FINAL REPORT

CSP318

Citrate-secreting break crops to unlock the fixed-P bank in conventional and organic farming rotations

PROJECT DETAILS

PROJECT CODE:	CSP318
PROJECT TITLE:	CITRATE-SECRETING BREAK CROPS TO UNLOCK THE FIXED-P BANK IN CONVENTIONAL AND ORGANIC FARMING ROTATIONS
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Summary

Typically, 60-80% of the phosphorus (P) fertiliser applied to crops becomes fixed in the soil and unavailable for plant uptake. Some pulses (e.g. chickpeas and albus lupins) exude organic acid anions from their roots, which mobilise fixed soil P and fertiliser P. Glasshouse experiments on low P cropping soils showed that organic anion exuding pulses accessed P not available to non-exuding crops, and improved the P nutrition and growth of a following wheat crop. In four field trials, there was no yield benefit of organic anion exuding crops to a following wheat crop, probably because of drought. Faba beans improved the P nutrition and growth of canola in the glasshouse, but not wheat in the field.

Conclusions

Glasshouse and laboratory experiments

1) Organic anion exuding crops, such as albus lupins, were able to access fixed pools of soil P not available to non or low exuding crops. These included wheat and canola for several soil types, ranging from acidic to neutral in pH.
2) There were positive carryover benefits from the organic anion exuding break crops to the P nutrition and growth of wheat and canola.
3) The magnitude of the rotational benefit was dependent on the break crop species, soil type and P status of the soil. The effects of soil type and its P status were explained by the amount of plant available P. The higher the plant available P, the less the break crop P benefit.
4) Changes in soil moisture status in the intervening period between the break crop and following crop had no significant effect on the magnitude of the P break crop benefit.
5) Faba beans had a large positive P effect on the following crop. This was attributed to the roots of the following crop taking up P, mineralised after the decomposition of the extensive P-rich root system of this species because faba beans did not exude significant amounts of organic anions or phosphatases from their roots.
6) Organic anions, such as citrate, oxalate and malate at concentrations found in the rhizosphere of organic anion exuding species, could mobilise significant amounts of organic P, particularly mono and diester forms, and render them more amenable to enzymic degradation to release inorganic P for plant uptake.

Field experiments

1) There was no rotational P benefit of an organic anion secreting crop to a following wheat crop in four field trials on different soil types low in plant available P. This was probably because of adverse seasonal conditions, such as drought masking any carryover P benefit.
2) Albus lupins were unresponsive to P fertiliser at all sites, presumably as a result of their ability to access fixed soil P. Rates of P for this crop could be adjusted downwards. Chickpeas and faba beans require P fertiliser to achieve maximum yields.
3) Reactive phosphate rock fertiliser was almost as effective as a P source as single superphosphate to the pulses during vegetative growth, but there were few responses in seed yield to any form of P fertiliser in the four trials. This was possibly a result of mineralisation of organic P during the season, and to adverse seasonal conditions restricting yields.
4) Any organic anions exuded by the pulses were likely to have been degraded by the time a following wheat crop was sown. Citrate was detected in the rhizosphere soil of albus lupins at flowering, but not from soil surrounding old lupin roots sampled just before wheat was sown.

Recommendations

No specific recommendations to growers regarding the inclusion of organic anion exuding crops resulted from the study because the field component of the project failed to show carryover P benefits from any organic anion exuding species to a following wheat crop, compared to non-secreting break crops or bare soil control plots that had no prior crop before wheat.

Even if organic acid-secreting crops are shown to have a beneficial P effect to a following wheat crop, a benefit/cost analysis needs to be undertaken, taking into account a number of possible scenarios. Given the likely significant increase in the production of biodiesel using oilseed, crops, such as canola, there will be a large amount of good quality meal flowing into feedlot markets, which could impact adversely on the price of traditional feedlot pulses, such as lupins, negating the value of any P benefits. Pulses, such as albus lupins and chickpeas, require better disease resistance to reduce the number of costly fungicidal sprays. This is particularly important for organic farming systems where low P availability is often one of the major problems limiting enterprise sustainability, and where the use of crops that free up fixed soil P, or access P from rock phosphate, would be of great benefit. Despite these possible limitations, the fact that sources of high quality rock phosphate are finite and diminishing rapidly should provide the stimulus for further research on P efficient crops.

