the maximum. Below this value, the pasture is likely to respond to freshly-applied phosphorus. Critical soil test values are listed for soil types with different PBI values in Table 1. These are for soils sampled to the standard soil sampling depth of 10 cm and are based on the Better Fertiliser Decisions manual.

How to use Table 1 — an example

If PBI is 18, the critical Colwell soil test P to achieve 95% of maximum pasture production for that soil is greater than 25.

If the Colwell soil test P is well above the critical Colwell soil test P value, the soil is highly likely to contain more than adequate phosphorus for 95% of maximum pasture production in the next growing season and no fertiliser phosphorus is required.
Table 1. For the top 10 cm of soil, phosphorus (P) sorption capacity measured by PBI, and critical Colwell soil test P values to achieve 95% of maximum production of clover based pastures in high rainfall (>600mm) areas (adapted from Victorian Department of Primary Industries (2007) by D. M. Weaver and R. N. Summers).

<table>
<thead>
<tr>
<th>PBI</th>
<th>Less than 5</th>
<th>5—9</th>
<th>10—14</th>
<th>15—34</th>
<th>35—69</th>
<th>70—139</th>
<th>140—279</th>
<th>280—840</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Colwell soil test P value (mg/kg)</td>
<td>above 10</td>
<td>above 15</td>
<td>above 20</td>
<td>above 25</td>
<td>above 29</td>
<td>above 34</td>
<td>above 40</td>
<td>above 55</td>
</tr>
</tbody>
</table>

If the soil test P is well below the critical Colwell soil test P value, it is highly likely that the soil does not contain sufficient phosphorus to achieve 95% of maximum pasture production in the next growing season so fertiliser phosphorus will be required.

If the soil test P is close to the critical Colwell soil test P value (±10%) a small application of fertiliser (roughly equivalent to the phosphorus removed in products) may be required to maintain the soil phosphorus status of the soil at that critical value.

The most profitable rate of phosphorus to apply will depend on many factors and can be determined in consultation between the farmer and a FertCare accredited adviser.

A more comprehensive discussion of this data is provided in DAFWA Bulletin 4808.
Plant tissue testing for phosphorus

Regular testing of plant tissue in selected paddocks through the growing season can be used to confirm phosphorus fertiliser decisions based on soil testing.

Plant tissue testing can be used to indicate when clover or ryegrass in the pasture are likely to be phosphorus deficient. Values are available for young plant samples (called young tissue) collected near the top of the pasture just before the pasture is grazed (grab samples), or for plant samples collected above the soil surface (called whole shoots). Separate samples need to be collected for ryegrass and clover because critical plant testing values, below which phosphorus deficiency is likely, differ for these species.

Suggested values are listed in Table 2.

Table 2. Critical plant phosphorus test values for ryegrass and clover (from data summarised by Pinkerton, Smith and Lewis 1997).

<table>
<thead>
<tr>
<th>Pasture species</th>
<th>Critical concentration (range) (per cent phosphorus in dry matter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young tissue</td>
</tr>
<tr>
<td>Ryegrass</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>(0.2—0.28)</td>
</tr>
<tr>
<td>Clover</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>(0.30—0.40)</td>
</tr>
</tbody>
</table>
Further reading


Bolland MDA, Russell WK (2008) Lime for high rainfall pastures: above 800 mm average annual rainfall. Bulletin 4750 (Department of Agriculture and Food: South Perth)
Bolland MDA, Russell WK (2009) Sulphur for high rainfall, rain-fed pastures: above 800 mm average annual rainfall. Farmnote No. 404


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