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Growth, P uptake and rhizosphere properties of intercropped wheat and chickpea in soil amended with iron phosphate or phytate

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Abstract

Intercropping has been shown to increase total yield and nutrient uptake compared to monocropping. However, depending on crop combinations, one crop may dominate and decrease the growth of the other. Interactions in the soil, especially in the rhizosphere, may be important in the interactions between intercropped plant genotypes. To assess the role of the rhizosphere interactions, we intercropped a P-inefficient wheat genotype (Janz) with either the P-efficient wheat genotype (Goldmark) or chickpea in a soil with low P availability amended with 100 mg P kg^{-1} as $FePO_4$ (FeP) or phytate. The plants were grown for 10 weeks in pots where the roots of the genotypes could intermingle (no barrier, NB), were separated by a 30 μm mesh (mesh barrier, MB), preventing direct root contact but allowing exchange of diffusible compounds and microorganisms, or were completely separated by a solid barrier (SB). When supplied with FeP, Janz intercropped with chickpea had higher shoot and grain dry weight (dw) and greater plant P uptake in NB and MB than in SB. Contact with roots of Janz increased shoot, grain and root dw, root length, shoot P concentration and shoot P uptake of chickpea compared to SB. Root contact between the two wheat genotypes, Janz and Goldmark, had no effect on growth and P uptake of Janz. Shoot and total P uptake by Goldmark were significantly increased in NB compared to MB or SB. In both crop combinations, root contact significantly increased total plant dw and P uptake per pot. Plant growth and P uptake were lower with phytate and not significantly affected by barrier treatment. Differences in microbial P, available P and phosphatase activity in the rhizosphere among genotypes and barrier treatments were generally small. Root contact changed microbial community structure (assessed by fatty acid methyl ester (FAME) analysis) and all crops had similar rhizosphere microbial community structure when their roots intermingled.

Keywords: Chickpea; Genotypic differences; Intercropping; Microbial community composition; P uptake; Phytate; Rhizosphere; Wheat

1. Introduction

Intercropping of two or more crops is popular in many developing countries because yields are often higher than in monocropping systems. Resources such as water, light and nutrients are utilised more effectively than in the respective monocropping systems; when one of the crops is a legume, N from symbiotic nitrogen fixation can benefit the whole intercropped system, thereby reducing inorganic fertilisers requirement (Willey, 1979; Jensen, 1996).

In recent studies with faba bean/maize intercropping (Li et al., 1999, 2003b; Zhang and Li, 2003), both crops showed increased yield in intercropping compared with monocropping. Moreover, the yield advantage of intercropping was strongly influenced by the below-ground interactions between the intercropped species. Nitrogen fixation and nodulation (nodule number and weight) of faba bean were increased in intercropping compared with monocropping (Li et al., 1999, 2003b). Increased N_2 fixation by faba bean was also found in a wheat–faba bean intercropping (Xiao et al., 2004) and is apparently due to the strong depletion of inorganic N by wheat. Xiao et al.

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(2004) determined that up to 5% of faba bean N was transferred to wheat probably via rhizosphere deposition of inorganic N, amino acids and lysed cells.

Plant growth can also be negatively affected by intercropping. In maize/wheat intercropping, maize growth was decreased in rows adjacent to wheat (Li et al., 2001a, b; Zhang and Li, 2003) until wheat was harvested. Maize growth then recovered and by the time of maize harvest, the yield was equal to or higher than that in maize monoculture. Li et al. (2006) have shown recently that the reduction in maize growth was at least partly due to the greater below-ground competitive ability of wheat. Wheat roots were found under the maize rows, and the root system of maize was restricted when intercropped with wheat (Li et al., 2006).

Root interactions may also be important in soils with low P availability. Despite high total soil concentrations of P, its concentration in the soil solution is very low (frequently less than 1 μM; Barber, 1995) compared to the requirement of plants and soil organisms. Poorly available inorganic P forms include Ca phosphates, Fe/Al phosphates, and P adsorbed onto Fe/Al oxides and organic matter. Soluble P fertilisers applied to soil rapidly become unavailable (fixed) due to adsorption and formation of poorly soluble P compounds. On the other hand, organic P, predominantly phytic acid, may represent up to 80% of total soil P (Schachtman et al., 1998). Phytate is a poor P source for plants grown under axenic conditions because plant roots have a low extracellular phytase activity (Richardson et al., 2001). Microorganisms, on the other hand, excrete phytase (Richardson and Hadobas, 1997) and may play an important role in plant P uptake from phytate (Richardson et al., 2001). However, the effectiveness of phytase in soil is unclear because (i) phytate is adsorbed to Fe/Al oxides, which strongly reduces its availability, and (ii) phytase is rapidly adsorbed to soil particles leading to decreased activity (George et al., 2005).

