Phosphorus Requirements for Cereals: What Role Does Crop Rotation Play?

By Andreas Neuhaus, James Easton and Charlie Walker

A network of field data refines critical soil test values for cereals based on the interaction between previous crop and soil P immobilization.

Strong response to P (29 kg P/ha) in wheat grown after canola on high phosphorus buffer index (>120) soil with Colwell P of 60 to 80 mg/kg. Control (zero P) is shown on the right in each photo.

Phosphorus recommendations in Australia are based on the Colwell P soil test. When used alone, this test sometimes shows poor correlation to yield responses (Mason et al., 2010). Using such weak correlations is likely to lower farm profits and reduce confidence in soil testing.

Cereal crops dominate the broad-acre systems in Australia. However, the common insertion of other rotational "break" crops adds an additional factor to consider when trying to determine the P requirement for any cereal that follows a break crop. Lush (2014) highlighted examples of different P requirements for wheat following cereals compared with wheat following either canola or legumes.

This study investigated P requirements in different cereal rotations using data from more than 100 field trials. The data used was from field research undertaken by two major fertilizer companies in Australia [CSBP Ltd. and Incitec Pivot Fertilisers (IPF)], as well as from the "Making Better Fertiliser Decisions for Cropping System in Australia" (BFDC) project (https://www.bfdc.com.au).

The BFDC project developed an interface that allows users to filter P-responsive field trials by various factors to improve soil P x yield response correlations. Insufficient data exists to filter by phosphorus buffer index (PBI – an index of a soil's ability to "lock-up" or adsorb P) or gravel content, which are factors suggested by Bell et al. (2013) as likely to improve the soil P x yield response relationship. Crop rotation is another factor interacting with the pools of plant available and sorbed soil P.

Abbreviations and notes: P = phosphorus; OC = organic carbon.

This study was undertaken because it has potential use for a) improving P soil tests; b) correlating/modelling the Colwell P x yield response curve in combination with other factors like soil type, pH or crop sequence; and c) investigating the dynamics of P cycling in different crop rotations. Applying a better understanding of interactions between PBI, Colwell P and crop rotation may improve P management on farms and also benchmark studies on soil P status.

The dataset contained 53 CSBP cereal field trials conducted in Western Australia (WA) from 2000 to 2014 with maximum yields from 1.5 to 6.5 t/ha. Trials, mainly wheat and barley, were on gravelly and non-gravelly soils, ranging from sand to clay. BFDC provided 43 trials [18 from South Australia (SA), 17 from WA and 8 from New South Wales (NSW)]. IPF made 6 trials available from Victoria (Vic)/NSW.

Results

Field trials showed a trend towards higher critical Colwell P for cereals on canola, especially on higher P sorption soils (**Figure 1**). Cereal after canola formed a different cluster to the other rotations on soils with a PBI_{+ColP} > 70 (classified by

