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Belowground interactions between intercropped wheat and *Brassicas* in acidic and alkaline soils

Dongmei Wang[a], Petra Marschner[b,*], Zakaria Solaiman[b,c], Zed Rengel[c]

[a]*School of Soil and Water Conservation, Beijing Forestry University, Key-Laboratory of Soil and Water and Combating Desertification, Ministry of Education, Beijing 100083, PR China*
[b]*Soil and Land Systems, School of Earth and Environmental Sciences, The University of Adelaide, DP 636, SA 5005, Australia*
[c]*Soil Science and Plant Nutrition, School of Earth and Geographical Science, The University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia*

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Abstract

Our previous studies showed that, under P-limiting conditions, growth and P uptake were lower in the wheat genotype Janz than in three *Brassica* genotypes when grown in monoculture. The present study was conducted to answer the question if P mobilised by the *Brassicas* is available to wheat; leading to improved growth of wheat when intercropped with *Brassicas* compared to monocropped wheat. To assess if the interactions between the crops depend on soil type, the wheat genotype Janz and three *Brassica* genotypes (two canolas and one mustard) were grown for 6 weeks in monoculture or wheat intercropped with each *Brassica* genotype in an acidic and an alkaline soil with low P availability (with two plants per pot). Wheat grew equally well in the two soils, but the *Brassicas* grew better in the acidic than in the alkaline soil. In the acidic soil, monocropped *Brassicas* had a 3 to 4 fold greater plant dry weight (dw) and P uptake than wheat; plant dw and P uptake in wheat were decreased or not affected by intercropping and increased in the *Brassicas*. In the alkaline soil, dw and P uptake of the *Brassicas* was twice as high as in wheat, with intercropping having no effect on these parameters. The contribution of wheat to the total shoot dw and P uptake per pot was 4–21% and 32–40% in acidic and alkaline soil, respectively. Mycorrhizal colonisation was low in all genotypes in the acidic soil (1–6%). In the alkaline soil, mycorrhizal colonisation of monocropped wheat was 62%, but only 43–47% in intercropped wheat. Intercropping decreased P availability in the rhizosphere of wheat in the acidic soil but had no effect on rhizosphere P availability in the alkaline soil. Intercropping had a variable effect on rhizosphere microbial community composition (assessed by fatty acid methylester analysis (FAME) and ribosomal intergenic spacer amplification (RISA)), ranging from intercropping having no effect on the rhizosphere communities to intercropping resulting in a new and similar rhizosphere community composition in both genotypes. The results of this study show that intercropping with *Brassicas* does not improve growth and P uptake of wheat; thus there is no indication that P mobilised by the *Brassicas* is available to wheat.

Keywords: *Brassicas*; Intercropping; Microbial community composition; Monocropping; Mycorrhiza; P uptake; 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 can be utilised more effectively than in the respective monocropping systems. When one of the crops is a legume, nitrogen (N) from symbiotic fixation can benefit the whole intercropped system, thereby reducing the requirement for inorganic fertilisers (Willey, 1979; Jensen, 1996). In faba bean/maize intercropping, nitrogen fixation and nodulation (nodule number and weight) of faba bean were increased in intercropping compared with monocropping (Li et al., 1999, 2003b). However, 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)

*Corresponding author. Tel.: +61 8 8303 7379; fax: +61 8 8303 6511.
E-mail address: petra.marschner@adelaide.edu.au (P. Marschner).

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until wheat was harvested. However, maize growth then recovered and by the time of maize harvest, the yield was equal to or higher than that in maize monoculture.

Root interactions may be important in intercropping on soils with low P availability. The P concentration in the soil solution is low (frequently less than 1 μM; Barber, 1995) compared to the requirement of plants and soil organisms. The form and availability of P is strongly influenced by soil pH. In alkaline soils, poorly available inorganic P is mainly in the form of Ca phosphates, whereas Fe/Al phosphates, and P adsorbed onto Fe/Al oxides dominate in acidic soils (Bertrand et al., 2003). Soluble P fertilisers applied to soil may rapidly become unavailable (fixed) due to adsorption and formation of poorly soluble P compounds (Schachtman et al., 1998).

