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Phosphorus for high rainfall pastures
Phosphorus for high rainfall pastures

Mike Bolland and Bill Russell, Department of Agriculture and Food, Bunbury, and David Weaver, Department of Agriculture and Food, Albany
Soil testing for phosphorus 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.

Legumes have higher phosphorus requirement than grasses.

Critical soil test phosphorus values do not change when nitrogen fertiliser is applied.

Role of phosphorus in plants

Phosphorus is an essential component of cell membranes, genetic material and 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 are adapted to cope with this.
Few native plants are profitable for agriculture so they were removed and introduced pasture and crop species planted. These plants could not access enough phosphorus from the soil so water-soluble phosphorus fertilisers, in which 80 to 90 per cent 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 P fertilisers may have a place on some very sandy soils. Single Superphosphate was the first of the granulated fertilisers. It contains about 9 per cent phosphorus—80 per cent of which is water-soluble—10.5 per cent sulphur and 20 per cent calcium.

Imported fertilisers include triple superphosphate, supplying only phosphorus, and ammonium phosphate fertilisers, supplying phosphorus and nitrogen. Triple superphosphate contains 20 per cent phosphorus—80 per cent being water-soluble—and 15 per cent calcium.

Imported ammonium phosphate fertilisers include MAP, containing 22 per cent phosphorus and 11 per cent nitrogen, and DAP, containing 20 per cent phosphorus and 17.5 per cent nitrogen, with 90 per cent 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 so water-soluble phosphorus 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) 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).

**Residual value of phosphorus fertilisers**

Phosphorus fertilisers supply phosphorus for plant uptake in the year of application and in following years—they have a residual value. Fertilisers have a residual value because plant roots can acquire water-soluble phosphorus from phosphorus which has been previously sorbed by soil and from the 10 to 20 per cent sparingly soluble phosphorus present in fertiliser granules. 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, protozoa, algae, fungi, 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 soil so little or no fertiliser phosphorus needs be applied. Depending on application rate, this could occur in under 10 years for soil with low phosphorus sorption—for example, Banksia sands—or more than 25 years for soils with high phosphorus sorption—for example, Karri loams.
Best pasture species for animal production

Clover, principally subterranean clover, and annual and Italian ryegrass, 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 acquire phosphorus from soil than clover so ryegrass has a lower requirement for phosphorus fertiliser than clover.

When is it profitable to apply fertiliser phosphorus?

It is not profitable to apply fertiliser phosphorus to pasture unless the pasture needs it. Soil and plant testing are used to indicate the likelihood of phosphorus deficiency and therefore whether or not it is likely to be profitable to apply phosphorus fertiliser.

However, three factors may need attention before it is profitable to apply phosphorus fertiliser to pasture:

- Grazing management.
- Amelioration of soil acidity.
- Renovating pastures that have deteriorated.

Only when all these three factors have been rectified is it likely to be profitable to apply phosphorus fertiliser—and then only when soil testing indicates it is required.

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 always profitable to improve grazing
management to use more paddock grown pasture, which improves persistence of clover and ryegrass in the pasture.

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 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, in addition to liming, subterranean clover and ryegrass may need to be re-established in the pasture.

Once soil acidification has been ameliorated, 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 will require another major liming program over many years to rectify.
Renovate pastures

Undergrazed and acidified pastures become dominated by poorly producing species. It is profitable to renovate these pastures to re-establish subterranean clover and ryegrass as 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.

Summary

• It is a waste of money to apply phosphorus fertiliser to acidified soils; apply lime.
• Renovate the pasture to re-establish subterranean clover and ryegrass.
• Improve grazing management to use more pasture.

When a soil's phosphorus soil test is above the critical level for that soil, the soil has enough phosphorus for pasture production in the next growing season.

Pasture production, and so animal production, is not increased if phosphorus fertiliser is applied when soil testing indicates none is required, so don’t waste money applying it.
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. 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. This should 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 Olsen or Colwell test. The Olsen method was developed in the early 1950s in the United States of America and is used in Victoria and Tasmania. The rest of Australia, including Western Australia, uses the Colwell method, which is a modified version of the Olsen procedure developed in the early 1960s in New South Wales.

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 matter, 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 Western Australia 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.

The first such method was the Phosphorus Retention Index (PRI) while the second method, developed recently in Eastern Australia and now the national standard procedure used in all states, is the Phosphorus Buffering Index (PBI).