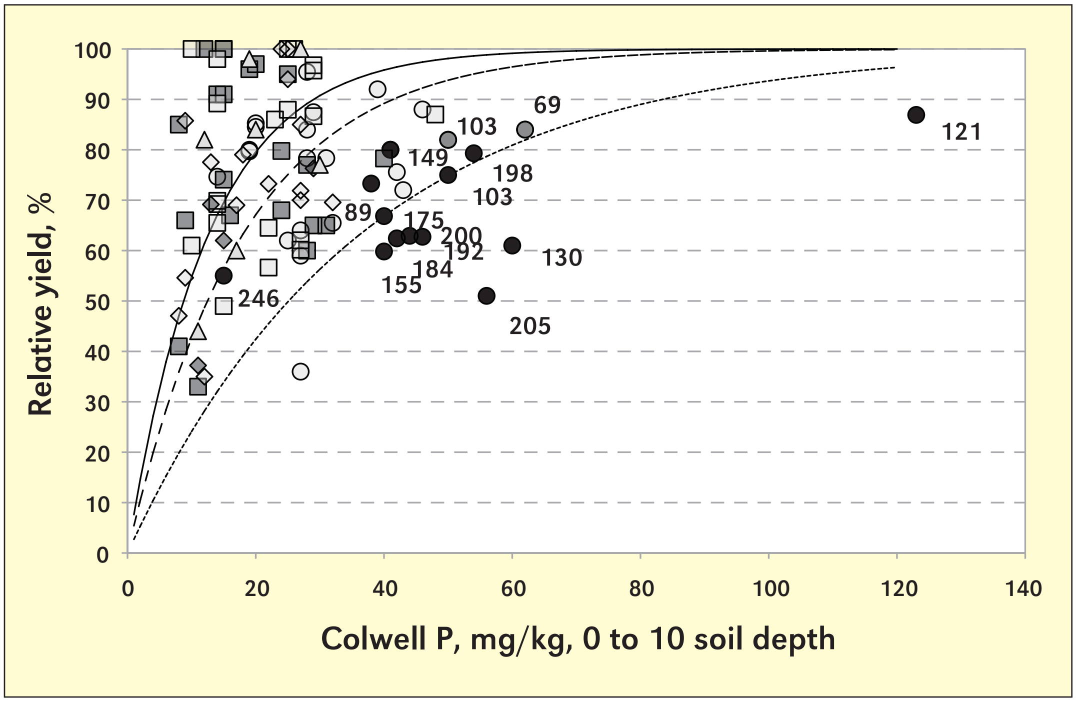

Figure 1. Relative yield in response to Colwell P. High phosphorus buffer index (PBI) plus Colwell P (PBI_{+ColP}) values are shown next to symbols (○) denoting cereal trials after canola. Darker and lighter filled symbols show cereal trials on soils above and below PBI_{+ColP} 70, respectively. The bottom and middle fitted calibration curves belong to cereal trials after canola (dotted line for $PBI_{+ColP} > 70$; dashed line for $PBI_{+ColP} < 70$) while the top curve is for all other trial data (solid line). Symbols represent the previous crop as cereals (□), pasture (◊) and lupins (Δ).

the Australian P sorption status as being above "very low") and improved soil test x relative yield relationships when fitted separately (**Figure 1**). Regression correlation coefficients (r) for previous crops in **Figure 1** were: 0.03 (canola; $PBI_{+ColP} <$ 70), 0.50 (canola; $PBI_{+ColP} >$ 70), 0.16 (cereals), 0.58 (pasture) and 0.76 (lupins). Consideration of subsoil Colwell P (10 to 20 cm) did not improve soil P x yield correlations.

Correlations between Colwell P and yield were weak, highlighting risks with decision making based on this factor alone. Using a principal component analysis, P yield response was affected by factors that were at least as important as Colwell P. Those factors, shown here in scatter plots, were soil OC% and PBI (PBI_{+ColP}), while for example pH_{CaCl2} was of lower importance (**Figure 2a-c**).

Colwell P has traditionally been regarded as the most important variable for P responses. This study found that measures of the capacity of the soil to immobilize P such as OC and PBI_{+ColP}, are of at least equal importance when generating P recommendations, in particular for a canola-cereal rotation. Canola extracts more P from the soil, but also leaves more residual P in its residue than cereals due to its higher biomass production (or lower harvest index). Inorganic and organic forms of P in canola could account for a large percentage of the initial P supply during cereal plant establishment. This P may become available to the next crop depending on the mineralization and soil P sorption capacity. Doolette et al., (2012), however, observed higher P mobilization and availability after lupins, but not after canola. Both crops are non-hosts for arbuscular mycorrhizal fungi (AMF). Despite the lack of AMF, a higher P uptake in wheat following canola or legumes has been reported (Lush, 2014) and hypothesized to be a result of a healthier cereal root system and increased root length as a result of improved N availability after rotational break crops.

