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Competitive ability of soybean cultivars with *Ipomoea indivisa*

Habilidade competitiva de cultivares de soja com Ipomoea indivisa

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ABSTRACT

Among the weeds that infest soybeans, the morning glory (*Ipomoea indivisa*) stands out for competing with water, light, nutrients and also interfering in the crop harvesting process. The aim of this study was to test the competitive ability of soybean cultivars in the presence of *I. indivisa*, in substitutive experiments. The experiments were carried out in a completely randomized design, with four replicates, using the soybean cultivars M 5838, DM 53i54, DM 57i52, DM 66i68, NS 5445, and NS 6601. A constant final yield for soybean and *I. indivisa* was observed with 24 plants per pot. Relative and total productivities were analyzed using diagrams applied to substitutive experiments with soybean and *I. indivisa* plants proportions of 24:0, 18:6, 12:12, 6:18, and 0:24 plants pot^{-1} (crop:weed). On 35 days after the emergence of the culture and the *I. indivisa*, the morphophysiological characteristics of the plants were assessed and the relative competitiveness indices were calculated considering the 50:50 plant ratio (12:12 plants pot^{-1}). Morning glory affected the morphophysiological characteristics of soybean cultivars, demonstrating superior competitive ability for environmental resources. There was a competition between soybean cultivars and *I. indivisa*, which caused reductions in the shoot dry matter for both species. In this study, interspecific competition was more harmful than intraspecific competition.
KEYWORDS: substitutive experiments*; Glycine max;* morning glory; competitive interaction.

RESUMO

Dentre as plantas daninhas que infestam a soja, a corda-de-viola (*Ipomoea indivisa*) se destaca por competir por água, luz, nutrientes e também interferir no processo de colheita da cultura. O objetivo deste trabalho foi testar a habilidade competitiva de cultivares de soja na presença de *I. indivisa*, em experimentos substitutivos. Os experimentos foram conduzidos em delineamento inteiramente casualizado, com quatro repetições, utilizando as cultivares de soja M 5838, DM 53i54, DM 57i52, DM 66i68, NS 5445 e NS 6601. Observou-se produtividade final constante para soja e *I. indivisa* com 24 plantas por vaso. As produtividades relativa e total foram analisadas por meio de diagramas aplicados a experimentos substitutivos com plantas de soja e *I. indivisa* nas proporções de 24:0, 18:6, 12:12, 6:18 e 0:24 plantas vaso^{-1} (cultivar:planta daninha) . Aos 35 dias após a emergência da cultura e da *I. indivisa*, foram avaliadas as características morfofisiológicas das plantas e calculados os índices de competitividade relativa considerando a proporção de plantas de 50:50 (12:12 plantas vaso^{-1}). A corda-de-viola afetou as características morfofisiológicas das cultivares de soja, demonstrando superior capacidade competitiva por recursos ambientais. Houve competição entre as cultivares de soja e *I. indivisa*, o que ocasionou reduções na matéria seca da parte aérea para ambas as espécies. Neste estudo, a competição interespecífica foi mais prejudicial do que a competição intraespecífica.
PALAVRAS-CHAVE: experimentos substitutivos; *Glycine max*; corda-de-viola; interação competitiva.

INTRODUCTION

Soybean crop (*Glycine max* (L.) Meer) is widely explored worldwide. It is an important oilseed used in human and animal nutrition, for the production of medicines, and also for biofuel production (ALMEIDA et al. 2018). Brazil is the world's largest soybean producer, with 142 million tons occupying an area of 38.9 million hectares in the 2020/21 crop season (CONAB 2021).

During the soybean cycle, there are several factors that can interfere in the grain yield. Among these, weed infestation stands out. The competition between the crop and weeds occurs for water, light, and

nutrients, which can become limiting for soybean plants (HAMMER et al. 2018, KOEHLER-COLE et al. 2021, KONZEN et al. 2021). Besides, some weed species can host diseases and insects (DALAZEN et al. 2017), or even release allelopathic substances that can cause grain yield losses (SHELDON et al. 2021). Also, recent studies have reported negative effects on the growth and development of maize hybrids with *Urochloa plantaginea* (FRANDOLOSO et al. 2019), which resulted in an economic injury level to the crop (GALON et al. 2019), mainly at high weed density. *Ipomea triloba* and *I. purpurea,* at a density of 8 plants m^{-2}, caused losses of 27 to 45% in grain yield of different soybean cultivars (PICCININI et al. 2018).

Competition depends, among other factors, on characteristics such as emergence rate, height development, dry matter and leaf area production. Soybean cultivars that show greater development have an advantage in competition with weeds. However, when weeds with high density infest a soybean crop, they tend to be more harmful to the crop (JHA et al. 2017, PIAZENTINE 2021). This occurs since competition can be intraspecific-characterized by competition existing in individuals from the same species, or interspecific, which refers to the competition between species (AGOSTINETTO et al. 2013).

