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Mycorrhizal association in soybean and weeds in competition

Cíntia Maria Teixeira Fialho[1*], Gustavo Soares da Silva[2], Laís Araújo Faustino[2], Felipe Paolinelli de Carvalho[2], Mauricio Dutra Costa[2] and Antonio Alberto da Silva[2]

[1]*Universidade Federal dos Vales do Jequitinhonha e Mucuri Vallyes, Rodovia MGT-367,* 583, Alto da Jacuba, 39100-000, Diamantina, *Minas Gerais, Brazil.* [2]*Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil. *Author for correspondence. E-mail: cintiamtfialho@yahoo.com.br*

ABSTRACT. The purpose of this study was to evaluate the effects of mycorrhizal association on the interference of *Bidens pilosa*, *Urochloa decumbens* and *Eleusine indica* on soybean culture in two conditions: a) plants competing without contact with roots of another species; b) with contact between roots. At 60 days after planting, growth, nutrient accumulation and mycorrhizal colonization of soybean and weeds were evaluated. The contact between roots of soybean plant and weed species increased the negative interference effects for both species, with less growth and nutrient accumulation. With the individualization of roots, higher competition occurred for soil resources up to 60 days of coexistence between species. In competition with soybean, *Bidens pilosa* and *Urochloa decumbens* stood out in accumulation of most nutrients without differing from when cultivated in monocultivation. The increase of the soybean mycorrhizal colonization was 53, 40 and 33% when in competition with *Urochloa decumbens, Eleusine indica* and *Bidens pilosa* species, respectively. A positive interaction occurred for soybean mycorrhizal colonization and competing plants irrespective of weed species or root contact.

Keywords: *Bidens pilosa*, *Urochloa decumbens* (*Syn. Urochloa decumbens*), *Eleusine indica*, arbuscular mycorrhiza fungi.

Associação micorrízica em soja e plantas daninhas em competição

RESUMO. Objetivou-se neste trabalho avaliar os efeitos da associação micorrízica na interferência de *Bidens pilosa*, *Urochloa decumbens* e *Eleusine indica* sobre a cultura da soja em duas condições: a) plantas competindo sem contato entre raízes de outra espécie b) com contato entre raízes. Aos 60 dias após o plantio, foram feitas avaliações do crescimento, acúmulo de nutrientes e colonização micorrízica da soja e plantas daninhas. O contato entre as raízes de plantas de soja e das espécies daninhas aumentou os efeitos negativos da interferência para ambas às espécies, com menor crescimento e acúmulo de nutrientes. Com a individualização das raízes, maior competição estabeleceu-se pelos recursos do solo até os 60 dias de convivência entre cultura e espécie competidoras. Em competição com a soja, *B. pilosa* e *U. decumbens* destacaram-se no acúmulo da maioria dos nutrientes não diferindo de quando cultivadas em monocultivo. O aumento da colonização micorrízica da soja foi de 53, 40 e 33 % quando em competição com *U. decumbens, E. indica* e *B. pilosa,* respectivamente. Ocorreu interação positiva para a colonização micorrízica da soja e das plantas competidoras independente da espécie daninha e do contato entre as raízes.

Palavras-chave: *Bidens pilosa*, *Urochloa decumbens*, *Eleusine indica*, fungo micorrízico arbuscular.

Introduction

Weeds can be a problem for any agricultural exploration, depending on the species and distribution in the crop, in a certain moment, when they are competing for light, water and nutrients. The complexity of factors that define the competition among plants has been studied by several investigators, aiming to define the mutual development capacity and species adaptation to the most different environments (Carvalho & Christoffoleti, 2008; Silva et al., 2009; Dias, Pinto, Mondo, Cicero, & Pedrini, 2011; Vivian et al., 2013).

In the soybean crop, the damages caused by weeds and management methods aiming at higher culture yield and preservation of its productive potential are investigated by several researchers (Silva et al., 2009; Bianchi, Agostinetto, & Rizzardi, 2011). Despite the advancements towards control, the presence of weeds in soybean is still a cause of losses in quality and yield. According to Pittelkow et al. (2009) and Benedetti, Pereira, Alves, and Yamauti (2009), not only the components of the culture must be observed, but it is also important to know the competition capacity of weed species for the determination of critical periods.

There is a complex relation between soil microbiota and vegetable species (Moreira & Siqueira, 2006) in such a way that the rhizosphere associated with plants can influence nutrient acquisition and absorption, development and even adaptability. Therefore, there is a need for identification of the competitive capacity of species, considering the interactions between soil microorganisms and competing plant as possible interference factors in the culture.