This study cautions against relying on higher P availability after break crops. Based on trial data presented here, it is speculated that after canola a higher proportion of the mineralized P is less plant available on higher PBI_{+ColP} soils. While the P cycle under contrasting PBI's is not investigated here, the data clearly suggest applying above maintenance P rates after canola on higher PBI soils to reduce the risk of under-fertilizing if no soil samples are taken for Colwell P.

Querying of the national BFDC database gave a critical Colwell P (95% max yield) of 34 mg/kg with a range of 29 to 40 (r = 0.47) for wheat trials where a cereal was the previous crop. Wheat following canola had a higher critical Colwell P of 49 (range 17 to 140) while wheat following a pulse crop had a lower critical Colwell P of 30 (range 17 to 53). These last two data sets were smaller, with weaker correlations of 0.24 and 0.35, respectively.

The critical Colwell P values obtained in this study only partly match outcomes of the BFDC project. Those previously reported critical Colwell P values by the BFDC project seem to hold only for "very low" PBI_{+ColP} soils (< 70). The critical Colwell P for 95% maximum cereal yield on PBI_{+ColP} soils > 70 was about 110 mg/kg. Cereals following lupins fitted the same yield curve as cereals following pasture or cereals. Interestingly a higher PBI_{+ColP} did not necessarily result in a higher critical Colwell P, but instead depended on crop rotation.

Crop rotation affects soil test interpretation for fertilizer P recommendations. Multifactorial crop modelling is best suited to improve P recommendations, especially for areas with gravelly forest soils in WA (**Figure 3**) and in the south eastern states (NSW, Vic, SA, Tasmania) where 40 and 8% of cropping soil tests fall into the category represented by orange and red, respectively.

Phosphorus deficiencies have been reported after canola even when fertilized according to critical soil test levels (Bowden et al., 1999). Different P distributions, positional availability problems, lack of AMF and root pruning after canola have been suggested as contributing factors to reduced P availability under higher PBI scenarios. Even more factors could affect P availability [i.e., P placement, P source and cereal cultivars that differ in P-use efficiency (Bell et al., 2013)]. Further confounding factors can be early periods of

