Fertiliser P management after the 2006 drought

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The following discussion describes the principles related to the efficient use of phosphorus (P) fertiliser based upon *current scientific evidence*. It assumes that dryland grain growers will need to adopt best management practises on all aspects of farming in 2007 to maximise economic returns following the 2006 drought. It also assumes that the 2007 seasonal conditions will be considerably better than those experienced in 2006, so that farmers can plan with some level of confidence next year.

Build-up and Maintenance P applications:

On soils of low P status, higher levels of P fertiliser must be applied regularly to *"build up"* soil P reserves. After many years of P fertilisers being applied, the P status of soils improves to a near optimal P status for crop growth. This is termed the *"maintenance phase"*, where lower P applications are required to replace the P removed in farm products (such as grain) or the P lost by P fixation or by leaching processes (in acidic sands).

A significant proportion of Australian farming soils have now reached the maintenance phase (NLWRA 2001; see Appendix 1). *However, some farms are still "mining" P because application rates are much less than crop removal – this is not a sustainable practice*.

Factors affecting soil P supply to crops:

When soils are fertilised with P, the availability of soil P for crop growth is increased. When fertiliser P is not re-applied regularly, the availability of soil P for crop growth slowly decreases with time and grain yield responses to applied P inevitably increase (Bolland 1999).

Reactions of P with soil

When soluble granular P fertilisers are applied to soil, soil water (or water vapour) moves into the granule and *dissolves* a large proportion of the fertiliser P. This reaction happens very quickly (within 24 hours) in most soils, even when the soil is drier than field capacity. The concentration of P around the fertiliser granule is high, and P may be lost from the plant available pool by *precipitation* reactions (see Figure 1). Precipitation is a process where soluble P combines with other elements in the soil (e.g. calcium, aluminium, iron) to produce new solid compounds. Some of these can dissolve slowly over time, or when a plant root reaches them, to release P into a soluble form again. However, some P compounds can remain very insoluble and are therefore effectively unavailable for plant uptake.

As P moves away from the granule through soil pores (termed *diffusion*), the concentration of P in the soil pore water decreases and precipitation reactions become less important, and the diffusing P binds to soil surfaces by a process called *adsorption*. This is where P is attracted to the clay mineral surface – some of the P on the surface remains in a plant available form (i.e. it can move back into soil pore water) but some may be very strongly bound in, or on, the mineral surface and be removed from the plant available pool. Reactions that remove P from the plant available pool are generally termed fixation reactions, and may be a combination of both *precipitation* and strong *adsorption.*

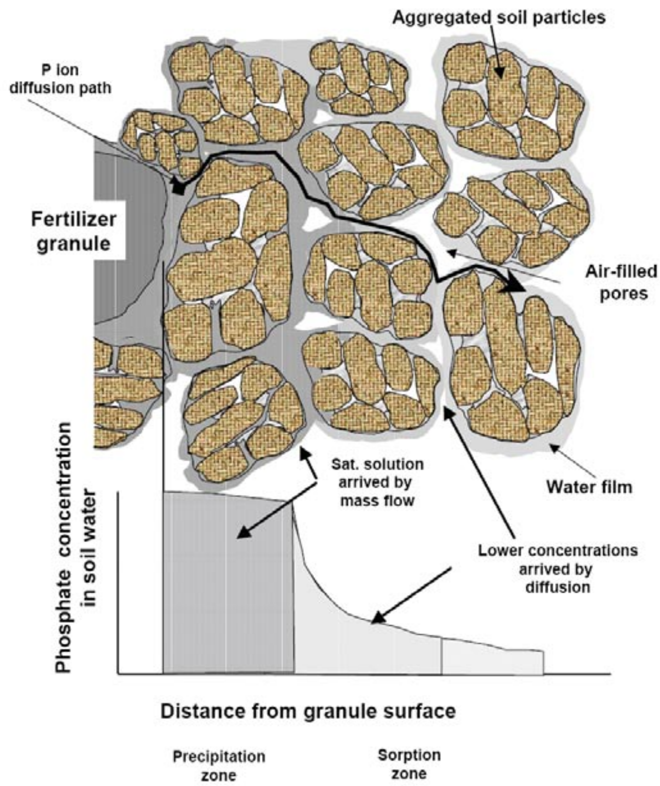

Figure 1. Schematic representation of the dissolution of fertiliser granules in soil and resultant reactions in the soil around the granule (from Hedley and McLaughlin 2006)

Diffusion of P through soil is very slow compared to diffusion of some other nutrients such as nitrogen – this is why it is so important that fertiliser P is banded in the soil at points where plant roots can readily access it soon after planting i.e. close to or below the seed (Jarvis and Bolland 1990; Holloway *et al. 2001*). 'Top dressing' P significantly reduces the ability of plant roots to access fertiliser P, even in sandy soils.