In conditions where there is competition for nutrients between culture and weeds, higher soil exploration by roots is essential, when some resources may be scarce and, consequently, stimulate colonization and sporulation of mycorrhizal fungi. In the case of soybean and other leguminous plants that have short or scarce root hairs, the association with mycorrhizal fungi is of extreme importance, resulting in better plant nutrition, as for example, phosphorous supply to the roots (Syibli, Muhibuddin, & Djauhari, 2014). The benefits of arbuscular mycorrhiza for plant growth are directly correlated with the degree of root colonization, and in the case of soy, it has an important role in favoring nodulation and biological nitrogen fixation (Moreira & Siqueira, 2006). Therefore, arbuscular mycorrhiza can minimize the effects of competition, being responsible for 80% of the soybean growth (Brito, Carvalho, & Goss, 2013).

Arbuscular mycorrhizal fungi are widespread in nature, and most plants are benefited from this association. In studies conducted by Santos et al. (2013) all 36 weed species, from 14 families presented mycorrhizal fungi colonization and, morphological types of arbuscular and coiled hyphae occurred in most species. The competitive advantage of weeds over cultures can be in part, result of the interaction of these plants with several groups of soil microorganisms (Reinhart & Callaway, 2006).

Plants in competition and with space limitation for development, can intercept their roots. The mycorrhizal fungi form a mycelial net that can extend beyond the root surface, thus, there may be a transfer of nutrients between plant species via mycorrhizal fungi (Finlay, 2008), where one of the species is benefited and the other has growth inhibition. The contact between roots can have effect on theincrease or reduction of competitiveness of species, in which mycorrhizal fungi can have a relevant contribution. In view of that, the purpose of this study was to evaluate growth, nutrient accumulation and mycorrhizal colonization of soybean in competition with *B. pilosa*, *U. decumbens*, *E. indica* with and without root system individualization.

Material and methods

The experiment was performed in a greenhouse, using Yellow-Red Latosol, with clay-sandy texture, presenting the following chemical characteristics: pH (water) = 4.7; organic matter = 2.40 dag kg^{-1}; P = 2.3 mg dm^{-3}, K = 48.0 mg dm^{-3}; Ca^{+2}, Mg^{+2}, Al^{+3}, H + Al, SB and $CTC_{effective}$ = 1.4; 0.4; 0.6; 6.27; 1.92 and 2.52 $cmol_c$ dm^{-3}, respectively; base saturation = 24% and aluminum saturation = 23%. The soil was fertilized with urea (200 g m^{-3} of soil), simple superphosphate (300 g m^{-3} of soil) and potassium chloride (180 g m^{-3} of soil). To increase base saturation to 60%, dolomitic limestone was used at 0.78g dm soil concentration.

Rectangular pots of 4 L (12.5 cm width x 38 cm length) were divided in two compartments using a nylon screen (50 μm mesh), which did not allow passage of roots; but allowed the passage of mycorrhizal hyphae and nutrient flow, according to Cruz and Martins (1998). Half of the pots were divided. All pots were filled with previously corrected and fertilized soil.

Sowing of soybean and *B. pilosa*, *U. decumbens* and *E. indica* species was carried out simultaneously in the pot in two conditions. In the first condition, divided pots, the culture stayed in a compartment and the competing species in another. In the second condition, pot without division, culture and competing species were sowed without separation. In both cases, one soybean plant and three weeds were cultivated per pot. Soil moisture was maintained by daily irrigations, maintaining the water content close to the field capacity.

The experiment was composed by treatments of soybean in competition with *B. pilosa*, *U. decumbens* and *E. indica* and also by monocultivation of soybean and competing species. For all these combinations, cultivation was performed with and without the use of the screen dividing the pot. For the soybean with weeds variables, a 4 x 2 factorial scheme (soybean with *B. pilosa*, *U. decumbens* and *E. indica* and in monocultivation, besides use or not of screen for root individualization) was used in randomized blocks delineation with four replications. To evaluate the weeds, a 3 x 2 x 2 factorial scheme (*B. pilosa*, *U. decumbens* and *E. indica versus* use or not of nylon screen and weed plant in competition with soybean and in monocultivation) was used, in randomized blocks delineation with four replications.

At 60 days after emergence, all plants were cut close to the ground. Density was determined in soybean plant roots, measured by the fresh matter weight to displaced water volume (g mL^{-1}) ratio when submerged in 1,000 mL graduated test tube. Subsequently, the leaf area was determined using an area integrator (model LI 3100), conditioning the plant parts, separately in paper bags for dry matter determination in forced air circulation oven (60°C), to a constant mass.

The following variables were calculated with the collected data: specific leaf area (SLA) (plant leaf area/ leaf dry matter); leaf mass ratio– LMR (leaf dry matter/total dry matter), stem matter ratio – SMR (stem dry matter/ total dry matter) and root mass ratio- RMR (root dry matter/ total dry matter); leaf area ratio - LAR (leaf area/ total dry matter), according to Benincasa (2003).