Among the important weeds in Brazil, we can highlight the morning glory (*Ipomoea indivisa* (Vell.) Hallier f.), widely found in the South, Southeast, and Midwest regions of Brazil (PICCININI 2015). *I. indivisa* belongs to the Convolvulaceae family, and it is an annual cycle plant with high seed production, ranging from 300 to 400. This species has a dormancy period in the winter, and emerges in the spring and summer (PICCININI et al. 2018). This weed has become important due to its increases in herbicides-tolerance, as glyphosate. This results in greater competition and has been reducing soybean productivity in different regions of Brazil (LUCIO et al. 2019).

The effectiveness of weed control can be enhanced by the development of management practices that improve crop competitiveness (DATTA et al. 2017). Intra or interspecific competition is evaluated with equal or different species densities, and requires adequate and specific experiments. Substitutive experiments are the most appropriate as they allow the assessment of competition between species through morphological characteristics, and also indicate which genotype or species is more competitive (FORTE et al. 2017).

Understanding the competitive ability between soybean cultivars with *I. indivisa* allows the development of management practices that can reduce the degree of competition. Thus, it is possible to improve the environment for the better use of light, water and nutrients, and a greater crop growth and productivity. Furthermore, the competitive ability of crops can be altered by their genetic differentiation. Thus, the characterization of different genetic materials in the presence of *I. indivisa* becomes very important for a more sustainable management.

In substitutive experiments, this study aimed to test the competitive ability of different soybean cultivars in the presence of *I. indivisa*.

MATERIAL AND METHODS

The experiments were carried out in a greenhouse at the Federal University of Fronteira Sul (UFFS), *campus* Erechim, Erechim, RS, Brazil (latitute -27,7239º, longitude -52,2944°, and altitude of 670 m). The climate in the region is classified as humid subtropical climate (Cfa), according to Köppen´s classification, with rainfall well distributed throughout the year. Each experimental unit consisted of a plastic pot (8 L) filled with humic Aluminiferic Red Latosol (EMBRAPA 2013), which was previously corrected and fertilized according to the technical recommendation for soybean (SBCS 2016). The physico-chemical characteristics of the soil were: pH 4.8 in water; OM = 35 g dm^{-3}; P = 4.0 mg dm^{-3}; K = 117.0 mg dm^{-3}; Al^{3+} = 0.6 $cmol_c$ dm^{-3}; Ca^{2+} = 4.7 $cmol_c$ dm^{-3}; Mg^{2+} = 1.8 $cmol_c$ dm^{-3}; CEC(t) = 7.4 $cmol_c$ dm^{-3}; CEC(T) = 16.5 $cmol_c$ dm^{-3}; H+Al = 9.7 $cmol_c$ dm^{-3}; SB = 6.8 $cmol_c$ dm^{-3}; V = 41%; and clay = 600 g dm^{-3}.

The experimental design was in a randomized block design with four replicates. Competitors tested included soybean (*Glycine max* (L.) Merr.) cultivars: Monsoy 5838 IPRO, DM 53i54 IPRO, DM 57i52 IPRO, DM 66i68 IPRO, NS 5445 IPRO, and NS 6601 IPRO; and the weed morning glory *(Ipomoea indivisa* (Vell.) Hallier f.). Soybean cultivars were selected for their genetic differences and also for being the most cultivated cultivars in the Rio Grande do Sul. The characteristics of the cultivars used in this study are shown in Table 1.

Initially, seven preliminary experiments were carried out, both for soybean cultivars and for *I. indivisa*, in a monoculture system, in order to determine the plant density in which the final production of shoot dry matter (DM) becomes constant. For this, the densities of 1, 2, 4, 8, 16, 24, 32, 40, 48, 56 and 64 plants pot^{-1} were used, which was equivalent to 24, 48, 96, 192, 384, 576, 768, 960, 1,152, 1,344 and 1,536 plants m^{-2}. The final constant production of DM was obtained with a density of 24 plants pot^{-1} for all soybean cultivars and also for the competitor, which was equivalent to 576 plants m^{-2}.

In the second stage, six experiments were carried out in a replacement series to evaluate the competitive ability of soybean cultivars in the presence of *I. indivisa*, varying the relative proportions of plants per pot: 24:0; 18:6; 12:12; 6:18 and 0:24 (100:0; 75:25; 50:50; 25:75 and 0:100%, crop versus weed) keeping the total plant density constant (24 plants pot^{-1}).

Table 1. Characteristics of soybean cultivars used in this study.

Cultivar	Size	Growth	Cycle	Maturation	Resistance
M 5838 IPRO	Low	Indeterminate	Semi-early	5.8	Diseases
DM 53i54 RSF IPRO	Medium	Indeterminate	Early	5.4	Diseases, herbicide and insects
DM 57i52 RSF IPRO	Medium	Indeterminate	Semi-early	5.7	Diseases, herbicide and insects
DM 66i68 RSF IPRO	High	Indeterminate	Semi-early	6.6	Diseases, herbicide and insects
NS 5445 IPRO	Medium	Indeterminate	Early	5.4	Insects and herbicide
NS 6601 IPRO	Medium	Indeterminate	Medium	6.6	Diseases

