Mechanisms behind the Efficient Nutrient Utilization in Intercropping via Interspecific Below-ground Interactions

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Abstract

Plant species or functional group diversity increases ecosystem productivity and improves nutrient cycling in natural plant communities as well as intercropping systems. This paper provided some evidence that below-ground interspecific interactions benefits nitrogen and phosphorus utilization in several intercropping systems. Main methodology for these studies was root barrier techniques under field and greenhouse conditions: 1) solid root barrier, which had no below-ground interactions; 2) a 37 μm nylon mesh barrier between two species roots where there was interspecific interactions; and 3) complete root interactions between intercropped species**.** We found that nodulation and nitrogen fixation of legumes intercropped with cereals were increased by 195% and 150%, respectively, even under 225 kg N/ha application. The pot experiment with ^{15}N isotope showed that root contact enhanced ^{15}N acquisition of wheat but decreased that of faba bean. %Ndfa of fababean was increased to 91% for root interactions from 58% without root interactions. Using direct labeling method, N transferred from faba bean to companion wheat was 15% of total N in wheat. Interspecific below-ground interactions also play an important role in efficient phosphorus utilization in intercropping systems. The interspecific rhizosphere effect stems from intensive rhizosphere acidification and carboxylate of faba bean or acid phosphatase released from chickpea roots leads to an overyielding of intercropped wheat or maize when wheat is intercropped with chickpea under organic P (phytate-P) supply or when maize was intercropped with faba bean under Fe-P, Al-P supplies. The results have significance in explaining interspecific facilitation in plant community.

Media summary
Understanding why some crop species are happy together

Key words
Interspecific facilitation, phosphorus utilization, N_2 fixation, legumes, cereals

Introduction
The relationship between plant species or plant functional group diversity and productivity has become an important issue of natural community (Tilman, et al., 1997a; 1997b; Loreau and Hector, 2001) as well as Agroecosystems (Vandermeer, 1989). Increased nutrient use efficiency at high species richness is an important underlying mechanism of complementary

nutrient uptake in space and time (van Ruijven and Berendse, 2005). Furthermore, this probably is one of mechanism of species diversity enhancing productivity of an ecosystem. The objective of this paper is to review the progress in this aspect.

Interspecific rhizosphere effect is one of the mechanisms on greater productivity in intercropping on P deficient soils

Some previous works has demonstrated that intercropping of P-efficient crop species which mobilize sparingly soluble P by root exudates improve growth and P uptake of P-inefficient species in pot experiments (Gardner and Boundy, 1983; Horst and Waschkies, 1987; Ae et al., 1990). In India, intercropping of pigeon pea (*Cajanus cajan* L.) with cereals is a proven management scheme in increasing available P (Vance, 2001). EI Dessougi et al. (2003) reported that maize yield increased by intercropped with groundnut due to a 60% higher P uptake than maize grown alone. The beneficial effects of maize and faba bean intercropping on crop yield have been suggested to be the outcome of interactions between the root systems of the two species (Li et al., 1999; 2003; 2007). One pot experiment showed that average acid phosphatase activity of chickpea roots supplied with phytate was 2 -3 fold as much as maize, consequently, soil acid phosphatase activity in the rhizosphere of chickpea was also significantly higher than maize regardless of P sources. Chickpea can mobilize organic P in both hydroponic and soil cultures, leading to an interspecific facilitation in utilization of organic P in maize/chickpea intercropping (Li et al., 2004). By using permeable and impermeable root barriers, we found that maize overyielding resulted from its uptake of phosphorus mobilized by the acidification of the rhizosphere via faba bean root release of organic acids and protons. Faba bean overyielded because its growth season and rooting depth differed from maize (Li et al., 2007).

Interspecific interactions benefit N_2 fixation of legumes intercropped with cereals

Using the natural ^{15}N abundance method, we measured biological N_2 fixation of faba bean intercropped with maize under 0 and 120 kg N ha^{-1} application rates. Results showed that Intercropping increased the proportion of nitrogen derived from air (%Ndfa) of the wheat/faba bean system, but not that of the maize/faba bean system when no N fertilizer was applied. When receiving 120 N kg/ha, however, intercropping did not significantly increase %Ndfa either in the wheat/faba bean system or in the maize/faba bean system in comparison with faba bean in monoculture. The amount of shoot nitrogen derived from air (Ndfa), however, increased significantly when intercropped with maize, irrespective of N-fertilizer application. Ndfa decreased when intercropped with wheat, albeit not significantly at 120 kg N/ha (Fan et al., 2006).

In a pot experiment, Xiao et al. (2004) found that the presence of wheat roots in both the mesh barrier and no-barrier treatment severely decreased soil and fertilizer N uptake by faba bean, and enhanced N_2 fixation. Increased competition from wheat (both with the mesh barrier and without barrier) resulted in a further decrease in soil and fertilizer N uptake by faba bean, and correspondingly, higher percentage of fixed N_2 (%Ndfa). The decreased soil N uptake by faba bean was reflected both in increased ^{15}N left in soil and in total soil N; moreover N acquisition of wheat in the intercrop was enhanced 115% under no nitrogen application condition and 76% under nitrogen application. These results proved that interspecific below-ground interactions indeed benefit intercropped cereals to get more soil or fertilizer N, which further enhance the N_2 fixation of intercropped legumes.

Interspecific interactions and root distribution in intercropping

Using a monolith method, the root distribution of wheat/maize (a competitive) and faba bean/maize (a facilitative) intercropping was investigated under field conditions. The results proved that interspecific interactions were closely related to root distribution of two intercropped species in intercropping. The results showed that the roots of intercropped wheat spread under maize plants, and had much greater root length density (RLD) at all soil depths than sole wheat. The roots of maize intercropped with wheat were limited laterally, but had a greater RLD than sole-cropped maize (Li et al., 2006). RLD of maize intercropped with faba bean at different soil depths was influenced by intercropping to a smaller extent, compared to maize intercropped with wheat. Faba bean had a relatively shallow root distribution, and the roots of intercropped maize spread underneath them. The results supported the hypotheses that the overyielding of species showing benefit in the asymmetric interspecific facilitation (Li et al., 2001) results from greater lateral deployment of roots and increased root length density, and that compatibility of the spatial root distribution of intercropped species contributes to symmetric interspecific facilitation (Li et al., 1999; 2003) in the faba bean/maize intercropping.

Conclusions

The interspecific rhizosphere effect stems from intensive rhizosphere acidification and carboxylate of faba bean or acid phosphatase released from chickpea roots leads to an overyielding of intercropped wheat or maize when wheat is intercropped with chickpea under organic P (phytate-P) supply or when maize was intercropped with faba bean under Fe-P, Al-P supplies. The results have significance in explaining interspecific facilitation in plant community and in understanding why the roots of some intercropped species can be intermingled in soil profile, but other species combination does not. This also has highlight on understanding positive relationship between plant species diversity and productivity.

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