Albus lupins were unresponsive to P fertiliser at all field sites, and this may indicate that growers could reduce their P fertiliser inputs (usually 20-25kg P/ha) for this crop because it can access some of the fixed P in a range of soils.

Outcomes

Increased profits for conventional and certified organic grain growers through the improved efficiency of recently applied P fertiliser, and improved access to the large pool of fixed soil P using a break crop, such as albus lupins, that exude organic acid anions from their roots, was the project goal. The concept could also be applicable to certified organic growers who used phosphate rock because the organic anions exuded from these plants enhance solubilisation.

A positive outcome could result in savings of more than $10 million a year for conventional wheat growers.

Benefits to the environment could also accrue through more efficient use of P fertiliser and its extraction of P from fixed forms of soil P because these measures would reduce P loading of the soil. This, in turn, would reduce undesirable on and off-farm impacts, such as P toxicity effects on native vegetation and P enrichment of water bodies, and associated eutrophication and toxic algal blooms.

Achievements/Benefits

Background

P deficiency is a major limitation to crop growth on many Australian soils as a result of high P fixation and/or low levels of total and plant-available soil P. Applying fertiliser P rectifies this, but it is an increasingly costly input. Most crop species have a low use efficiency of P fertiliser because a large proportion (50-80%) of the P becomes fixed to soil minerals or incorporated into organic compounds and is unavailable to plants. Given that the supply of good quality phosphate rock is finite, a major challenge is to improve the P use efficiency of cropping systems. An agronomic measure that may free-up some of the fixed P in the soil P bank is the inclusion of P mobilising crops into the farming system. Some pulses, such as chickpeas and albus lupins, exude organic acid anions from their roots in response to low available P. Albus lupins develop special cluster roots that exude citrate, enabling the plant to access P from fixed soil P and/or fertiliser P that is largely unavailable to non-secreting crops, such as wheat. Preliminary glasshouse studies showed improved growth and P nutrition for P inefficient crops when intercropped or grown in rotation with organic anion secreting pulses. Despite these promising results, there has been negligible evaluation of the rotational P benefits of organic anion secreting pulses under field conditions.

The major objective of the project was to enable grain growers to improve the use efficiency of P from P fertilisers, or organic amendments, and to withdraw P from the bank of fixed soil P through the inclusion of an organic anion exuding break crop in their rotations. The project combined glasshouse and laboratory work aimed at understanding the effects of organic anions on soil P chemistry, and evaluating organic anion exuding crops for their capacity to release fixed P for their own uptake and for uptake by a subsequent crop. Field trials were conducted to evaluate the rotational P benefits of organic anion secreting pulses to a following wheat crop under growing conditions on different soil types.

Major achievements

1) Glasshouse experiments

The first experiment evaluated the performance of a break crop, wheat rotation for four organic acid secreting pulses as a function of soil type, P application and the water regime between both crops. In phase 1 of the experiment, albus lupins, sandplain lupins, chickpeas, pigeon peas, wheat and canola were grown in four soils ranging from acidic to calcareous, amended with no P, 40mg P/kg as reactive phosphate rock, or 40mg P/kg as single super phosphate (SSP). After harvesting, pots were allowed to dry for six weeks, then subjected to either a wet or a dry water regime. Four weeks later, all pots were sown to wheat (phase 2). The work showed that phosphate rock was a relatively ineffective P source for increasing biomass compared to SSP. The effects of soil type and P application on the growth of the break crops could be fully explained by the amount of plant available P in the soil. The lupins were the most tolerant of low P availability, with chickpeas and pigeon peas slightly less tolerant. Wheat and canola were intolerant of low P and showed the greatest response to SSP. Wheat growth in phase 2 was affected by soil type, prior P fertiliser and preceding crops, but not by the soil water regime in the period between phases 1 and 2. Wheat following canola or wheat had less growth than wheat following any of the pulses. The break crop P benefit of the pulses decreased with increasing P availability, with wheat growth after the pulses averaging 1.37, 1.22, and 1.15 times wheat growth after canola for no P, phosphate rock and SSP treatments, respectively. The decrease in the rotational benefit with P application (no P, phosphate rock, SSP) indicates that P availability is the key factor governing the magnitude of rotational P benefits. These results clearly demonstrated a positive carryover benefit from organic acid secreting crops to the P nutrition of wheat.