Chickpea improved growth of intercropped wheat in a soil with low P availability amended with $FePO_4$ or phytate; however, growth of chickpea was reduced (Li et al., 2003a). The effect of chickpea on P uptake by wheat varied with P form added. Chickpea improved P uptake by wheat in the presence of phytate but not when $FePO_4$ was added. Later, Li et al. (2004) showed that chickpea also improved growth and P uptake of maize and that chickpea released greater amounts of acid phosphatase than maize. Phosphatase could contribute to the mineralisation of phytate. The inorganic P could then be taken up by the other crop (e.g., wheat or maize) if their roots are in the vicinity of the chickpea roots. These results suggest that the P form may play a role in the interactions between crops in intercropping.

Our recent studies showed that the wheat genotype Goldmark grew better and took up more P than wheat genotype Janz in an acidic soil with low P availability amended with $FePO_4$ (Marschner et al., 2006). The aims of the present study were to determine whether growth and P uptake of the P-inefficient wheat genotype Janz could be improved by intercropping with either the P-efficient genotype wheat genotype Goldmark or with chickpea in a soil with low P availability amended with two poorly available P forms: $FePO_4$ (inorganic) or phytate (organic). We also measured various rhizosphere properties such as microbial P, available P, phosphatase activity and microbial community structure to assess their role in the interactions between intercropped plant genotypes.

2. Materials and methods

2.1. Experimental set-up

Loamy sand (0–10 cm) was collected from Mount Bold (South Australia) (38.11°S, 138.69°E) and sieved to 2 mm. The soil has the following properties: pH (H_2O) 5.0, 41 g organic C kg^{-1}, 23% clay, 24% silt, 53% sand, 306 mg total P kg^{-1}, 7 mg microbial P kg^{-1} and 2 or 19 mg P kg^{-1} available P, determined as resin P or Colwell P, respectively. When the soil was collected, it contained 2.6 mg NH_4 kg^{-1} and 26 mg NO_3 kg^{-1}.

Basal nutrients were supplied at the following rates (g kg^{-1} soil): $Ca(NO_3)_2$ 0.92, K_2SO_4 0.17, $MgSO_4$ 0.19, micro-nutrients (mg kg^{-1} soil) Fe-EDTA 0.4, $CuSO_4$ $5H_2O$ 2.0, $MnSO_4$ H_2O 0.6, $Co(NO_3)_2$ $6H_2O$ 0.4, H_3BO_3 0.5, $Na_2M_0O_4$ H_2O 0.5, $ZnSO_4$ $7H_2O$ 2.2. Nitrogen was reapplied at the initial rate after 2, 4 and 6 weeks. Amended soil was placed in pots (20 cm × 14 cm × 12 cm) with a total of 2.5 kg per pot. There were three barrier treatments: no barrier (NB), mesh barrier (MB) (33 μm) and a solid barrier (SB). In the latter two treatments the pot was divided into two equal compartments (10 cm wide each).

In the first experiment, 100 mg P kg^{-1} soil was added as $FePO_4$. The poorly soluble $FePO_4$ was chosen because iron phosphates are dominant P forms in many acidic soils. To remove easily soluble P fractions, the iron phosphate salt was washed several times with deionised water, once with 1 M HCl, and then rinsed with deionised water before being dried and ground (Osborne and Rengel, 2002a). In the second experiment, 100 mg P kg^{-1} soil was added as phytate (Sigma) (Osborne and Rengel, 2002b).

2.2. Plant growth

Three plant genotypes were used: wheat (*Triticum aestivum* L.) cultivars Goldmark (P-efficient) and Janz (P-inefficient) and chickpea (*Cicer arietinum* L cv. Deshi). In a previous experiment, the wheat genotype Goldmark grew better than Janz in the same soil (Marschner et al., 2006). All seeds were imbibed in water overnight and then germinated on filter paper (Whatman #42) in the dark for 1 d. Six germinated wheat seeds or three germinated chickpea seeds were planted on one side of the compartmented pot and thinned to two and one seedling, respectively, after emergence. In the treatment without barrier, the seeds were placed in the same locations as in