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Phosphorus retention of sandy horticultural soils on the Swan Coastal Plain

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Soils can be ranked according to their phosphorus retention capacity by the phosphorus retention index (PRI). This is the ratio of phosphorus absorbed by soil to that remaining in solution under a set of standard conditions.

Although it is a laboratory measurement, the PRI seems to be a good indication of what happens in practice.

A list of the PRIs of some Western Australian soils in their virgin state and some amendment materials is given in Table 1.

The iron and aluminium (sesquioxide) content of soils is important in their ability to retain phosphorus. The sands of the coastal plain generally have lower concentrations of iron and aluminium than soils further inland, such as the gravelly soils of the hills or the red-brown earths of the wheatbelt.
Vegetable production in the Perth area traditionally developed on the peat and marl soils of the lake beds and adjacent areas where the high watertables were used as natural subirrigation during summer.

With the development of sprinkler irrigation technology in the 1950s, vegetable production moved onto the reddish-orange (Spearwood) and yellow (Karrakatta) sands of the western portion of the coastal plain both north and south of Perth. These soils were close to the coast and experienced milder winters and summers than further inland. In addition there were plentiful supplies of shallow groundwater.

With the expansion of the urban area in the 1960s and 1970s, vegetable production was forced onto similar soils further north and also onto the poor pale-yellow to grey Karrakatta and Bassendean sands further east. Although groundwater was plentiful, these soils have proved to be less satisfactory from an environmental point of view because of poorer nutrient (phosphorus, nitrogen, potassium) retention than the better quality sands.

Soils that have poor nutrient retention cost the grower money in lost fertilizer nutrients. They also pollute adjacent water bodies. This pollution costs the community money in lost amenity value of wetlands, rivers and estuaries and the resources needed to reverse the environmental degradation.

Soils that are used for horticultural production in Western Australia’s south-west must retain the applied phosphorus for best crop yields and to minimize damaging pollution to surface water bodies.

During 1988-89 researchers gathered information from several sources (Jeffery 1989) on the phosphorus-retention capacity of sandy coastal plain soils used for vegetable production. This information should be useful in planning strategies to locate horticulture in the most appropriate areas.

However, even amongst the sands there are large differences in phosphorus retention capacity (Table 1). The sands with higher iron and aluminium contents such as the reddish-orange Spearwood (with limestone near the surface) and the yellow Karrakatta sands appear to retain significantly more phosphorus than the poorer Karrakatta and grey Bassendean (Joel) sands. The increased phosphorus retention capacity with depth in some soils was probably related to increased limestone because limestone (calcium carbonate) readily precipitates phosphorus.

The actual amount of fertilizer phosphorus (after accounting for native phosphorus) retained in a number of sandy soils on the coastal plain after various periods of vegetable cropping was measured using chemical analysis during 1988-89. A rotary air blast drill was used to obtain deep soil samples at the Guilderton sites.

Yellow Karrakatta sands

A yellow Karrakatta sand had been cropped to vegetables for five years at Guilderton (see photo on page 28). In that time over 1,400 kg of phosphorus per hectare had been applied to nine vegetable crops (including broccoli, carrots, Chinese cabbage, lettuce, onion and potatoes). Assuming 200 kg of phosphorus per hectare was removed in harvested product, more than 1,200 kg of phosphorus per hectare from fertilizer would remain in the soil.

### Table 1. Phosphorus retention index (PRI), iron and aluminium content of some virgin Western Australian soils according to depth, and (sesquioxide) amendment materials

