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Can arbuscular mycorrhizal fungi improve competitive ability of dill + common bean intercrops against weeds?

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ABSTRACT

Competition for soil resources plays a key role in the crop yield of intercropping systems. There is a lack of knowledge on the main factors involved in competitive interactions between crops and weeds for nutrients uptake. Hence, the purpose of this work was to compare the effects of arbuscular mycorrhial fungi (*Funneliformis mosseae*) colonization in interspecific competitive relations and its effect on nutrients uptake and weed control in dill and common bean intercropping. Two field experiments were carried out with factorial arrangements based on randomized complete block design with three replications during 2013–2014. The factors were cropping systems including a) common bean (*Phaseolus vulgaris* L.) sole cropping (40 plants m^{-2}), b) dill (*Anethum graveolens* L.) sole cropping at different densities (25, 50 and 75 plants m^{-2}) and c) the additive intercropping of dill + common bean (25 + 40, 50 + 40 and 75 + 40 plants m^{-2}). All these treatments were applied with (+AM) or without (-AM) arbuscular mycorrhiza colonization. In both cropping systems, inoculation with *F. mosseae* increased the P, K, Fe and Zn concentrations of dill plants by 40, 524, 57 and 1.0 $\mu g\,kg^{-1}$ DW, respectively. Intercropping increased Mn concentration in common bean (4.0 $\mu g\,kg^{-1}$ DW) and dill (3.0 $\mu g\,kg^{-1}$ DW), and also seed yields of both crops (198 $g\,m^{-2}$ and161 $g\,m^{-2}$, respectively). AM colonization improved seed yields of dill and common bean by 169 and 177 $g\,m^{-2}$ in 2013 and 2014, respectively. Moreover, AM application enhanced competitive ability of dill + common bean intercrops against weeds at different intercropping systems. Intercropping significantly changed weed density compared to sole cropping, as weed density was decreased in the dill + common bean intercropping. Diversity (H), Evenness (E) and richness of weed species of weeds for intercrops were higher than those for sole crops.

1. Introduction

The intercropping system greatly contributes to improve yields by its effective utilization of resources, as compared to the monoculture cropping system (Inal et al., 2007). This farming system may be a practical application of ecological principles based on biodiversity, biotic interactions and other natural regulation mechanisms (Malézieux et al., 2009), allowing efficient weed management with low reliance on off-farm inputs. In terms of competition this means that the components are not competing for the same ecological niches and then the interspecific competition is weaker than the intraspecific competition for a given factor (Vandermeer, 1989).

Intercrops can be more effective than sole crops in preempting resources used by weeds and suppressing weed growth, because complementary patterns of resource use and facilitative interactions between intercrop components can lead to a greater capture of light, water, and nutrients (Liebman et al., 2001). Some authors have studied how weed suppression is affected by an increase of biomass and the corresponding light interception for intercrops, assuming that both weeds and crops are mainly competing for aboveround resources (Baumann et al., 2000).

It is possible that intercrops promote the use of the available resources, thus, leaving less opportunity for the establishment and growth of weeds. Indeed, many crop mixtures show substantial yield advantages over sole crops, suggesting that the intercrops use the available resources more effectively (Hauggaard-Nielsen et al., 2009). A number of studies addressed weed problems and potential solutions offered by intercropping systems (Baumann et al., 2000; Liebman and Davis, 2000). In contrast to aboveground competition

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which primarily involves a single resource light, plants compete for a broad range of soil resources including water and several essential mineral nutrients like nitrogen (N), phosphorus (P), potassium (K), sulfur (S) and calcium (Ca) that differ in size, valence, oxidation state and mobility within the soil (Casper and Jackson 1997). Belowground interactions are now considered to be a key issue that needs to be investigated to improve the understanding and management of intercropping systems. Therefore, the belowground compartments responsible for the uptake of limited soil resources, i.e. fine roots and the internal mycelia of endomycorrhizal fungi, together play an important role in intraspecific and interspecific competition between crops and weeds. However, the characteristics of these belowground compartments are poorly understood in different cropping systems. Corn-legume intercropping led to a higher crop canopy cover and decreased light availability for weeds, which resulted in a reduction in weed density and dry matter, compared with sole crops (Kumar et al., 2010).

Arbuscular mycorrhiza (AM) fungi can provide a number of beneficial ecosystem services such as improving soil structure (Caravaca et al., 2006; Rillig and Mummey, 2006; Bedini et al., 2009), influencing plant nutrient uptake (Smith and Read, 2008; Clark and Zeto, 2000), suppressing weed populations (Rinaudo et al., 2010), and influencing major element cycles (e.g. carbon, phosphorus, nitrogen) (Fitter et al., 2011). In an experiment with three *Funneliformis* species, Jansa et al. (2005) found that *Funneliformis mosseae* and *Rhizophagus intraradices* acquired P from a greater distance from roots than *Claroideoglomus claroideum*. Plant growth can be suppressed even though the AM pathway contributes greatly to plant P uptake (Smith and Read, 2008). Moreover, it is well known that AM fungi can increase the uptake of micronutrients and other mineral nutrients with low mobility including Fe (Clark and Zeto, 2000), Zn (Kothari et al., 1991) and Cu (Li et al., 1991). Some nutrients including P, N, Zn, and Cu are enhanced in host plants grown in many soils (e.g., high and low soil pH), but K, Ca, and Mg are increased when plants are grown in acidic soils (Clark and Zeto, 2000). In this research we focus on AM fungi, a widespread group of soil fungi that can enhance yield of several agricultural crops (Sohrabi et al., 2012a,b; Smith and Read, 2008), especially when soil fertility is low. However, AM may also suppress growth of agricultural weeds as was recently proposed by Jordan et al. (2000). The induction of plant defense and production of toxic compounds by AM (Francis and Read, 1994, 1995) may be considered as direct effects. Although AM networks can suppress weeds, it may not eliminate them completely. Thus, interactions between AM fungi and additional edaphic factors including soil nutrients and disturbance also should be considered. These interactions certainly warrant further investigation for the validation of AM application as bio-control agents for weeds in agro-ecosystems.