Part of the dissolved P is also incorporated into the soil organic matter by the soil microbial biomass but can be later *mineralised* to soluble P by other microbial processes and exudates from plant roots. Soil microbes however compete with crop roots for soil solution P (McLaughlin and Alston 1986; McLaughlin *et al.* 1988).

Crops derive their P from the soil solution that is in equilibrium with the adsorbed P in the soil (this process is called *desorption*) and from P compounds that can readily dissolve. Within the rhizosphere of roots of many species, organic acids are also excreted that aid the release of sorbed P into the soil solution (Nuruzzaman *et al.* 2005).

Efficiency of P cycling:

In a field experiment at Mallala in SA using radioactive P sources, it was demonstrated that only 12 % of the current P fertiliser applied was accumulated in a 95 day-old wheat crop which accounted for only 16 % of total plant P uptake (McLaughlin *et al.* 1988). A major part of the crop P uptake was derived from the existing soil P reserves (Figure 2).

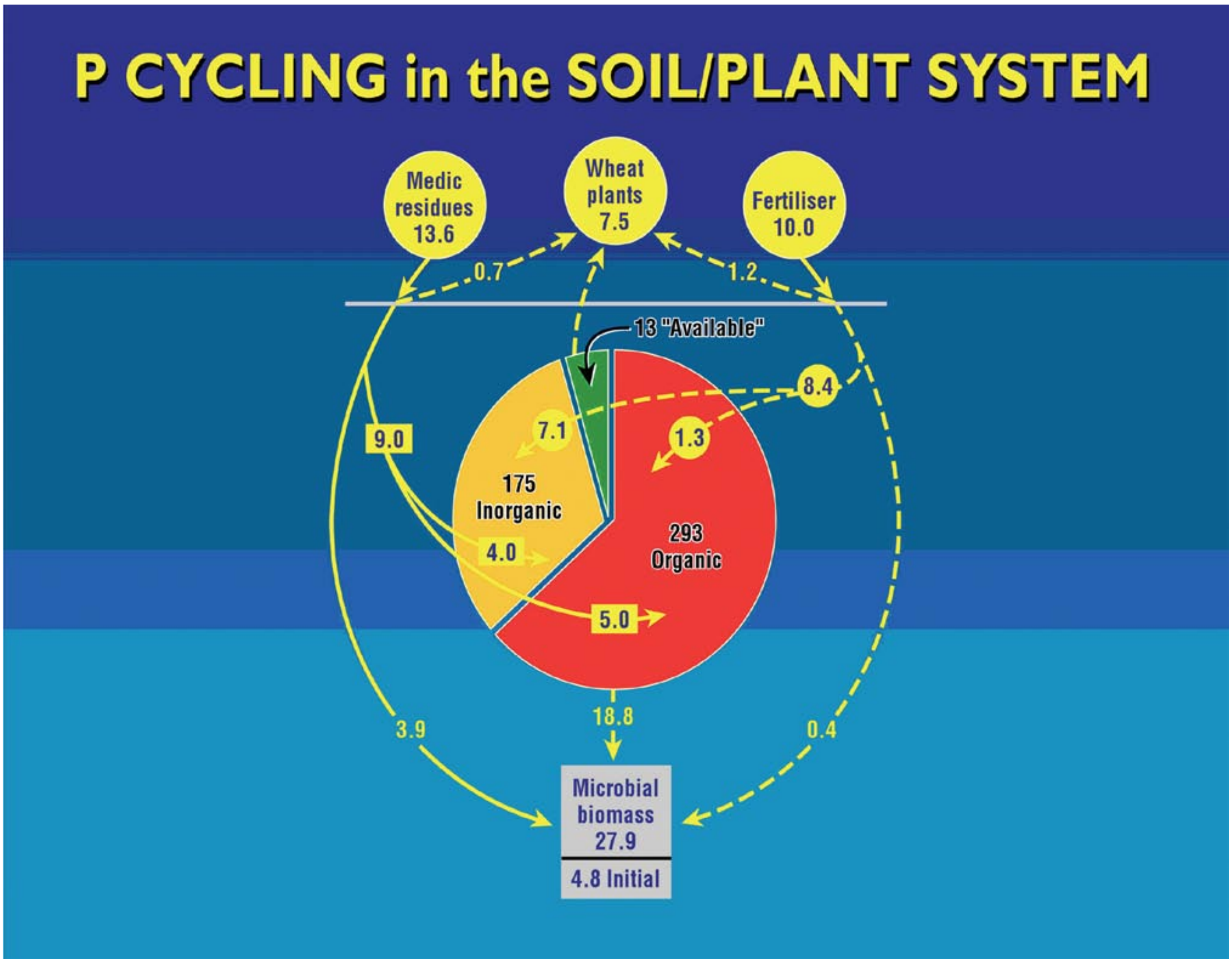

Figure 2. Distribution and movement of P from P fertiliser and crop residues added to a calcareous soil in SA. Values represent kg P per hectare in each pool, and arrows indicate movement of P in the 3 months after planting (from McLaughlin et al. 1988).

About 70 % of the P applied became sorbed onto soil particles (inorganic soil P) & 13 % became associated with the soil organic matter (organic soil P). Both of these pools ultimately contribute to increasing soil P reserves for future crops but the rate at which this happens can vary from weeks to years.

The soil microbial biomass also held about 4 times more P than the P accumulated by 95-day old wheat plants (Figure 2).

Crop demand for P:

Cereals have a high functional requirement for P during early plant growth stages (Elliott et al. 1997b,c; Hoppo et al. 1999), but crops continue to accumulate P throughout their growth. At crop maturity, about 80 % of the total P in shoots is contained in the grain (Elliott et al. 1997b).

Root growth in wheat is also markedly reduced by water stress (Fawcett and Quirk 1962) but less so than shoots. However P deficiency can significantly reduce root growth of the young plant, thereby reducing the ability of the crop to access soil water and other nutrients (Tennant 1976; Elliott et al. 1997a).