<table>
<thead>
<tr>
<th>Soil type/amendment</th>
<th>Depth (cm)</th>
<th>PRI†</th>
<th>(Iron and aluminium) %†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joel sand</td>
<td>0-100</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Grey Karrakatta sand</td>
<td>0-100</td>
<td>0.3-0.4</td>
<td>-</td>
</tr>
<tr>
<td>Grey Karrakatta sand</td>
<td>150-200</td>
<td>1.2</td>
<td>-</td>
</tr>
<tr>
<td>Wongan grey sand</td>
<td>0-20</td>
<td>2.7</td>
<td>0.15</td>
</tr>
<tr>
<td>Yellow Karrakatta sand</td>
<td>0-100</td>
<td>3.2-4.1</td>
<td>0.4-1.0</td>
</tr>
<tr>
<td>Spearwood sand</td>
<td>0-100</td>
<td>7.0</td>
<td>-</td>
</tr>
<tr>
<td>Wongan yellow loamy sand</td>
<td>0-20</td>
<td>13.0</td>
<td>0.5-0.6</td>
</tr>
<tr>
<td>Yellow Karrakatta sand</td>
<td>200-700</td>
<td>16.0-26.0</td>
<td>-</td>
</tr>
<tr>
<td>Gingin red loam</td>
<td>Surface</td>
<td>70.0</td>
<td>2.5-4.0</td>
</tr>
<tr>
<td>Red mud</td>
<td>-</td>
<td>310.0</td>
<td>20.3</td>
</tr>
</tbody>
</table>

† Extracted in citrate-dithionite.
†† PRI is the ratio of phosphorus adsorbed by soil (micrograms per gram) compared to that remaining in a solution (of initial concentration of 10 mg phosphorus per litre) after 16 hours.
The PRI over the top 100 cm in the virgin soil was between 3 and 5 (Table 1) and the pH (CaCl₂) 6.4 to 6.7. Even though these PRI figures are low compared with many soils, more than 90 per cent of the applied phosphorus appears to have been retained in the top 100 cm (Figure 1) after cropping. There was little evidence of phosphorus being leached further than one metre.

In addition, the bicarbonate extractable phosphorus (that is, soil test phosphorus) was 70 ppm after fertilization compared with only 3 ppm on the virgin site. This provides further evidence that this soil has the capacity to build up a bank—indeed a ‘superbank’—of residual phosphorus.

**Reddish-orange (Spearwood) sands**

A Spearwood sand at Medina Research Station (see photo on page 28) had been cropped to a wide range of vegetables for 25 years. It received more than 7,500 kg of phosphorus per hectare after allowing for removal in the harvested product. The PRI in the top 100 cm of the virgin soil was 7.0, higher than a yellow Karrakatta sand, and a pH of 7.0 which is slightly higher than the Karrakatta sands. All of the fertilizer phosphorus (Figure 2) could be accounted for in the top 100 cm just above the limestone.

The extractable phosphorus in the top 20 cm increased from 15 ppm in the virgin soil to over 250 ppm after fertilization, indicating this soil retains phosphorus and can build a superbank. The reddish-orange Spearwood sands appear to be the most phosphorus-retentive of the four sands investigated.

**Grey (pale-yellow) Karrakatta sands**

The grey Karrakatta sands at Guilderton had a lower PRI (0.3 to 0.4) in the surface layers than the yellow Karrakatta or Spearwood sands (Table 1), although it increased with depth. The pH was similar to the yellow Karrakatta sand. Despite this, they still managed to retain reasonable quantities of phosphorus. After two years of vegetable cropping (carrots, cauliflowers) and over 900 kg of applied phosphorus (allowing for removal in harvested product), more than 70 per cent of the phosphorus was retained in the top one metre, and 90 per cent in the top 1.5 m (Figure 3). It appears these soils can retain phosphorus, but not as well as the yellow Karrakatta or Spearwood sands.

The extractable phosphorus in the top 100 cm was 30 ppm after fertilization compared with 2 ppm in the virgin soil, indicating a moderate although limited capacity to build up a superbank. These soils need to be managed carefully to prevent phosphorus leaching into shallow watertables, particularly near wetlands.