After roots were separated from soil and washed in running water, 1.0 g root sample from each pot species was collected and maintained in 50% ethanol, for evaluation of mycorrhizal colonization. Root samples were cut in segments of 1 cm length, clarified in 10% KOH solution, acidified with 1% HCl, stained with 0.05% trypan blue and kepted in lactoglycerol (Schenck, 1982). Each sample was distributed on Petri dishes with grids, where percentage colonization count was performed in stereomicroscope, using the magnified intersection method (Giovannetti & Mosse, 1980).

After dry matter determination, root samples and aerial part were submitted to grinding in a Willey-type mill, equipped with fine sieves (40 mesh). Macro and micronutrient content present in the soybean, *B. pilosa*, *U. decumbens* and *E. indica* were determined. Phosphorous (P) content of the extract was determined by colorimeter (725 nm) after nitric-perchloric digestion of vegetable material using the vitamin C method (Braga & Felipo, 1974). In the same extract, potassium (K) was determined by flame photometry, sulfur (S) by sulfate turbidimetry (Jackson, 1958); and calcium analyses (Ca), magnesium (Mg), by atomic-absorption spectroscopy. The N-Total content was determined by the Kjeldahl method (Yasuhara & Nokihara, 2001), after sulphuric digestion of the material. With macro and micronutrient levels observed, total plant nutrient accumulation was calculated from the dry matter of roots and aerial part.

For interpretation of results, analysis of variance was employed using the F test ($p \leq 0.05$ probability) and Tukey's post hoc test at 5% probability for multiple comparisons between competing species and use of screen.

Results and discussion

From the performed analyses, it could be verified that species in competition with soybean presented distinct responses and their differences, with or without screen separating roots, represented divergent skills for each species. The dry matter, area ratio and specific area of the soybean leaf in monocultivation did not differ from those in competition with weed species, when using screen to separate roots. For total dry matter and leaf area of soybean in competition with *E. indica*, even when the screen was used, these variables were lower regarding soybean in monocultivation (Tables 1 and 2).

Table 1. Leaf dry matter (LDM) and total dry matter (TDM) of soy, submitted to competition with *B. pilosa*, *U. decumbens* and *E. indica*, evaluated at 60 days, in environment with or without root system contact.

Treatment	LDM (g)		TDM (g)	
	Screen	No screen	Screen	No screen
Soybean + BIDPI	3.70 aA[1]	2.94 bA	8.73 abA	6.47 bB
Soybean + ELEIN	3.42 aA	2.92 bA	7.74 bA	7.46 bA
Soybean + URDC	3.86 aA	2.17 bB	8.26 abA	5.59 bB
Soybean	5.52 aA	5.91 aA	12.51 aA	13.26 aA
C.V (%)	28.75		27.29	

[1]Means followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's post test at 5% significance level. *Bidens Pilosa* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC).

Without the use of the screen separating roots, soybean in monocultivation presented higher leaf dry matter, total dry matter and leaf area in relation to soybean in competition, regardless of species. Soybean in competition with *B. pilosa* presented lower leaf area ratio and the lowest specific leaf area was for soybean in monocultivation (Tables 1 and 2).

Comparing treatments with and without screen for soybean in competition with weeds, distinguished behavior was observed for each species depending on the variable (Tables 1 and 2). In general, soybean variables presented lower values in treatments with root contact, and coexisting with *B. pilosa* and *U. decumbens* comparing with treatments with no root contact.

Table 2. Leaf Area (LA), leaf area ratio (LAR), and specific leaf area (SLA) of soybean submitted to competition with *B. pilosa*, *U. decumbens* and *E. indica*, evaluated at 60 days, in environment with or without root system contact.

Treatment	LA (cm^2)		LAR ($g\ g^{-1}$)		SLA ($cm^2\ g^{-1}$)	
	Screen	No screen	Screen	No screen	Screen	No screen
Soy + BIDPI	993.01 abA[1]	557.16 bB	116.24 aA	80.57 bB	205.92 aA	179.07 abB
Soy + ELEIN	796.06 bA	593.59 bA	103.71 aA	84.09 abA	189.98 aA	209.94 aA
Soy + URDC	942.24 abA	538.47 bB	114.45 aA	97.18 abA	215.08 aA	245.69 aA
Soy	1323.63 aA	1484.75 aA	106.24 aA	114.52 aA	179.79 aA	155.97 bA
C.V (%)	28.58		15.87		14.89	

[1]Mans followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's post test at 5% significance level. *Bidens Pilosa* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC).

The soybean variables (stem and root dry matters) showed no interactions among the studied factors, only the weed species variable was significant. Soybean in competition presented reduction of independent variables of competing species for stem and root dry matters (Table 3).

Table 3. Stem dry matter (SDM) and root dry matter (RDM) of soy, submitted to competition with *B. pilosa*, *U. decumbens* and *E. indica* evaluated at 60 days.

