Extractable phosphorus (Colwell) concentrations of soil after banding fertiliser with seed in relation to the critical phosphorus requirement of a wheat crop

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Abstract
The phosphorus (P)-balance efficiency of wheat crops in southern Australia is typically about 50% (i.e. about 2 units of P are applied in fertiliser to produce 1 unit of P in grain). We investigated the concentrations of Colwell extractable P in the surface soil (0-10 cm) of a red kandosol (pH_{CaCl_2} 4.42) within the planting row of a wheat crop sown on 31 May 2011 at Condobolin, NSW. Triple superphosphate had been banded at 0, 4, 8 or 20 kg P/ha with the wheat seed which was sown at 4.5 cm depth. The aim was to quantify the temporal mismatch between P availability in the band and the critical P requirement (Colwell P concentration corresponding to 95% of maximum growth rate) of the crop. The critical Colwell P concentration of topsoil in the crop row was initially low, but increased during tillering and was ~54 mg P/kg during grain filling. To achieve this concentration of Colwell P after anthesis it was necessary to apply ~15.3 kg P/ha at sowing. It was estimated that this would initially generate a Colwell P concentration of 80-90 mg P/kg and it was concluded that the Colwell P concentration of topsoil in the crop row (i.e. soil associated with the fertiliser band) would remain above the critical requirement of the crop for the first 126 days (~70%) of the crop's growth period.

Key Words
Phosphorus use efficiency.

Introduction
The phosphorus (P)-balance efficiency (P_{output} in products/P_{input} in fertiliser and feed) of Australian agriculture is relatively low, due mainly to the accumulation of P in soils that have moderate to high P-sorption capacity. For grazing farms, the median P-balance efficiency is 11-29% depending on enterprise type; for crop production it is 48% (Weaver and Wong 2011). A major factor in the higher P-efficiency of cropping over grazing is the ability to band fertiliser either with, or adjacent to seed at sowing. This practice (when compared with topdressing) typically reduces the P-fertiliser requirement of a crop by 30-60% (Eghball *et al*. 1990; Jarvis and Bolland 1991).

The P requirement for optimal growth of a plant is influenced by its internal P efficiency (i.e. the P concentration of plant tissues), its ability to explore nutrient-rich soil layers (root foraging ability) and the rate at which phosphate diffuses through soil to the root. Banding fertiliser improves P availability to the plant by placing a high concentration of P relatively close to its roots. This also stimulates proliferation of roots in the region of the fertiliser band. However, a proportion of the P applied in bands is sorbed by soil minerals (Moody *et al*. 1995) and becomes sparingly available to the crop.

Our hypothesis was that the concentration of P in soil achieved by banding fertiliser at sowing would initially exceed the P-requirement of a crop during its early stages of development when growth was relatively slow and that the temporal 'mismatch' in supply and demand for P may contribute to inefficient P-use. For example, small and frequent additions of P to the root zone of barley has been used to experimentally control P supply and has improved P uptake efficiency relative to P applied once at sowing (Nyborg et al. 1998). We measured the concentrations of extractable P (Colwell 1963) in the surface soil of a wheat crop after banding P with seed at sowing and compared them with the P concentrations needed for near-maximum crop growth to determine the period over which P supply may exceed demand by the crop.

Methods
Crop management
Two near-isogenic lines of wheat (6266N, 6266P) differing in expression of the *tin* gene for reduced tillering (Richards 1988) were sown on 31 May 2011 at the Condobolin Agricultural Research Station, Condobolin,