**Bassendean sands**

The Joel sands at Keysbrook had a lower PRI (about 0) than the other sands (Table 1) and a lower pH (5.0 to 5.5). After five years of vegetable cropping (mainly carrots) and over 1,000 kg of phosphorus applied per hectare, there was less than 30 per cent retained in the top 100 cm (Figure 4).
In addition, the extractable phosphorus never exceeded 8 ppm in the top 20 cm after fertilization, indicative of a soil with negligible capacity to retain phosphorus. The extractable phosphorus in the virgin soil was 2 ppm. The phosphorus readily leached into the shallow (120 cm) water table underlying these soils. These soils will have to be amended with high phosphorus-fixing materials such as ‘red mud’ and red loam to prevent phosphorus leaching or polluting adjacent water bodies.

**Phosphorus in the water**

The phosphorus concentration in the water leaching from agricultural and horticultural soils determines the quantity of phosphorus that enters water bodies. In this respect, subsurface and surface flow is usually more important than water movement deep in the aquifer.

Water leaching from soils that have very low phosphorus retention capacity is usually higher in phosphorus than water from better quality soils. For example, subsurface water from Joel sands under vegetable cropping had a phosphorus concentration of between 15 and 20 milligrams per litre for most of the year. By contrast, water leached from yellow Karrakatta and Spearwood sands contained less than 0.10 to 0.15 mg of phosphorus per litre. Consequently, aquifers under these sands show very little evidence of phosphorus enrichment. The limestone under Spearwood sands would act as an additional barrier to phosphorus movement.

The poorer quality Bassendean sands have very low capacity to retain phosphorus after vegetable cropping. Unless amended with phosphorus-fixing materials, they present an environmental risk.
Management

The management of horticultural crops on soil naturally low in phosphorus must focus on a more efficient use of fertilizer phosphorus to reduce the risk of pollution of surface water bodies.

On the better soils, the Spearwood and yellow Karrakatta sands, the risk of phosphorus leaching is minimal. Nevertheless even on these soils, phosphorus application rates should closely match crop needs to reduce the risk of phosphorus reaching shallow watertables. These soils build up a significant bank of residual phosphorus (more than 250 ppm of extractable phosphorus) after long periods of vegetable cropping. These levels of soil phosphorus should be adequate for most vegetable crops. Consequently, phosphorus fertilizer management should be based on soil tests of residual phosphorus and rates of applied phosphorus reduced at high soil test values.

For example, a soil test of 60 to 70 ppm (extractable) phosphorus was adequate for maximum yields of carrots on a Spearwood sand at Medina and no fertilizer phosphorus was necessary. Research has started to determine the critical soil test levels of phosphorus for a range of vegetable crops on the coastal sands. If the critical level (that is the level of phosphorus in the soil required for maximum yield) is exceeded then it is either not necessary to apply phosphorus or only necessary to apply a maintenance dressing of 200 to 300 kg superphosphate per hectare for each crop.

The capacity of the poorer quality Karrakatta sands to retain phosphorus is limited. The risk of phosphorus leaching and possible pollution of shallow watertables and adjacent water bodies is therefore greater than from the better quality soils.

Soil amendments such as ‘red mud’ (gypsum-treated) and red loam have high phosphorus retention capacities (Table 1) since they are derived from soils with high iron and aluminium contents. These and similar materials will probably be used to improve the phosphorus-retention capacity of the poorer quality soils close to wetlands and other surface water bodies.

Preliminary experiments indicate that rates of 60 to 150 t/ha of red mud may be necessary to minimize phosphorus leaching on sandy soils. No firm recommendations on the use of red mud on soils destined for vegetable production can be made until it can be demonstrated there are no significant side effects of its use.

The Joel sands have negligible capacity to retain phosphorus and will need amendment. Even if at some distance from wetlands, subsurface flow high in phosphorus from these soils can flow into rivers feeding estuaries many kilometres away (for example the Peel Inlet-Harvey Estuary). The shallow watertables (120 cm) under these soils further limit their capacity to retain phosphorus.

Amendment of these poorer soils will increase their phosphorus retention and should enable a build-up of a superbank. Soil tests could then be used to minimize rates of phosphorus application. Under these conditions these soils could possibly be used for intensive horticulture.

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