Treatment	SDM (g)	RDM (g)
Soybean + BIDPI	2.48 b[1]	1.60 b
Soybean + ELEIN	2.49 b	1.91 b
Soybean + URDC	2.10 b	1.81 b
Soy	4.04 a	3.13 a
C.V (%)	28.62	18.3

[1]Means followed by same letter in column do not differ by Tukey's test at 5% significance level. *Bidens Pilosa* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC).

In the process of initial competition between soybean and weeds in the conditions of pots without separation and with roots developing together, lower development of the culture was probably associated with overlapping nutrient uptake between plant root zones. The occupation of soil space by the root is of primary importance in the competition process and each species may present different competitive skills in the root system. There are studies in the literature reporting these skills of competing plants, *B. pilosa* is outstanding in phosphorous extraction (Cury et al., 2013), while gramineous plants can presented rapid root system formation and soil occupation (Silva et al., 2013).

When there was no superposition of nutrient uptake zones, in pots divided by screen, it was noticed that aerial part variables of soybean were less affected than the roots. Probably the competing plant developing near the soybean contributed to lower nutrient availability and the soybean had the root development affected up to 60 days of coexistence. Studies conducted by Bianchi, Fleck, & Dillenburg (2006) observed that during the period of initial vegetative growth of soybean, the competition for soil resources predominated on the competition for solar radiation, resulting in reduction of growth variables.

Variables related to species *B. pilosa*, *E. indica* and *U. decumbens* presented no significance for the screen factor. Thus, the interaction was separated between species and type of cultivation (competition with soy, monocultivation) (Table 4). In comparisons of growth variables of weeds in competition with soybean and in monocultivation, it is important to observe the effect of the soybean competition over these species. However, the comparison between species is of little relevance as the found differences are more influenced by intrinsic characteristics of species than by the analysed treatments.

It was noticed that weeds cultivated in presence of soybean, also had the development negatively affected. In general, *B. pilosa* had higher reduction of aerial part variables, while gramineous ones presented lower values when in competition with soybean for variables associated with roots. In systems of competition for growth resources, the involved plants presented special characteristics; therefore, the understanding of the behavior of both culture and weeds is important for preparation of management strategies.

The weed variables root mass ratio and leaf mass ratio were not modified when in competition with soybean (Table 5). Among the weed species, *B. pilosa* stood out with higher leaf area ratio and leaf mass ratio values. The competition for soil resources and solar radiation is not independent, and both the root system and the aerial plant part played quick exchanges concerning photoassimilate allocation, when one or another fraction is more recruited in the competition (Cahill & Lamb, 2007; Kiær, Weisbach, & Weiner, 2013). This increase of photoassimilate allocation to the aerial part of *B. pilosa* was probably a competitive strategy of the species.

The accumulation of nutrients in soybean plants was higher when in monocultivation, for the two pot conditions (with and without screen), except for P accumulation (Table 6). Without the contact of soybean roots and competing species, P accumulation in the culture did not differ between treatments. This fact can be associated with low mobility of this element in the soil, which is transported by diffusive flow, occurring higher competition for P when roots were very close, in this case without the use of screen. The competition for 'non-motile' elements exists in lower intensity, as its transport distance does not exceed 1 mm of distance from the root (Novais & Mello, 2007).

Table 4. Leaf dry matter (LDM), root dry matter (RDM), leaf area (LA) and leaf mass ratio (LMR) of *B. pilosa*, *U. decumbens* and *E. indica* cultivated in competition (WC) with soybean and in monocultivation (MC), evaluated 60 days after emergence.

Weeds	RD		RMR		LMR		SLA	
	WC	MC	WC	MC	WC	MC	WC	MC
BIDPI	0.08 bA[1]	0.08 bA	0.24 bA	0.26 bA	130.57 aA	129.17 aA	320.53 aB	292.59 aA
ELEIN	0.13 abA	0.12 bA	0.37 aA	0.35 aA	61.04 bA	61.40 bA	154.25 bA	143.54 bA
URDC	0.15 aB	0.20 aA	0.32 abA	0.35 aA	66.48 bA	60.17 bA	164.26 bA	151.51 bA
CV (%)	20.69		14.31		24.88		21.15	

[1]Means followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's test at 5%. *Pilosa Bidens* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC). WC, with competition; MC, monocultivation.

Table 5. Root Density (RD), root mass ratio (RMR), leaf mass ratio (LMR) and specific leaf area (SLA) of *B. pilosa*, *U. decumbens* and *E. indica* cultivated in competition (WC) with soybean and in monocultivation (MC), evaluated 60 days after emergence.

Weeds	RD		RMR		LMR		SLA	
	WC	MC	WC	MC	WC	MC	WC	MC
BIDPI	0.08 bA[1]	0.08 bA	0.24 bA	0.26 bA	130.57 aA	129.17 aA	320.53 aB	292.59 aA
ELEIN	0.13 abA	0.12 bA	0.37 aA	0.35 aA	61.04 bA	61.40 bA	154.25 bA	143.54 bA
URDC	0.15 aB	0.20 aA	0.32 abA	0.35 aA	66.48 bA	60.17 bA	164.26 bA	151.51 bA
CV (%)	20.69		14.31		24.88		21.15	

[1]Means followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's test at 5% significance level. *Pilosa Bidens* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC). WC, competition; MC, monocultivation.