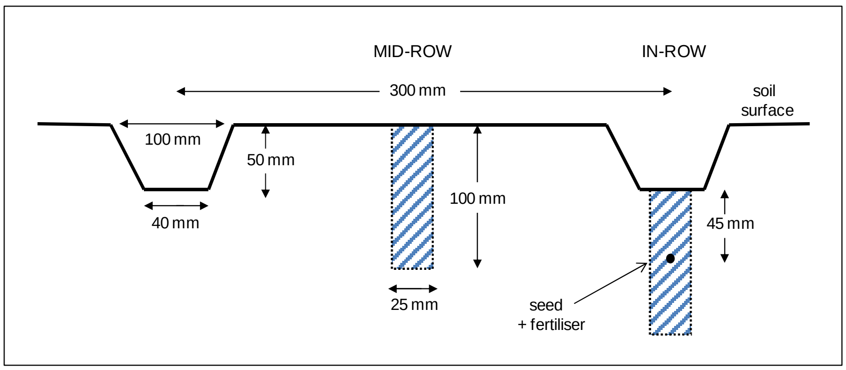
NSW in 2 x 8 m plots to achieve a planting density of 88 plants/m^2. In addition, 6266P was sown at 136 plants/m^2 to also alter tiller density. Row spacing was 30 cm.

The soil was a red kandosol (pH_{CaCl2} 4.42). Seed and triple superphosphate were placed at 4.5 cm depth via a 2.5 cm diameter tube at the rear of tines fitted with 4 cm points and the soil in the row was pressed firmly using a following press wheel (4 cm wide). Triple superphosphate was applied at 0, 4, 8 or 20 kg P/ha in bands with wheat seed or was applied immediately prior to sowing at 8 kg P/ha in a topdressed fertiliser (non-banded) comparison. Nitrogen fertiliser was not applied because the crop was following more than five years of a lucerne-based pasture. Stored soil water (0-120 cm depth) at sowing was 70 mm. Seasonal rainfall (June-October) was low and totalled 129 mm: (June 8.2, July 13.8, August 37.5, September 18.2, October 51.1 mm).

Soil and plant sampling
Soil and shoots were harvested on 22-23 June (10 seedlings/plot; DC13, Zadoks *et al*. 1974), 27-28 July (from 50 cm lengths of each of the inner 4 rows; DC22), 5-6 September (hereafter from 1 m lengths of the inner 4 rows; DC50, first spikelet visible), 4 October (DC65, anthesis) and 15-16 November (maturity).

Shoots were washed to remove dust and then dried at 70°C prior to dry weight determination. Critical in-row soil P concentrations were estimated from graphs of shoot yield vs Colwell P, as the soil P concentration corresponding to ~95% of maximum shoot yield.

Figure 1: Positions of in-row and mid-row soil samples (hatched rectangles) relative to the soil surface, seed and fertiliser placement.



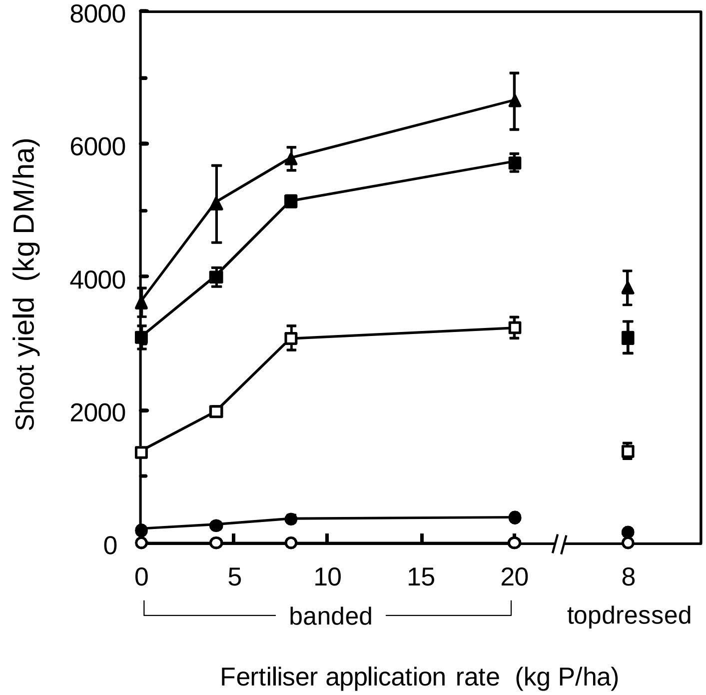
Soil was sampled by taking 16 cores (2.5 cm diam. x 10 cm depth) from in-row and mid-row positions of each plot. Because a press wheel was used at sowing, the physical location of the soil samples differed between in-row and mid-row positions as shown in Figure 1. Soil samples were air-dried and extractable P was determined (Colwell 1963). In-row soil samples were expected to reflect the availability of P resulting from banding fertiliser with seed, and mid-row samples reflected the original fertility of the site or the influence of fertiliser when it was topdressed.