Critical soil test values

The critical soil test value for a soil is the value which produces a target pasture yield expressed as a percentage of the maximum. Intensively grazed pasture systems such as dairies are likely to target 95% of maximum production, whilst less intensive beef and sheep grazing systems may aim for 80 to 85% of maximum production. Your production level target should be discussed with your FertCare accredited advisor.

Critical soil test values are listed for different soil types for 95% of maximum production in Table 1, together with the capacity of that soil to sorb phosphorus, measured using reactive iron, PRI and PBI. These figures are based on the standard soil sampling depth of 10 cm and are based on the Better Fertiliser Decisions manual. Critical soil test values are listed for different soil types for 90%, 85% and 80% of maximum production in Table 2.
Table 1. For the top 10 cm of different soils, phosphorus (P) sorption category, capacity of soil to sorb P measured using reactive iron, PRI and PBI, and critical Colwell soil test P values to achieve 95% of maximum production of clover based pastures in high rainfall (>600mm) areas (developed by D. M. Weaver and R. N. Summers).

<table>
<thead>
<tr>
<th>Capacity of soil to sorb P</th>
<th>Reactive Iron (mg/kg) A</th>
<th>PRI (L/g) A</th>
<th>PBI B</th>
<th>Critical Colwell soil test P (mg/kg) B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exceedingly Low</td>
<td>0–100</td>
<td>&lt;0.35</td>
<td>&lt;5</td>
<td>&lt;7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7–10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;10</td>
</tr>
<tr>
<td>Exceptionally Low</td>
<td>100–200</td>
<td>0.35–1</td>
<td>≥5–10</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10–15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;15</td>
</tr>
<tr>
<td>Extremely Low</td>
<td>200–280</td>
<td>1–2</td>
<td>≥10–15</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15–20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;20</td>
</tr>
<tr>
<td>Very, very low</td>
<td>280–650</td>
<td>2–9</td>
<td>≥15–35</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Very low</td>
<td>650–1250</td>
<td>9–28</td>
<td>≥35–70</td>
<td>&lt;25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25–29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;29</td>
</tr>
<tr>
<td>Low</td>
<td>1250–2500</td>
<td>28–87</td>
<td>≥70–140</td>
<td>&lt;29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29–34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;34</td>
</tr>
<tr>
<td>Moderate</td>
<td>2500–4950</td>
<td>87–275</td>
<td>≥140–280</td>
<td>&lt;34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34–40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;40</td>
</tr>
<tr>
<td>High</td>
<td>4950–14500</td>
<td>275–1680</td>
<td>≥280–840</td>
<td>&lt;40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40–55</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;55</td>
</tr>
</tbody>
</table>

A, ranges estimated from reactive iron, PRI and PBI data collected by Summers and Weaver (2006).
C, Lower production targets will reduce the critical Colwell soil test P values. See Table 2 for 90%, 85% and 80% of maximum production critical Colwell soil test P values.
Table 2. For the top 10cm of different soils, PBI, and critical Colwell soil test P values to achieve 90%, 85% and 80% of maximum production of clover based pastures in high rainfall (>600mm) areas (developed by D.M. Weaver and R.N. Summers).

<table>
<thead>
<tr>
<th>PBI&lt;sup&gt;A&lt;/sup&gt;</th>
<th>Phosphorus Status with reference to 90% of maximum production</th>
<th>Phosphorus Status with reference to 85% of maximum production</th>
<th>Phosphorus Status with reference to 80% of maximum production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Critical Colwell soil test P (mg/kg)</td>
<td>Critical Colwell soil test P (mg/kg)</td>
<td>Critical Colwell soil test P (mg/kg)</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>&lt;5</td>
<td>&lt;6</td>
<td>6–8</td>
<td>&gt;8</td>
</tr>
<tr>
<td>≥5–10</td>
<td>&lt;8</td>
<td>8–11</td>
<td>&gt;11</td>
</tr>
<tr>
<td>≥10–15</td>
<td>&lt;11</td>
<td>11–15</td>
<td>&gt;15</td>
</tr>
<tr>
<td>≥15–35</td>
<td>&lt;15</td>
<td>15–20</td>
<td>&gt;20</td>
</tr>
<tr>
<td>≥35–70</td>
<td>&lt;20</td>
<td>20–22</td>
<td>&gt;22</td>
</tr>
<tr>
<td>≥70–140</td>
<td>&lt;22</td>
<td>22–25</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

A, refer to Table 1 for equivalent PRI and reactive iron values.
How to use Table 1 and 2

If the PBI is 18, to achieve 95% of maximum production, the critical Colwell soil test P (High P Status) for that soil is a value greater than but not equal to 25. The equivalent PBI value for reactive iron is 280–650 and for PRI is 2–9. While reactive iron and PRI are no longer used, these values are included in Table 1 so people familiar with these historical measures can compare them. To achieve 80% of maximum production (Table 2) with a PBI of 18, the critical Colwell soil test P for that soil is a value greater than but not equal to 14.