Table 6. Macronutrient accumulation in soybean plants submitted to competition with *B. pilosa*, *U. decumbens* and *E. indica* in coexistence for 60 days, with or without root contact of species in competition.

Treatment	P		N		K		Mg		Ca	
	mg plant^{-1}									
	Screen	No screen	Screen	No screen	Screen	No screen	Screen	No screen	Screen	No screen
Soy+BIDPI	3.50 aA[1]	1.62 bB	282.73 bA	196.63 bB	121.05 bA	79.85 bB	38.56 bA	29.48 bB	135.65 bA	101.11 bA
Soy +ELEIN	3.54 aA	2.08 bB	213.36 bA	186.23 bA	111.80 bA	73.73 bB	37.49 bA	30.05 bA	124.90 bA	93.32 bA
Soy +URDC	3.64 aA	2.22 bB	271.26 bA	142.64 bB	101.32 bA	53.36 bB	42.25 bA	26.48 bB	143.57 abA	71.41 bB
Soy	4.19 aA	4.05 aA	424.71 aA	437.02 aA	183.03 aA	202.01 aA	62.63 aA	68.75 aA	197.33 aA	227.11 aA
C.V (%)	11.62		13.48		13.57		14.77		22.80	

[1]Means followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's test at 5% significance level. *Pilosa Bidens* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC).

There was a tendency of less nutrient accumulation in soybean when there was contact among species roots, with variation among nutrients and species. This fact was observed for most treatments in which soybean was cultivated with *B. pilosa* and *U. decumbens*. Nitrogen and potassium are two elements high extracted by weed (Kabba, Knight, & Rees, 2011; Cury et al., 2013), being a strong competing for these elements.

Soybean presents an extra source to supply N demand through N_2 biological fixation, process performed by several bacteria species that live in the soil. However, it presented less accumulation of this element when in coexistence with competing species. Direct competition may have occurred for the element or perhaps N has not been a limiting factor for soy, but the deficiency of other elements, which can damage nitrogen accumulation for the culture. An example would be the N x K interaction, the absorption of an element leads to the demand for the other (Cantarella, 2007). Another possibility is the lower dry matter accumulation of soybean in competition with weeds, resulting in less N accumulation. In this case, knowing the level of elements in the plant organs would be of extreme importance.

There was interaction between plant species and cultivation type (monocultivation or competition with soy) for all elements, exception for Ca and Mn which did not present significant differences (Table 7). This fact shows that both species suffer damage when in competition. However, the damages of the culture are more significant, since they are directly associated with yield and profitability. Weeds in many cases are more efficient in the competitive process of the culture, even without having been submitted to selection of high quality seed, and in many cases without receiving fertilizer, only by skills acquired along time and due to high adaptation capacity, besides other characteristics inherent in each species. It is also mentioned that cultivated plants have lower competition capacity, due to the breeding process, which they are submitted (Fontes, Shiratsuchi, Neves, & Filho, 2003).

There was no difference in nutrient accumulation of competing species when in monocultivation and in cultivation with soy, and it is possible to infer that the species is a good competing for the element. Thus, *B. pilosa* stood out in P and Mg accumulation; *E. indica* only in K accumulation, and *U. decumbens* in K and Mg accumulation.

Table 7. Macronutrient accumulation in *B. pilosa*, *U. decumbens* and *E. indica* cultivated in competition with soybean (WC) and in monocultivation (MC), evaluated 60 days after emergence.

Treatment	P		N		K		Mg		Ca	
	mg plant^{-1}									
	WC	MC	WC	MC	WC	MC	WC	MC	WC	MC
BIDPI	12.86 cA[1]	13.29 cA	231.68 bB	311.16 bA	275.17 bB	363.79 aA	52.68 cA	56.22 cA	8.03 cA	10.23 cA
ELEIN	26.93 aB	42.34 aA	398.01 aB	429.14 aA	212.54 bA	247.94 bA	67.65 bB	111.17 aA	38.22 aB	58.78 aA
URDC	19.93 bB	33.00 bA	354.74 bB	438.86 aA	295.04 aA	280.95 bA	87.69 aA	92.09 bA	23.47 bA	23.34 bA
C.V (%)	15.59		15.76		12.26		13.84		23.12	

[1]Means followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's test at 5% significance level. *Pilosa Bidens* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC). WC, with competition; MC- monocultivation.