Most weed research is devoted to study particular weed characteristics, mainly crop–weed competition, whereas only few studies are focused on the assemblage of multiple species communities composed of crop and weed species (Martınez-Ghersa et al., 2000). Concordantly, research on the changes in the weed community structure due to intercropping is sparse (Janiya and Moody, 1984; Mohler and Liebman, 1987). A major concern for farmers growing grain legumes in low-input agricultural systems is the weak competitive ability towards weeds (Liebman and Dyck, 1993). For the sustainable crop production, it is essential to develop mechanisms by which weeds can effectively be controlled. However, it is still unclear how weed species respond to AM application and dill + common bean intercropping, and how individual responses are affected by these crops. The potential role of AM fungi in weed management has already been discussed (Jordan et al., 2000; Cameron, 2010), but in order to realize this potential, a better understanding of the effects of AM fungi on individual weed species is required. The importance of land use policy and sustainable agriculture in the world has been investigated in enormous investigation (Valipour, 2014a,b, 2015). In addition, one of the major advantages of this work is more attention to sustainable agriculture with respect to the importance of intercrops and limitations of agricultural land use.

This intercropping may decrease the weed competition and then will increase the crop production also produce greater changes than monocultures in weed community structure, characterized by its species diversity, compositions of species and functional traits. Thus, the aims of this research were: (1) to determine the ability of dill + common bean intercrops to suppress weeds, (2) to investigate the effects of AM colonization on the competitive ability of dill + common bean intercrops against weeds in both intercrops and sole crops, (3) to determine the species diversity of the weed community in both intercrops and sole crops.

The hypotheses of this experiment are: (1) intercropping decreases the weed competition and this, in turn, will increase the crop production. (2) Intercropping produces greater changes than monocultures in weed community structure, species diversity, species compositions and functional traits and these changes increase the crop production.

2. Materials and methods

2.1. Experimental design

Two field experiments were conducted in the Agriculture and Natural Resources Research Center of Kurdistan Province during 2013–2014. Soil samples were taken from depths of 0–10 cm and 10–25 cm, using a soil auger. These samples were collected in spring from 8 points of experimental area. All samples were air dried at laboratory for 3 days and then followed by oven drying at 60 °C for 72 h until the weight of the samples remained constant, and then crushed and sieved through a 2 mm sieve (An et al., 2011; Santín-Montanyá et al., 2013). Subsequently, various chemical and physical properties of soils were determined (Table 1). Weather conditions during the experimental period are shown in Fig. 1. The experiments were carried out with a factorial arrangement based on randomized complete block design with three replications. The factors were (1) cropping systems including: a) common bean (*Phaseolus vulgaris* L.) sole cropping (C40 = 40 plants m^{-2}), b) dill (*Anethum graveolens* L.) sole cropping at different densities (D25, D50 and D75: 25, 50 and 75 plants m^{-2}, respectively) and c) the additive intercropping of dill + common bean (25 + 40, 50 + 40 and 75 + 40 plants m^{-2}) and (2) all these treatments were applied with (+AM) or without (-AM) arbuscular mycorrhiza colonization. The size of each plot was 4m × 5m.

The experimental site has been cultivated with a pea-wheat-oilseed rape rotation. Oilseed rape (*Brassica napus* L.) was grown in 2012 growing season. The biomass of oilseed rape was removed from the experimental area. Primary tillage was conducted in the third week of October 2012 and 2013. A mounted moldboard plow (3 bottoms with a 30 cm working width and working depths of 20–25 cm) was used for primary tillage in April. Secondary tillage was performed by a tandem disk harrow (20 disks with a 530 mm diameter, 5 each in 4 rows, working width of 1400 mm and working depths of 15–20 cm) in the same direction of plowing. The crops were managed according to organic farming practices without pesticide or fertiliser use. No mechanical weeding was performed after sowing.

Sowing dates of dill and common bean were 4 April, 2013 and 11 April, 2014. Dill was spaced 50 cm × 2.66 cm, 50 cm × 4 cm and 50 cm × 8 cm for 75, 50 and 25 plants m^{-2}, respectively, and common bean was spaced 50 cm × 5 cm for 40 plants m^{-2} in sole cropping. Dill was spaced 25 cm × 2.66 cm, 25 cm × 4 cm and