Supplying adequate P to crops can also minimise the impact of some factors that affect root growth such as acidity and certain root diseases. Furthermore, it is difficult to supply P to an established crop if it is discovered that the crop is experiencing P deficiency. This contrasts to some other nutrients such as N, which can be topdressed post-planting and will leach into the root zone if sufficient rainfall subsequently occurs.

As a generalisation, broad leaf crops such as most pulses tend to be more reliant on fertiliser P than cereals (which have fine roots and are therefore more efficient scavengers of soil P).

Collectively, this suggests that a small amount of fertiliser P should be applied in close proximity to the seed when crops are sown in 2007 to help stimulate root & shoot growth of newly sown crops (on soils of marginal P status). Higher rates of application would be required for soils of low P status.

How will the 2006 drought affect P fertiliser decisions in 2007?

1. P losses from 2006 crops are low:

Failed or low yielding crops would have taken up only a *small percentage of the fertiliser P applied in 2006*, partly because their root systems were severely reduced by water stress (Fawcett and Quirk 1962).

Grain from harvested cereal crops may contain up to 3 kg P per tonne. P removal in grain of grain legumes and canola could be up to 3.5 and 5 kg P per tonne respectively. Crops cut for hay could contain up to 2 kg P per tonne. The above values are for normal crops.P is not leached on most soils, being strongly adsorbed onto soil particles. However, P is leached from acidic sands, but leaching losses during 2006 would be expected to be minimal.

2. Soil P testing is critical information:

The decision-making process starts with knowing the P status of the surface soil (0 – 10 cm depth). The test should be a locally calibrated soil P test (extractable soil P) and an estimate of the new P buffering index (PBI) that defines how strongly P is held by the soil particles & how easily crops can access P from the soil solution (Burkitt *et al.* 2002; Moody 2007).

Recent Australian studies have shown strong positive relationships exist between PBI and the Colwell soil P level required for near maximum crop yield (see Figure 3 for wheat). These relationships vary for different crop or pasture species (Moody 2007). For example, soils with a high PBI, (such as the highly calcareous soils found on parts of the Eyre Peninsula or the red soils of the Burnett region of Queensland) have a higher critical soil P level for near maximum yield than soils with a low PBI (e.g. cracking clay/Vertosol soils of the Victorian Wimmera).