The understanding of the biological aspects of competing species is fundamental, highlighting the nutritional demands and the responses to environment alterations, among others (Kabba et al., 2011). Thus, it is important to analyse how efficient competing species were in nutrient accumulation. Nutrient accumulation in *B. pilosa*, *U. decumbens* and *E. indica* plants was differentiated depending on the element and on the cultivation condition, being that for N, K and Mg there was interaction between plant species with or without screen separating the pots (Table 8). In the cultivation without screen, *U. decumbens* accumulated less N and Mg, and *B. pilosa* presented lower K accumulations. This is probably not due to the use of the screen itself, but to the presence of soybean in competition, as noticed in Table 7.

The mycorrhizal colonization percentage in soybean roots was higher when cultivated with *U. decumbens*, followed by soybean cultivated with *E. it indica* and *B. pilosa* (Table 9). The screen factor was not significant; in other words, root contact in the competitive process did not alter the percentage of mycorrhizal colonization of soybean. Mycorrhizal symbiosis strongly influences the patterns and intensity of effects of intra and interspecific competition between weed, and the benefit degree of the species is consequence of the plant mycorrhizal dependence (Rinaudo, Bárberi, Giovannetti, & Van Der Heijden, 2010; Silva et al., 2015). As observed, other species involved in the competition process also presented influences of mycorrhizal associations. In this case, increase of colonization occurred by mycorrhizal fungi in soybean roots when in competition.

Mycorrhized plants demonstrably have higher access to soil nutrients, mainly P (Santos et al., 2013; Brito et al., 2013). In case of soil elements limitation, it is probable that more associations between plants and mycorrhizal fungi are established, attempting to increase the volume of root exploration and to have more access to nutrients.

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Mycorrhized plants demonstrably have higher access to soil nutrients, mainly P (Santos et al., 2013; Brito et al., 2013). In case of soil elements limitation, it is probable that more associations between plants and mycorrhizal fungi are established, attempting to increase the volume of root exploration and to have more access to nutrients.

In the intercropping between soybean and competing species, root colonization by mycorrhizal fungi, can act simultaneously with the process of biological fixation of nitrogen. The soybean dry matter production and mycorrhizal dependence are higher in presence of rhizobium (Brito et. al., 2013). Arbuscular mycorrhiza fungi allow interconnections between roots of different species through a mycelial net that is developed in the soil, creating the possibility of nutrient transfer between them. Paulino, Alves, Barroso, Urquiaga, and Espindola (2009) noticed that crotalaria and gliricidia transferred to the graviola tree from 22.5 to 40% of N from biological fixation when intercropping. Perhaps the same thing occurs with weeds, they manage to absorb nitrogen through the connection between mycorrhizal hyphae of the species, originating from the nitrogen biological fixation. Thus, it is interesting for the weed that the soybean has higher mycorrhizal colonization.

Table 8. Nitrogen (N), potassium (K) and magnesium (Mg) accumulation in *B. pilosa*, *U. decumbens* and *E. indica*, evaluated 60 days after emergence, in environment with ou without root system contact.

Species	N		K		Mg	
	mg plants per vase^{-1}					
	Screen	No screen	Screen	No screen	Screen	No screen
BIDPI	257.67 bA[1]	285.16 cA	204.84 bA	255.65 bB	53.31 bA	55.59 bA
ELEIN	423.03 aA	464.12 aA	302.99 aA	335.97 aA	89.32 aA	89.50 aA
URDC	430.23 aA	363.37 bB	299.02 aA	276.98 bA	99.71 aA	80.07 aB
C.V (%)		15.76		12.26		13.84

[1]Means followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's test at 5% significance level. *Pilosa Bidens* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC).

Table 9. Percentage of mycorrhizal colonization of soybean in competition with *B. pilosa*, *U. decumbens* and *E. indica*, evaluated at 60 days.

Treatment	Mycrorrhizal Colonization Percentage
Soybean + BIDPI	34.30 b[1]
Soybean + ELEIN	38.92 b
Soybean +URDC	49.70 a
Soy	22.97 c
C.V	17.97

[1]Means followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's test at 5% significance level. *Pilosa Bidens* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC).

For mycorrhizal colonization of weeds, the screen factor was not significant. Difference in colonization percentage between weed species and when in monocultivation or in competition with soybean was observed (Table 10). Weed species that developed in monocultivation presented percentage variation in mycorrhizal colonization; *U. decumbens* colonization had approximately 38% more mycorrhizal fungi than *B. pilosa*. When the competing species developed with soy, a higher stimulus to mycorrhizal colonization was noticed, due to the increase of this variable, mainly for *B. pilosa* and *U. decumbens*. Mycorrhizal colonization increase was 42 and 20% for *B. pilosa* and *U. decumbens*, respectively, when in competition with soy.

Table 10. Percentage of mycorrhizal colonization of *B. pilosa*, *U. decumbens* and *E. indica* in competition with soybean (WC) and in monocultivation (MC) evaluated at 60 days.