Experimental design
Dry seasonal conditions meant that the anticipated tillering phenotypes of the lines were expressed poorly and shoot yields of the 3 plant treatments did not differ. Consequently, data for all wheat lines were combined and are presented here as a single crop. The experiment was sown as a split plot design with 3 replicates and P treatments as main plots and wheat lines as split plots. Because the data for individual lines were combined, the original experimental design was effectively simplified and was analysed as a randomised complete block design with 5 P treatments and 3 replicates.

Results and Discussion

Shoot yield
Crop growth was barely influenced by P-fertiliser at the earliest harvests, but as crop growth rate increased a clear requirement for fertiliser P emerged (Fig. 2). Only banded applications of P were effective, with 8 kg P/ha topdressed being equivalent to having applied no fertiliser (Fig. 2, Fig. 3). This was considered to be a consequence of the low seasonal rainfall which resulted in dry topsoil over much of the crop growth period (e.g. McBeath *et al*. 2012). The critical Colwell P concentration of the banded fertiliser zone (in-row samples), which was in moist soil, was estimated to be $\leq$ 20 in June, 53 in July, 39 in September, 53 at

Figure 2. Shoot yields of wheat sown on 31 May that were achieved with banded and topdressed applications of P at various rates and harvest dates: (○) 22 Jun, (●) 27 Jul, (□) 5 Sep, (■) 4 Oct (anthesis) and (▲) 15 Nov (maturity). Bars indicate 2x se.



anthesis (October), and 54 mg P/kg soil by maturity (Fig. 4). Of these, the critical P estimate for July is probably least reliable because the response to P was essentially flat at this time.

Soil fertility

The Colwell P concentration of soil in the crop row (banded fertiliser zone) was increased substantially by fertiliser application, but declined over the crop growth period (Fig. 3a). The Colwell P concentration of in-row soil that had not been fertilised and mid-row soil (both unfertilised and topdressed) did not change markedly during crop development. The impact of banding fertiliser on the soil P concentration experienced by wheat roots can be seen most clearly by comparing Colwell P concentrations achieved in mid-row soil samples when 8 kg P was broadcast per hectare, with the same quantity of P drilled with the seed (in-row soil samples) (Fig. 3a, 3b).

The critical Colwell P concentration of topsoil in the crop row was initially low, but increased during