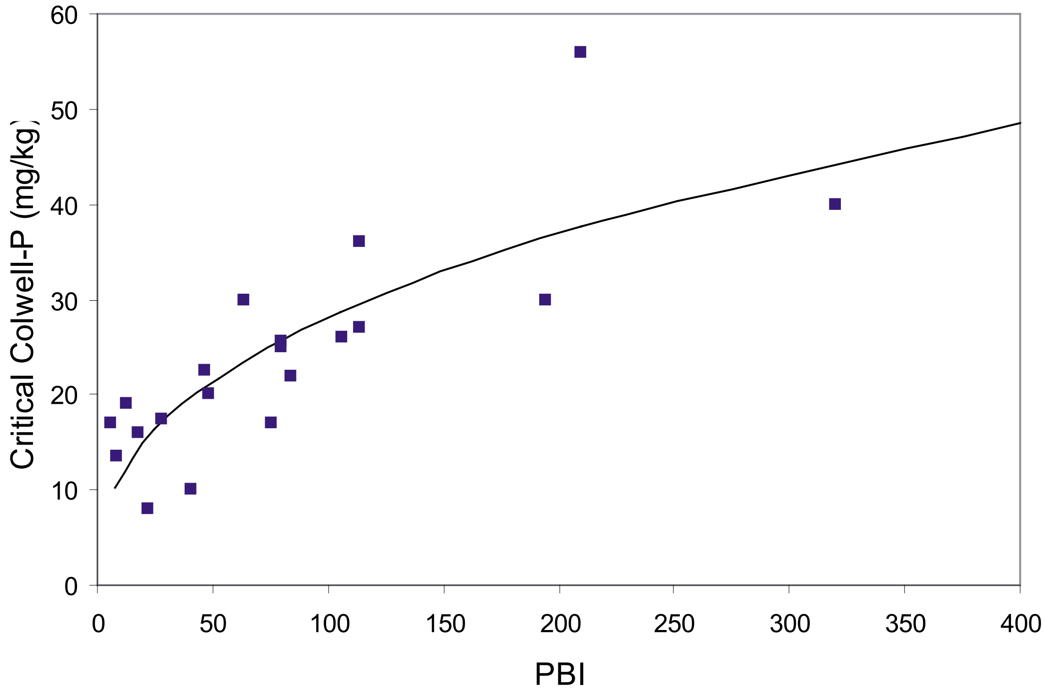

Figure 3: Relationship between PBI and the critical Colwell soil P value (0 – 10cm) determined at 90% maximum grain yield of wheat (Moody 2007).

3. Impact of drought on soil P processes:

Depending on the dominant P reactions which cause fixation (discussed above), dry soil conditions can either increase or decrease the residual value of fertiliser P for the next years' crop.

Using P solutions (Bramley et al. 1992 a, b) and ground superphosphate (Bolland and Baker 1987) mixed throughout soil, it was shown that air-dry soil conditions fixed inorganic soil P pools at a lower rate than where soils were maintained moist, because under moist soil conditions immobilising soil reactions proceed more rapidly. Indeed, the effectiveness of superphosphate for wheat growth applied and incubated in dry acidic soil was shown in glasshouse experiments to be similar to freshly applied superphosphate. Incubation in moist soil reduced P effectiveness (Bolland & Baker 1987). These experiments were undertaken with P mixed throughout the soil, and hence were designed to measure the effects of soil moisture content on P adsorption.

On the other hand, precipitation reactions of granular P can be enhanced in dry soil conditions in calcareous soils. Fertiliser granules will dissolve because of movement of water vapour to the granule even when the soil is drier than field capacity, but as the P is present in a more concentrated solution in the soil this can promote precipitation reactions with calcium in or near the granule. This process does not appear to occur with fluid P fertilisers to the same extent and explains the better performance of fluid fertilisers compared to granular P forms in dry years (Lombi et al. 2004; Holloway et al. 2001).

This means that in non-calcareous soils less of the P applied in 2006 would have been immobilised than in a more normal year. The sorption/fixation processes may have been slower and perhaps confined to a smaller volume of soil. In calcareous soils, P losses through fixation are likely to have been unchanged or increased.

