Grain legume crops increase soil phosphorus availability to subsequently grown wheat

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Abstract

Two pot experiments were conducted to determine whether legume crops influence the growth and phosphorus (P) uptake of subsequent wheat plants, and to determine whether the roots of the preceding legume crops are responsible for any improved P uptake and growth by the subsequent wheat. In the first experiment, field pea, faba bean, white lupin and wheat were grown in three different P-deficient soils to which no or 20 mg P/kg soil was added. This experiment clearly demonstrated a residual benefit of the legumes on the growth of the subsequent wheat crop due to enhanced P uptake. Faba bean was the best of the species tested in promoting subsequent wheat growth, and therefore it appears to be a suitable P-mobilising legume crop for use in rotations with wheat. The results of the second experiment, using one soil type, showed that the increased growth and P uptake of the subsequent wheat did not require the presence of the roots of the previous crops, suggesting that rhizosphere effects on soil P status were more important for P availability than mineralization of root residues.

Media summary

Wheat grew better after legumes than after wheat due to enhanced phosphorus uptake. Faba bean appears to be an excellent phosphorus-mobilising legume crop for use in rotations with wheat.

Introduction

Soils of the Western Australian cropping regions are old, highly weathered, and consequently very low in P (McArthur 1991). Consequently, P fertilisers are used extensively, but much of the fertiliser P is not taken up by the crop in the season of application, and remains in the soil as various residual forms of P. Crop species vary in their ability to take up this residual P, but certain grain legume crops can access poorly available forms of P by altering the rhizosphere chemically through the exudation of compounds such as organic-acid anions (Ae et al. 1991; Veneklaas et al. 2003). These crops may also improve P availability for crops grown in rotation with them (Hocking and Randall 2001). It is important to quantify these effects, since the wheat-legume rotation is one of the most important cropping systems in Australia (Siddique and Skyes 1997). The aim of the present study was to determine the impact of grain legume crops on the P nutrition and growth of succeeding wheat plants, and to assess whether the remaining legume roots had any beneficial effect on the growth of the wheat.

Materials and methods

Experiment 1

White lupin, field pea, faba bean and wheat were grown in pots for 100 days in P-deficient soils from Bindoon, Mingenew and Nyabing, Western Australia; no or 20 mg P/kg soil was added to the pots as KH_2PO_4. The day after the harvest of the shoots of the first crop, wheat was grown for 35 days with no applied P fertiliser. Controls were wheat in pots without a previous crop for each P treatment.

Experiment 2

White lupin, field pea, faba bean and wheat were grown for 75 days in pots of Mullewa (Western Australia) soil collected from a field that had produced a poor wheat crop because of drought in 2002. The soil had been fertilised at rates of 0 (P0), 2.5 (P1), 5 (P2), 10 (P3) and 40 (P4) kg P/ha. At the start of the experiment, Colwell-extractable P levels were 25.7 (P0), 26.4 (P1), 30.8 (P2), 39.0 (P3) and 51.9 (P4) mg P/kg. After harvesting the crops, the soil from each pot was re-mixed with or without the roots of the first crop. The pots were then sown to wheat, which was grown for 57 days.

Results

Experiment 1

Wheat grew better after the legumes than after wheat in all three soils. This effect was greater when the previous species had received P fertiliser. At P0, wheat grown after white lupin, field pea and faba bean produced 37%, 74% and 141%, respectively, more dry matter than the wheat grown in the pots without a previous crop (control). At P20, averaged for all soils, wheat following white lupin, field pea and faba bean had 30%, 61% and127%, respectively, more dry matter than wheat following wheat. With added P, wheat after white lupin, field pea and faba bean produced 49%, 45% and 47% more dry matter, respectively, compared with the pots that did not receive fertiliser. Wheat after faba bean produced 32% more dry matter than the wheat in the pots without a previous crop. The prior legume crops, particularly faba bean and field pea, increased the P uptake of the following wheat beyond the amounts that were taken up from the pots without a previous crop, but with fertilised soil. Although a significant amount of P was removed by the harvest of the shoots, the P content of the wheat after faba bean was 80% greater than that of wheat grown in pots without a previous crop (Figure 1).

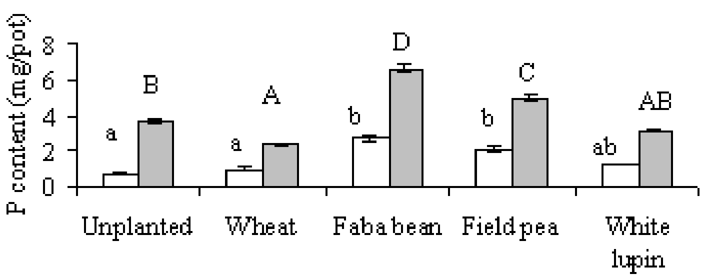

Figure 1. Phosphorus content of wheat grown for 35 days without P supply in pots that were previously not planted or planted with wheat, faba bean, field pea and white lupin, and fertilised with 0 (open bars) and 20 (filled bars) mg P/kg soil. Results are means of 3 soils; n = 4. Means with different letters are significantly different. Lower case letters indicate significant differences amongst crops in the P0 treatment, and capital letters indicate significant differences amongst the P20 treatment.