Our previous studies showed that, in monoculture, growth and P uptake of the wheat genotype Janz was lower than in wheat genotype Goldmark in an acidic soil (Marschner et al., 2006) suggesting that Janz is relatively P-inefficient. Intercropping with chickpea increased growth and P uptake of Janz compared to monocropping in the same soil (Wang et al., 2007), whereas intercropping with the wheat cultivar Goldmark had no effect. The rhizosphere of chickpea was characterised by high concentrations of available P and microbial P as well as high phosphatase activity. The positive effect of chickpea on growth and P uptake of the inefficient wheat indicates that P mobilised by chickpea can be taken up by the intercropped wheat. Similar positive effects on P uptake of wheat by intercropping were also found by Li et al. (2003a) for chickpea and by Horst and Waschkies (1987) for lupin. In our study with Janz intercropped with wheat genotype Goldmark or chickpea, root contact changed microbial community structure (assessed by fatty acid methyl ester (FAME) analysis) with crops having similar rhizosphere microbial community structure when their roots intermingled (Wang et al., 2007).

In our previous studies, *Brassicas* differed in growth and P uptake when grown in monoculture in the acidic Mt Bold soil (Marschner et al., 2007), and to a lesser extent in the alkaline Cungena soil (Solaiman, unpublished data). Growth of the *Brassicas* was lower in the alkaline soil compared to the acidic soil, whereas growth of wheat was similar in both soils. Hence, dry weight (dw) of the *Brassicas* compared to wheat was 3–8 fold and 2–4 fold higher than in wheat in the acidic and alkaline soil, respectively. In the acidic soil, growth of the mustard Chinese greens was greater than in the canola genotypes Drum and Outback (Marschner et al., 2007). The mustard also had the highest P availability in the rhizosphere. Compared to the wheat genotype Janz in the acidic soil (Marschner et al., 2006), P availability in the rhizosphere of mustard was twice as high, whereas it was similar in the two canolas (Marschner et al., 2007).

Based on our previous studies, the present experiment was conducted to answer the following questions: (i) can P mobilised by the *Brassicas* be taken up by wheat, leading to improved growth and P uptake of intercropped wheat compared to monocropped wheat? (ii) since *Brassicas* grow less well in alkaline soil compared to acidic soil, will soil type affect the interactions between the *Brassicas* and wheat in intercropping? (iii) will the *Brassica* genotype with the highest concentration of available P in the rhizosphere (mustard in previous experiments) improve growth and P uptake of wheat to a greater extent than the other *Brassica* genotypes? And (iv) will the microbial community composition in the rhizosphere of the genotypes differ when grown alone but be similar in the intercropped genotypes?

2. Materials and methods

2.1. Experimental set-up

The top 10 cm were collected from two different soils (Table 1) and air-dried immediately. The acidic loamy sand was from Mount Bold (Adelaide Hills, South Australia) (38.11°S 138.69°E) and the alkaline sandy soil from Cungena (Eyre Peninsula, South Australia) (32.36°S 134.42°E). Although the alkaline soil has relatively high available P concentrations as determined by the Colwell method (Colwell, 1963), previous studies have shown that growth of wheat is improved by P addition, indicating that the soil is P deficient (Li et al., 2005).

Both soils were sieved to 2 mm, and basal nutrients were supplied at the following rates (g kg^{-1} soil): $Ca(NO_3)_2$ 0.92, K_2SO_4 0.17 and $MgSO_4$ 0.19, with micronutrients (mg kg^{-1} soil) FeEDTA 0.4, $CuSO_4$ $5H_2O$ 2.0, $MnSO_4$ $4H_2O$ 0.6, $Co(NO_3)_2$ $6H_2O$ 0.4, H_3BO_3 0.5, Na_2MoO_4 $2H_2O$ 0.5 and $ZnSO_4$ $7H_2O$ 2.2. Nitrogen (as $Ca(NO_3)_2$) was re-applied at the initial rate after 2 and 4 weeks.

The P application rate to acidic soil was 100 mg P kg^{-1} soil as $FePO_4$. The poorly soluble $FePO_4$ was chosen as a P source because iron phosphates are dominant P forms in many acidic soils (e.g. Hu et al., 2005). 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, 2002). No P was added to

Table 1
Properties of the acidic and the alkaline soils used in this study

		Acidic soil	Alkaline soil
pH (H_2O)		5.0	8.5
Organic C	g organic C kg^{-1}	41	6
NH_4	mg kg^{-1}	2.6	0.8
NO_3	mg kg^{-1}	26	26
$CaCO_3$	g kg^{-1}	2	368
Clay	%	23	16
Silt	%	24	11
Sand	%	53	73
Total P	mg kg^{-1}	306	301
Microbial P	mg kg^{-1}	7	1
Available P (resin)	mg kg^{-1}	2	3
Available P (Colwell)	mg kg^{-1}	19	34