The residual effectiveness of fertilisers is enhanced in years with good growing season rainfall. This means that if 2007 is a good year, then crops will have good access to P left over in the soil from 2006. If 2007 is also a dry year (or at least experiences a dry start), the residual value of fertiliser P applied in 2006 will be low in 2007 (Bolland 1999).

Examination of crop responses to P in years following drought by Scott et al. (personal communication) in NSW has suggested that P rates can be reduced slightly from recommended rates, by approximately 20% based on examination of soil test data.

Conclusions:

1. Removal of P in grain of low yielding crops in 2006 is likely to be low.
2. Leaching of P on sands in 2006 is likely to have been minimal.
3. P fertiliser investment decisions for 2007 should start with knowing or defining soil P status. The status of other plant nutrients should also be assessed by either soil (before sowing) or plant analysis (during crop growth).
4. Maintenance rates of fertiliser P normally vary with soil P status (soil test value), soil type (PBI value), target grain yields, climatic conditions and method of P fertiliser application. In 2007, mainte nance P rates should be lower than normal. On soils in the "build up phase", apply a level of P that can be afforded.
5. Normally a major proportion of P taken up by crops is derived from the soil reserves. Only about 20 % is derived from freshly applied P fertiliser.
6. Residual effectiveness of fertiliser P applied in 2006 for crops in 2007 is likely to be low on calcareous soils and above average on neutral and acidic soils

Recommendations:

- *If soils have been tested regularly or recently, then expenditure on further testing is not warranted for the 2007 crop. If not, then soil testing is recommended.*
- *If soil P tests are in the optimal or high range, then no P fertiliser should be applied in 2007.*
- *On soils with low soil P levels, consideration should be given to applying some P fertiliser in 2007.*
- *Drill-applied P fertiliser with or below the seed is the most efficient method of application. Broadcast ing P is known to be inefficient.*
- *In neutral and acidic soils, a significant amount of P fertiliser applied to 2006 crops may still be effective for the 2007 crop due to reduced and slower soil P fixation occurring in very dry soil conditions experienced in 2006 – rates of application could possibly be reduced.*
- *In calcareous soils, P fixation should not be discounted due to drought conditions in 2006. Cost effective fluid fertilisers should be considered as a replacement for granular P products .*
- *If 2007 has good growing season rainfall, crops will have better access to fertiliser P applied in 2006.*
- *Where crops failed in 2006 and soil P status is at the maintenance phase, 2007 P application rate up to 5 kg P /ha should be considered..*

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Appendix 1: Findings from the NLWRA Nutrient Balance & Soil Testing project (NLWRA 2001)

Fertiliser P use:

- Rates of P (& N) fertiliser use are lower in more arid, lower yielding cropping regions than in the more reliable, higher yielding regions – decisions are linked to anticipated crop returns.
- In the dryland cropping regions, fertiliser use in the drought year (1994) & the following year were markedly lower.
- P use in cropping regions is now directed at crops. Little is applied to pastures (FIFA estimated that 48 % of P applied to pastures is applied to dairy pastures).

Soil P Status:

- About 106,000 soil samples are analysed annually (1 sample/1000ha).
- Colwell soil P status (spanning 1990 – 1999) was gener ally lower in the more arid cropping regions than in the higher yielding cropping regions.
- Colwell soil P status (for all land uses) still cover a wide span of values, but over 50 % of samples had values in the optimum/near optimum to high range (see % numbers of samples for each State with defined soil P ranges). This can be linked to regular P applications over many decades building up soil P reserves.

State	Colwell soil P ranges (mg/kg) in 0 – 15 cm*					
	≤10	10 - 20	20 - 30	30 - 40	40 - 80	≥ 80
WA	15	36	26	12	9	1
SA	7	26	27	17	19	4
VIC	7	22	20	14	23	14
TAS	4	13	16	13	33	21
NSW	11	27	22	14	17	9
QLD	19	20	13	9	21	17
Aust	13	31	24	13	13	4

Farm-gate P Balance:

- Lower nutrient exports occur from more arid cropping regions than from regions with more favourable climates
- Farm-gate P balances (fertiliser P inputs minus P exports in farm products) were mainly neutral or slightly positive over large areas of each cropping regions.
- Negative balances occurred in the Wimmera, northern slopes of the GDR in Victoria, the northern slopes of NSW & SE Queensland – Colwell soil P status in these regions were marginal.

Appendix 2 - Suggestions for further reading

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