Weeds	Mycorrhizal Colonization Percentage	
	WC	MC
BIDPI	37.17 aA[1]	21.54 bB
ELEIN	28.08 bA	27.22 abA
URDC	42.75 aA	33.93 aB
C.V	19.41	

[1]Means followed by same letter, small letter in column and capital letter in line, for each variable, do not differ by Tukey's test at 5% significance level. *Pilosa Bidens* (BIDPI), *Eleusine indica* (ELEIN), *Urochloa decumbens* (URDC). WC, competition; MC, monocultivation.

Mycorrhizal fungi significantly influence the effects of competition and responses of both plant species, can a crop or weed was influenced or not. For example, weed species had reduction of competitive effects with sunflower when inoculated by arbuscular mycorrhizal fungi, indicating that a crop can be beneficiated and its competitive power is highly dependent of mycorrhizal associations (Rinaudo et al., 2010).

Conclusion

From the set of analyses obtained in the cultivation of soybean and B. pilosa, U. decumbens and E. indica, it is possible to summarize that the weed is extremely competitive with the culture, fundamentally for lower growth and accumulation of nutrients evidenced at the end of 60 days of cultivation. This positive interaction for mycorrhizal colonization of soybean and competing plants occurred irrespective of the contact between roots. Therefore, further studies on this topic, including cultivation in sterilized soils and with other plant combinations are necessary.

References

Benedetti, J. G. R., Pereira, L., Alves, P. L. C. A., & Yamauti, M. S. (2009). Período anterior à interferência de plantas daninhas em soja transgênica. *Scientia Agraria, 10*(4), 289-295. doi: 10.1590/S0100-83582009000100009

Benincasa, M. M. P. (2003). *Análise de crescimento de plantas: noções básicas* (2nd ed.). Jaboticabal, SP: Funep.

Bianchi, M. A., Agostinetto, D., & Rizzardi, M. A. (2011). Interferência de *Raphanus sativus* na produtividade de cultivares de soja. *Planta Daninha, 29*(4), 783-792. doi: 10.1590/S0100-83582011000400008

Bianchi, M. A., Fleck, N. G., & Dillenburg, L. R. (2006). Partição da competição por recursos do solo e radiação solar entre cultivares de soja e genótipos concorrentes. *Planta Daninha, 24*(4), 629-639. doi: 10.1590/S0100-83582006000400003

Braga, J. M., & Felipo, B. V. (1974). Determinação espectrofotométrica de fósforo em extratos de solos e plantas. *Revista Ceres, 21*(113), 73-85.

Brito, I., Carvalho, M., & Goss, M. J. (2013). Soil and weed management for enhancing arbuscular mycorrhiza colonization of wheat. *Soil Use and Management, 29*(4), 540-546. doi: 10.1111/sum.12069

Cahill, J. F., & Lamb, E. G. (2007). Interaction between root and shoot competition and plant traits. *HortScience, 42*(5), 1110-1112.

Cantarella, H. (2007). Nitrogênio. In: Novais, R. F., Alvarez, V. H., Barros, N. F., Fontes, R. L. F., Cantarutti, R. B., & Neves, J. C. (Eds.), *Fertilidade do solo* (p. 471-537). Viçosa, MG: Sociedade Brasileira de Ciência do Solo.

Carvalho, S. J. P., & Christoffoleti, P. J. (2008). Competition of *Amaranthus* species with dry bean plants. *Scientia Agricola, 65*(3), 239-245. doi: 10.1590/S0103-90162008000300003

Cruz, A. F., & Martins, M. A. (1998). Efeito de fungos mycorrhizal arbusculares e doses de N sobre plantas cultivadas em sistema de consórcio. *Revista Ceres, 45*(257), 41-54.

Cury, J. P., Santos, J. B., Silva, E. B., Braga, R. R., Carvalho, F. P., Silva, D. V., & Byrri, E. C. M. (2013). Eficiência nutricional de cultivares de feijão em competição com plantas daninhas. *Planta Daninha, 31*(1), 79-88. doi: 10.1590/S0100-83582013000100009

Dias, M. A. N., Pinto, T. L. F., Mondo, V. H. V., Cicero, S. M., & Pedrini, L. G. (2011). Direct effects of soybean seed vigor on weed competition. *Revista Brasileira de Sementes, 33*(2), 346-351. doi: 10.1590/S0101-31222011000200017

Finlay, R. D. (2008). Ecological aspects of mycorrhizal symbiosis: with special emphasis on the functional diversity of interactions involving the extraradical mycelium. *Journal of Experimental Botany, 59*(5), 1115-1126. doi: 10.1093/jxb/ern059

Fontes, J. R. A., Shiratsuchi, L. S., Neves, J. L., & Sodré Filho, L. J. J. S. (2003). *Manejo integrado de plantas daninhas.* Planaltina, DF: Embrapa.