If the Colwell soil test P is well above the high P status critical 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 P is required.

If the Colwell soil test P is well below the high P status critical 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 high P status critical value (±10%), a small application of fertiliser (roughly equivalent to the phosphorus removed in products, and losses in leaching, runoff and P sorption) 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.

Plant 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 clover and ryegrass because critical plant testing values, below which phosphorus deficiency is likely, usually differ for clover and ryegrass. Suggested values are listed in Table 3.

**Table 3.** Critical plant phosphorus test values for clover and ryegrass (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>Clover</td>
<td>0.35 (0.3–0.40)</td>
</tr>
<tr>
<td>Ryegrass</td>
<td>0.24 (0.2–0.28)</td>
</tr>
</tbody>
</table>
Decline in phosphorus soil test when no fertiliser is applied

Soils with a high PBI 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 slowly for soils with PBI greater than 70—they do not crash.

An example is shown in Table 4, using results from a dryland experiment conducted on a dairy farm near Boyanup. Six rates of phosphorus, as superphosphate, were applied three weeks after pasture emerged at the start of each growing season—the standard recommendation for the region. The soil test and yield data shown in Table 4 are for the nil-phosphorus treatment.

The yield data are for pasture dry matter consumed for all grazings in each year. Because the soil test values for the nil-phosphorus treatment were always above the critical value for the soil (34 mg/kg = ppm, for a PBI of 132), 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.

The experiment started mid-June 2000, so yields are lower than in subsequent years because pasture yields before the start of the experiment in 2000 were not measured.

The experiment was terminated at the end of the 2004 growing season. Phosphorus soil tests in sandy soils with a very low PBI may fall more quickly than those with a high PBI.
Table 4. Gradual decline in Colwell soil test phosphorus (P) values when no phosphorus fertiliser was applied since 2000, and pasture dry matter consumed by dairy cows each year (from Bolland and Guthridge 2007a).

<table>
<thead>
<tr>
<th>Year</th>
<th>Soil test phosphorus for the nil-phosphorus treatment (mg/kg)</th>
<th>Pasture dry matter consumed each year (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>73</td>
<td>4.9</td>
</tr>
<tr>
<td>2001</td>
<td>62</td>
<td>9.3</td>
</tr>
<tr>
<td>2002</td>
<td>52</td>
<td>12.3</td>
</tr>
<tr>
<td>2003</td>
<td>52</td>
<td>9.6</td>
</tr>
<tr>
<td>2004</td>
<td>48</td>
<td>11.2</td>
</tr>
</tbody>
</table>

Nitrogen Fertiliser

Clover usually provides enough nitrogen for pasture production so it is generally not profitable to apply nitrogen fertiliser to pasture, except to grow silage and hay. In addition, nitrogen is often strategically applied to grassy paddocks when paddock-grown feed is scarce, such as near the start of the growing season.

However, when pasture use has been maximised for milk production, clover no longer provides enough nitrogen for pasture production. Pasture use is maximised by adopting the three-leaf
grazing strategy for ryegrass-based pastures outlined by Fulkerson and Donaghy (2001) when about 80 per cent of the pasture is consumed by dairy cows at each grazing. Nitrogen fertiliser needs to be applied to these pastures after each grazing. Both clover and ryegrass plants respond to the nitrogen by growing bigger leaves and stems. However, between grazings, ryegrass plants grow over the top of, and shade out clover, which rapidly disappears from the pasture, so ryegrass soon dominates pastures treated with nitrogen after each grazing.

Critical soil test phosphorus values have been found to be unaffected regardless whether or not nitrogen fertiliser is applied after each grazing, and whether the pasture comprises mostly clover or ryegrass, or both clover and ryegrass co-exist in the pasture.

Further reading


Mike Bolland and Bill Russell (2008) Lime for high rainfall pastures: above 800 mm average annual rainfall. Bulletin 4750 (Department of Agriculture and Food: South Perth)

Mike Bolland and Bill Russell (2009) Sulphur for high rainfall, rain-fed pastures: above 800 mm average annual rainfall. Farmnote No. 404