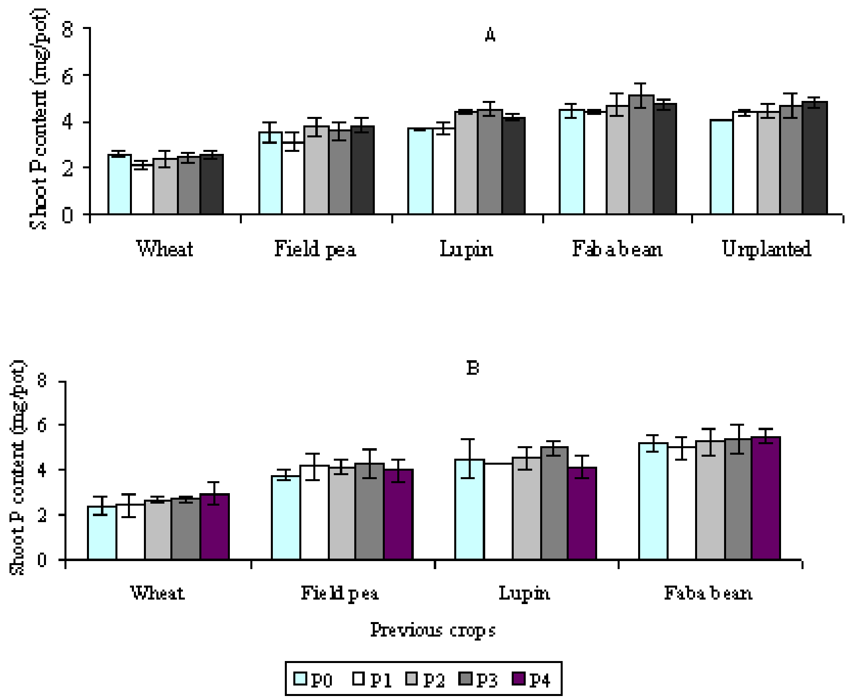

Figure 2. Shoot P content (mg/pot) of wheat grown in pots that were previously not planted or planted with wheat, white lupin, field pea and faba bean in soil with different levels of residual P. Roots of the previous crops were removed (A) or incorporated (B). Refer to Materials and methods for P levels.

Experiment 2

Wheat following the legumes grew better at all residual P levels than wheat after wheat. The different residual P levels did not result in large differences in plant growth or P content, and neither did incorporation of the roots of the first crop. However, the effect of the legume crops on the subsequent wheat was clear. Wheat grown after faba bean, field pea and white lupin produced 65%, 39% and 50% more shoot dry matter, respectively, than wheat grown after wheat. Amongst the legumes, faba bean resulted in a 96% increase in shoot P content of the succeeding wheat, while field pea and white lupin increased wheat shoot P content by 46% and 68% compared with wheat after wheat (Figure 2). Wheat grown in pots without a previous crop had a 75% greater shoot P content than wheat grown after wheat.

Discussion

The results of the first experiment strongly suggest that the legume species improved P availability to the subsequent wheat plants, leading to better growth in soils where P availability was the main limiting factor. Not only did wheat following white lupin, field pea and faba bean produce more biomass than wheat after wheat, but it also had higher tissue P concentrations, particularly when the previous crop had received P fertiliser. The concurrent increase in growth and P concentrations indicates that the legumes somehow enhanced the availability of P for uptake by wheat. It is possible that during their growth, legumes may have mobilised P from soil through the action of carboxylates. This mechanism has been suggested as an explanation for the positive rotational benefits of legumes, e.g., white lupin (Kamh et al. 1999) and pigeon pea (Ae et al. 1991). However, it is unlikely that the exuded carboxylates would have a direct effect on the subsequent crop, since carboxylates are subject to rapid turnover in soil, depending on temperature and soil type (Jones et al. 2003). The rotational benefit of the legumes, therefore, is probably related to the recycling of mobilised P through plant residues (Horst et al. 2001). Interestingly, faba bean, for which we did not find high rhizosphere carboxylate concentrations, had the greatest positive effect on the subsequent wheat crop. This suggests that the rotational benefit is more closely related to the mineralisation of P-rich plant residues rather than to residual effects of the root exudates on soil P chemistry, which led us to the second experiment that tested the effect of the presence of roots of the previous crops. Since the effect of legume crops on subsequent wheat growth and P uptake was present even in the absence of their roots, we conclude that the beneficial effect of these legumes was due to effects on soil P status other than mineralisation of root residues. Root-derived P compounds or very small root fragments that were left behind after removing the roots probably provided the observed beneficial effects of the legume crops. The present results suggest that faba bean is a very suitable P-mobilising legume crop for rotation with wheat.

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