The second glasshouse experiment used three soils representing a range of available and total P concentrations. The proportion of total plant available P ranged from 0.05% to 3.6%. The soils were labelled with 33P and sown to albus lupins, chickpeas, faba beans, wheat and canola, and the plants grown for 42 days. There was a bare soil control. Twenty days after harvesting the break crop shoots, canola was sown and its shoots were harvested after 42 days. The 33P activity in the shoots was used to determine the labile value (L-value), a measure of the total amount of P available to a plant. In phase 1, albus lupins had the highest L-value, and wheat and canola the lowest. The work confirmed that white lupins access P from a pool of soil P two to three times greater than wheat and canola. The L-values indicated that chickpeas did not have access to a greater pool of soil P than wheat and canola, despite claims that chickpeas are P efficient because they exude organic acid anions from their roots.

The results indicated that faba beans accessed the same available P pool as wheat and canola. Extraction of the 33P-labelled soil from the unplanted pots with organic anions showed that a significant proportion of the P taken up by the organic anion exuding species was likely to have been derived from the enzyme labile soil organic P pool, mobilised by the exuded organic anions. In phase 2, canola grew better after the pulses (especially faba beans) than after wheat or canola. The reason for the large increase in growth of canola following faba beans is unknown because its roots exuded negligible amounts of organic anions and phosphatases under P deficiency. The effect may be related to the canola roots growing down and around root channels formed by the very large, spreading root systems of faba beans, and accessing mineralised P from the decomposing faba bean roots.

2) Laboratory experiments

Selected soil samples were fractionated to determine organic and inorganic P pools. The soils were extracted with a range of low molecular weight organic anions (LMWOAs) found in the rhizosphere of organic anion exuding plants, such as albus lupins. It was found that the LMWOAs were adsorbed into the soils in the order oxalate >> malate = citrate. Although the LMWOAs released P from the fixed inorganic P pool, the majority of the P extracted by the LMWOAs was from the organic P pool for soils high in organic matter. The organic P mobilised by the LMWOAs was more susceptible than water extracted organic P to enzyme degradation to release inorganic P for plant uptake. Diester (e.g. sugar phosphates) and especially monoester (e.g. phytate) forms of organic P were identified as being readily mobilised by organic anions, and citrate was more effective than the other LMWOAs tested, including malate and oxalate. This was the first time that organic anions were shown to free up P from the organic P fraction, and indicates that the exudation of organic anions plays an important role in accessing soil organic P by plants.

3) Field experiments

Four field trials were conducted in the cereal belt of southern and central New South Wales (NSW) on low available P soils in 2001-02 (Berthong and Greenethorpe) and 2004-05 (Boorowa and Grenfell) in which organic anion secreting crops (albus lupins and chickpeas) and non-secreting pulses (e.g. faba beans) were grown in the first season with and without P fertiliser. In the second season, the plots were split and wheat was sown with and without P fertiliser. Despite the promising results from the glasshouse work, the results from the four trials showed there was no carryover P benefit to the yield of wheat by the secreting pulses. This was probably because of a number of adverse seasonal factors, including drought in 2002, and a late break in 2004, and a very late break in 2005. In general, wheat had similar yields following all the pulses, and there was little residual effect of the previous year's fertiliser application, whether it was rock phosphate or superphosphate. Albus lupins were unresponsive to P fertiliser at all sites, presumably because of their ability to access fixed soil P. Recommended rates of P for this crop could be adjusted downwards. Chickpeas and faba beans require P fertiliser to achieve maximum yields. Reactive phosphate rock fertiliser was almost as effective as a source of P as SSP to the pulses during vegetative growth, but there were few responses in seed yield to any form of P fertiliser in the four trials. This was possibly a result of mineralisation of organic P during the season, and to the adverse seasonal conditions restricting yield. Any organic anions exuded by the pulses are likely to be biodegraded by the time the following wheat crop is sown. Citrate was detected in the rhizosphere soil of albus lupins at flowering, but not from soil surrounding old lupin roots sampled just before the wheat was sown.

Benefits to industry

While the glasshouse work showed promising results, they did not translate to the field, most likely because of adverse seasonal conditions. Consequently, it was not possible to assess economic benefits to the grains industry. The discovery that organic anions exuded from roots could mobilise P from organic P is especially important because it can be the major pool of P in soils. This has important implications for organic grain growers, for whom low plant available P is a major limitation to the viability of their enterprises. In addition, it is clear that the rate of P applied to albus lupins could be reduced without sacrificing yield because the crops were unresponsive to P fertiliser at all sites.