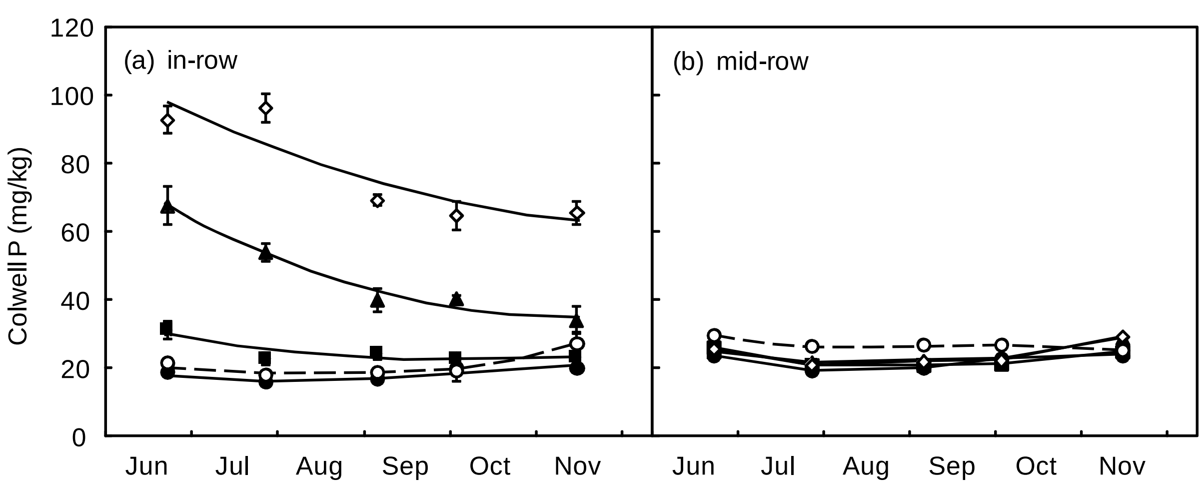


Figure 3. Colwell P concentration of soil (0-10 cm) in (a) in-row and (b) mid-row positions for 4 banded P treatments, 0 kg P/ha (●), 4 kg P/ha (■), 8 kg P/ha (▲) and 20 kg P/ha (◊), and for P topdressed at 8 kg P/ha (○). Error bars are 2 x se, but are not shown for mid-row samples for reasons of clarity. The average co-efficient of variation of mid-row soil samples was 6% (range: 1-15%). Regressions in (a) are polynomial fits generated using Microsoft Excel.

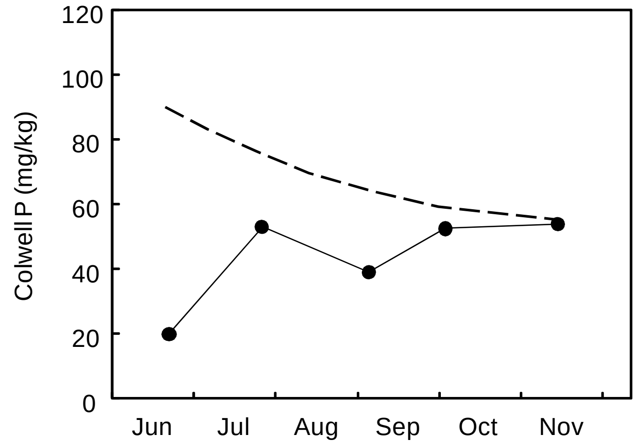


Figure 4. Critical Colwell P concentrations (●) needed in-row for near maximum shoot yield of the crop at differing stages of its growth and the likely concentrations of extractable P (dashed line) that would be achieved by banding 15.3 kg P/ha with the seed at sowing.

tillering and was ~54 mg P/kg for an in-row soil sample during grain filling (Fig.4). By assuming a linear relationship between the in-row Colwell P concentrations that were achieved when applying 8 and 20 kg P/ha (Fig. 3a), it was estimated that ~15.3 kg P/ha would need to have been applied at sowing to achieve a Colwell P of ~54 mg P/kg (in-row) after anthesis. This would initially generate an in-row Colwell P concentration of 80-90 mg P/kg (Fig. 4).

Conclusion

Two main reasons are usually given for controlling the release of P from fertiliser: (i) to minimise immobilisation reactions with soil, and (ii) to avoid oversupply by matching P release to crop demand. This experiment demonstrated that the Colwell P concentration of topsoil in the crop row (i.e. soil associated with the fertiliser band) exceeded the critical requirement of the wheat crop for the first 126 days (~70%) of the crop's growth period. Unnecessarily high concentrations of P in the soil probably do mean that there will be some immobilisation of P during this period because P-sorption is a product of the concentration of P in soil solution and the time over which the sorption reactions proceed (Barrow 1980). However, it was also clear that controlled release of P to meet the crop's requirements (if it were possible) and banding the optimum amount of P with seed at sowing will both lead to a relatively high concentration of extractable P in the banded zone of the soil after the crop is harvested and this would probably also contribute to a low crop P-balance efficiency.

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