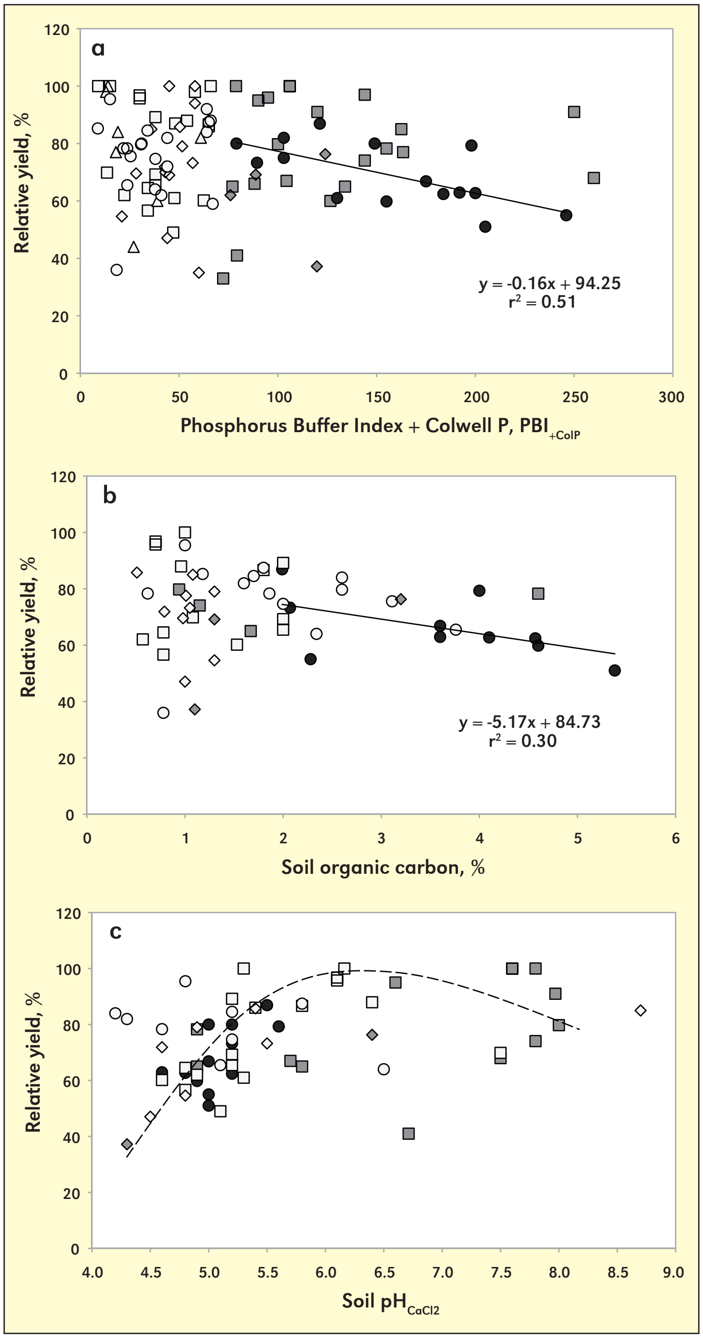

Figure 2. Relative yield in response to (a) PBI + Cowell P, (b) organic carbon, and (c) pH_{CaCl2}. Darker and lighter filled symbols show cereal trials on soils above and below PBI_{+ColP} 70, respectively. Linear trend lines with equations are only for cereal trials after canola (○) on soils with $PBI_{+ColP} > 70$. Other symbols represent the previous crop as cereals (□), pasture (◊) and lupins (Δ).

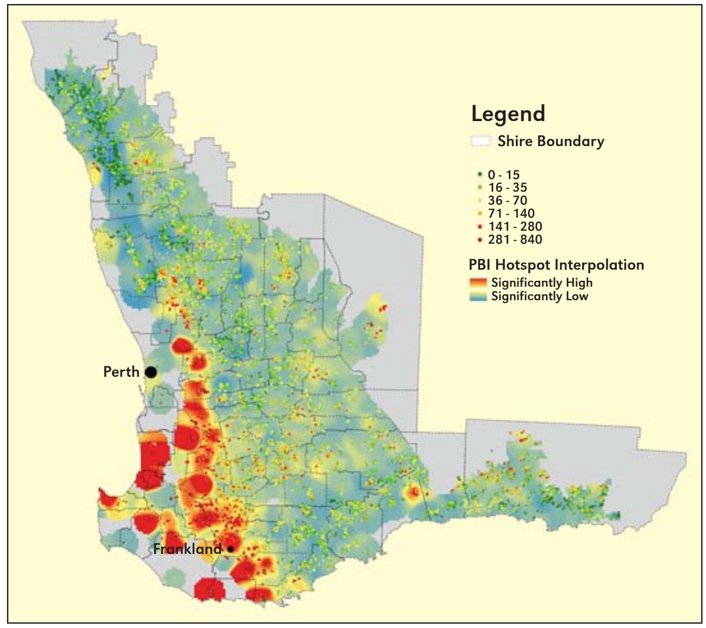

Figure 3. The phosphorus buffer index (PBI) map of Western Australia, grouped according to the national PBI categories, highlights locations of soils with PBI's above 70. These are marked in orange (10% of total samples) and red colors (5% of total samples) and can be described as mainly gravelly forest soils.

dry growing conditions, water repellent soil or a compacted soil layer in the profile. Despite all the complexities, this study refines critical Colwell P values, improves decision support systems for P recommendations, and could improve survey or benchmark reports for soil P status. BC

Dr. Neuhaus (e-mail: andreas.neuhaus@csbp.com.au) and Mr. Easton (e-mail: james.easton@csbp.com.au) are with CSBP Ltd., Kwinana, Western Australia, Australia. Mr. Walker (e-mail: charlie.walker@incitecpivot.com.au) is with Incitec Pivot Fertilisers, North Geelong, Victoria, Australia.

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