Other research

The mechanism by which faba beans conferred a P benefit to a following canola crop in the glasshouse experiment should be investigated further, even though it did not show a P benefit in field trials. The large break crop effect of faba beans was somewhat unexpected, as the labile value (L-value) data indicated that faba beans did not access a significantly larger pool of soil P than wheat or canola. In follow-up experiments, designed to identify possible mechanisms by which faba beans might increase soil P availability, significant root exudation of organic anions or phosphatases in P deficient plants were not detected. Consequently, the hypothesis for the break crop effect of faba beans is that the decomposition and mineralisation of the root residues supply P to the roots of a following crop growing in or near faba bean root channels. Some preliminary observations in the field indicated that wheat roots tended to grow in the root channels of the previous crops. This has been reported by many other researchers. Although this mechanism may be valid for any break crop, the very large lateral root system of faba beans might explain its superior rotational benefit to a following crop compared to some other pulses that exude organic anions. A large, positive effect of faba bean root residues on a following wheat crop has also been reported by Nuruzzaman et al (Plant and Soil, 271: 175-187) in a pot experiment. They also found that faba beans secreted only low levels of organic anions, and concluded that the break crop benefit was because of the mineralisation of the P-rich root residues. But it must be kept in mind that in all the pot experiments which reported a positive rotational P benefit for faba beans, the plants were grown for only six to seven weeks, so the roots would have had a high P concentration. The situation for plants grown to maturity may well be quite different because after flowering P is withdrawn from vegetative organs (including roots) and transported to the pods and seeds.

Further work needs to be done on the capacity of organic anion exuding plants to free-up P from the soil organic P pool because this can comprise more than 50% of the total P in soil. The project revealed that organic anions not only mobilise organic P compounds, but that the amenability of these compounds to enzymatic hydrolysis, and their plant availability, is increased (Hens et al 2003). This suggests that the exudation of organic anions plays a key role in the utilisation of soil organic P by plants. If this is the case, then it has important implications for organic growers who may apply organic amendments or use green manure crops.

An evaluation of intercropping an organic acid exuding crop such as albus lupins and a less P uptake efficient crop (e.g. wheat) may be another research and development (R&D) opportunity, particularly for organic growers. If the roots of the two crops intermingle, the wheat may be able to access some of the P released by root exudates from the more P-efficient crop. Intercropping is widely practised in a number of countries, and there is evidence that combinations, such as pigeon peas and sorghum, are effective.

Additional information

1) Hens, M. and Hocking, P.J. (2001): Organic acid exudation from cluster roots increases plant-available soil phosphorus.

Workshop on Structure and Functioning of Cluster Roots and Plant Responses to Phosphate Deficiency, Perth, Oct. 2001.

2) Hocking, P.J. and Hens, M. (2002): Phosphorus mobilization by organic-acid exudation: processes governing benefits in rotational cropping. 17th World Congress of Soil Science, Bangkok, Thailand, August 2002.

3) Hens, M. and Hocking, P.J. (2002): Organic acid induced increases in plant-available soil phosphorus; biotic vs abiotic controls. 17th World Congress of Soil Science, Thailand, August 2002.

4) Hens, M., Turner, B. and Hocking, P.J. (2003): Nature and enzymatic hydrolysis of soil organic phosphorus mobilized by organic anions. In : Abstracts of Organic Phosphorus Workshop, Monte Verita, Switzerland, 28-29.

5) Hens, M. and Hocking, P.J. (2003): Root exudates and P acquisition: mechanisms and their potential to improve the P-use efficiency in rotational cropping. In: Proc. Genetic Solutions for Hostile Soils, Canberra, November 2003.

6) Hens, M., Turner, B.L. and Hocking, P.J. (2003): Chemical nature and bioavailability of soil organic phosphorus mobilized by organic anions. Proc. 2nd Int. Symposium on Phosphorus Dynamics in the Soil-Plant Continuum, 16-17.

7) Hens, M. and Hocking, P.J. (2004): An evaluation of the phosphorus benefits from grain legumes in rotational cropping using 33P isotopic dilution. Proc. 4th Internat. Crop Sci. Congress, Brisbane.

8) Richardson, A., George, T., Hens, M. and Simpson, R.J.(2005): Utilization of soil organic phosphorus by higher plants. In 'Organic phosphorus in the environment'. pp. 165-184. (CABI Publishing: Wallingford, UK).