Giovannetti, J. W., & Mosse, B. (1980). An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. *New Phytologist, 48*(1), 489-500. doi: 10.1111/j.1469-8137.1980.tb04556.x

Jackson, M. L. (1958). *Soil chemical analysis*. New Jersey: Prentice Hall.

Kabba, B. S., Knight, J. D., & Rees, K. C. J. V. (2011). Modeling nitrogen uptake for hybrid poplar with and without weed competition. *Forest Ecology and Management, 262*(2), 131-138. doi: 10.1016/j.foreco.2011.03.013

Kiær, L. P., Weisbach, A. N., & Weiner, J. (2013). Root and shoot competition: a meta-analysis. *Journal of Ecology, 101*(1), 1298-1312. doi: 10.1111/1365-2745.12129

Moreira, F. M. S., & Siqueira, J. O. (2006). *Microbiologia e bioquímica do solo* (2a ed, atual. e ampl.). Lavras, MG: UFLA.

Novais, R. F., & Mello, J. W. V. (2007). Relação solo-planta. In Novais, R. F., Alvarez, V. H., Barros, N. F., Fontes, R. L. F., Cantarutti, R. B., & Neves, J. C. (Eds.), *Fertilidade do solo* (p. 133-198). Viçosa, MG: Sociedade Brasileira de Ciência do Solo.

Paulino, G. M., Alves, B. J. R., Barroso, D. G., Urquiaga, S., & Espindola, J. A. A. (2009). Fixação biológica e transferência de nitrogênio por leguminosas em pomar orgânico de mangueira e graviola. *Pesquisa Agropecuária Brasileira, 44*(12), 1598-1607. doi: 10.1590/S0100-204X2009001200006

Pittelkow, F. K., Jakelaitis, A., Conus, L. A., Oliveira, A. A., Gil, J. O., Assis, F. C., & Borchartt, L. (2009). Interferência de plantas daninhas na cultura da soja transgênica. *Global Science and Technology, 2*(3), 38-48. doi: 10.1590/S0100-83582009000100009

Reinhart, K. O., & Callaway, R. M. (2006). Soil biota and invasive plants. *New Phytologist, 170*(1), 445-457. doi: 10.1111/j.1469-8137.2006.01715.x

Rinaudo, V., Bárberi, P., Giovannetti, M., & Van Der Heijden, M. G. A. (2010). Mycorrhizal fungi suppress agressive agricultural weeds. *Plant Soil, 333*(1), 7-20. doi: 10.107/s11104-009-0202-z

Santos, E. A., Ferreira, L. R., Costa, M. D., Silva, M. C. S., Reis, M. R., & França, A. C. (2013). Occurrence of symbiotic fungi and rhizospheric phosphate solubilization in weeds. *Acta Scientiarum. Agronomy, 35*(1), 49-55. doi: 10.4025/actasciagron.v35il.15047

Schenck, N. C. (1982). *Methods and principles of mycorrhizal research.* Saint Paul, MN: The American Phytopatology Society Publication.

Silva, A. F., Concenço, G., Aspiazú, I., Ferreira, E. A., Galon, L., Freitas, M. A. M., ... Ferreira, F. A. (2009). Período anterior à interferência na cultura da soja-RR em condições de baixa, média e alta infestação. *Planta Daninha, 27*(1), 57-66. doi: 10.1590/S0100-83582009000100009

Silva, A. J. N., Silva, R. A., Santos, J. S., Medeiros, J. C. S., Carvalho, F. G., Silva, V. N., ... Gomes Jr, J. G. (2015). Soil chemical properties and growth of sunflower (*Helianthus annuus* L.) as affected by the application of organic fertilizers and inoculation with arbuscular mycorrhizal fungi. *Revista Brasileira de Ciência do Solo, 39*(1), 151-161. doi: 10.1590/01000683rbcs20150194

Silva, D. V., Santos, J. B., Cury, J. P., Carvalho, F. P., Silva, E. B., Fernandes, J. S. C., ... Concenço, G. (2013). Competitive capacity of cassava with weeds: Implications on accumulation of dry matter. *African Journal of Agricultural Research, 8*(6), 525-531.

Syibli, M. A., Muhibuddin, A., & Djauhari, S. (2014). Arbuscular mycorrhiza fungi as indicator of soil fertility. *Agrivita*: *Journal of Agricultural Science, 35*(1), 44-53. doi: 10.17503/Agrivita-2013-35-1-p44-53

Vivian, R., Dourado-Neto, D., Filho, R. V., Silva, A. A., Franco, R. B., & Correa, S. T. R. (2013). Interactions between soybean and weeds in a replacement series system, considering the effects of water stress. *Planta Daninha, 31*(4), 749-763. doi: 10.1590/S0100-83582013000400001

Yasuhara, T., & Nokihara, K. (2001). High-throughput analysis of total nitrogen content that replaces the classic Kjeldahl method. *Journal of Agricultural and Food Chemistry, 49*(10), 4581-4583. doi: 10.1021/jf010448z

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