At 35 days after emergence (DAE), physiological and morphological variables were determined in soybean and *I. indivisa* plants. This period corresponded to the beginning of the flowering stage and is recommended for competitiveness studies (RIZZARDI et al. 2003). The chlorophyll index (CI) was obtained from the measurement at three points on each sheet using a portable chlorophyll meter (SPAD 502 - Plus, Konica Minolta Sensing Americas, Inc, NJ, USA). Photosynthetic rate (*A,* µmol CO_2 m^{-2} s^{-1}), stomatal conductance (g_S, mol H_2O m^{-2} s^{-1}), transpiration (*E*, mol H_2O m^{-2} s^{-1}), and internal CO_2 concentration (Ci, µmol mol^{-1}) were evaluated using an infrared gas analyzer (IRGA, LCA PRO, Analytical Development Co. Ltd, Hoddesdon, UK), between 7:00 and 11:00 am. Carboxylation efficiency (CE) and water use efficiency (WUE, mol CO_2 mol^{-1} H_2O) were calculated by the ratios *A*/Ci and *A*/*E*, respectively. Leaf area (LA, cm^{-2} pot^{-1}) was determined using a leaf area portable meter (LI-3100C, Li-Cor®, Nebraska, USA). Afterward, the shoot material was collected, placed in paper bags, and dried in an oven with forced air circulation at 60 °C ± 5 °C for 72 h, to obtain the dry matter (DM, g pot^{-1}).

From the data of LA and DM, a graphic analysis of the variation or relative productivity was performed (COUSENS 1991, BIANCHI et al. 2006b). The method consists of building a diagram based on the variations or relative productivity (RP) and total relative productivity (TRP). When the result of RP is a straight line, it means that the species skill is equivalent. If the RP results in a concave line, it indicates that there is a loss in the growth of one or both species. On the other hand, if the RP shows a convex line, there is a benefit in the growth of one or both species. When TRP is equal to unity one (straight line), competition for the same resources occurs; if it is greater than 1 (convex line), competition is avoided. If the TRP is less than 1 (concave line), there is mutual damage to growth (COUSENS 1991).

The relative competitiveness indices (RC), relative clustering coefficient (K) and aggressiveness (AG) were also calculated for the proportion of 50:50 plants (density of 24 plants pot^{-1}) of the species used in the experiment (soybean versus *I. indivisa*) according to the equations described by COUSENS & O'NEILL (1993). The RC represents the comparative growth of soybean cultivars (x) in relation to the competitor *I. indivisa* (y); K indicates the relative dominance of one species over another, and AG indicates which species is more competitive. Soybean cultivars (x) are more competitive than *I. indivisa* (y) when RC > 1, Kx > Ky and AG > 0; on the other hand, *I. indivisa* (y) is more competitive than soybean cultivars (x) when RC < 1, Kx < Ky and AG < 0 (HOFFMAN & BUHLER 2002). The global analysis of these values indicates the competitiveness of the species involved in the community with greater precision.

The statistical analysis procedure of productivity or relative variation included the calculation of differences for RP values (DRP) obtained in the proportions 25, 50, and 75% in relation to the values belonging to the hypothetical line in the respective proportions, that is, 0.25, 0.50 and 0.75 for RP (BIANCHI et al. 2006b, FLECK et al. 2008, AGOSTINETTO et al. 2013). The *t* test was used to verify the differences related to the DRP, TRP, RC, K, and AG indices (HOFFMAN & BUHLER 2002, BIANCHI et al. 2006b). It was considered as a null hypothesis to test the differences in DRP and AG that the means were equal to zero (Ho = 0); for TRP and RC, that the means were equal to one (Ho = 1); and for K, that the means of the differences between Kx and Ky were equal to zero [Ho = (Kx – Ky) = 0]. The criterion to consider the RP and TRP curves different from the hypothetical straight lines (represented by dotted lines) was that, in at least

two proportions, there were significant differences by the *t* test (BIANCHI et al. 2006b, FLECK et al. 2008, AGOSTINETTO et al. 2013). Likewise, for the RC, K, and AG indices, the existence of differences in competitiveness was considered when, at least in two of them, there was a significant difference by the *t* test.

The data obtained for the morphophysiological variables, both for soybean and for the competitor, were submitted to analysis of variance by the F test for each of the experiments (soybean cultivars: Monsoy 5838 IPRO, DM 53i54 IPRO, DM 57i52 IPRO, DM 66i68 IPRO, NS 5445 IPRO and NS 6601 IPRO versus *I. indivisa*) and when these were significant, the means were compared by Dunnett's test, considering the monocultures as controls. All statistical analyzes were performed considering a 5% probability ($p \leq 0.05$).

RESULTS AND DISCUSSION

The analysis of variance showed a significant effect between the proportions of plants of each soybean cultivar and/or *I. indivisa* for the physiological (CI, *A*, *gs*, *E*, Ci, CE, and WUE) and morphological (LA and DM) variables. Substitutive experiments between soybean cultivars versus *I. indivisa* indicated competition between species, in which the yield values obtained in different plants proportions, in general, deviated from the expected yield line (RP and TRP). In general, the association between the species caused mutual harm for both soybean and *I. indivisa* (Figures 1 and 2; Tables 2, 3, 4, 5 and 6).

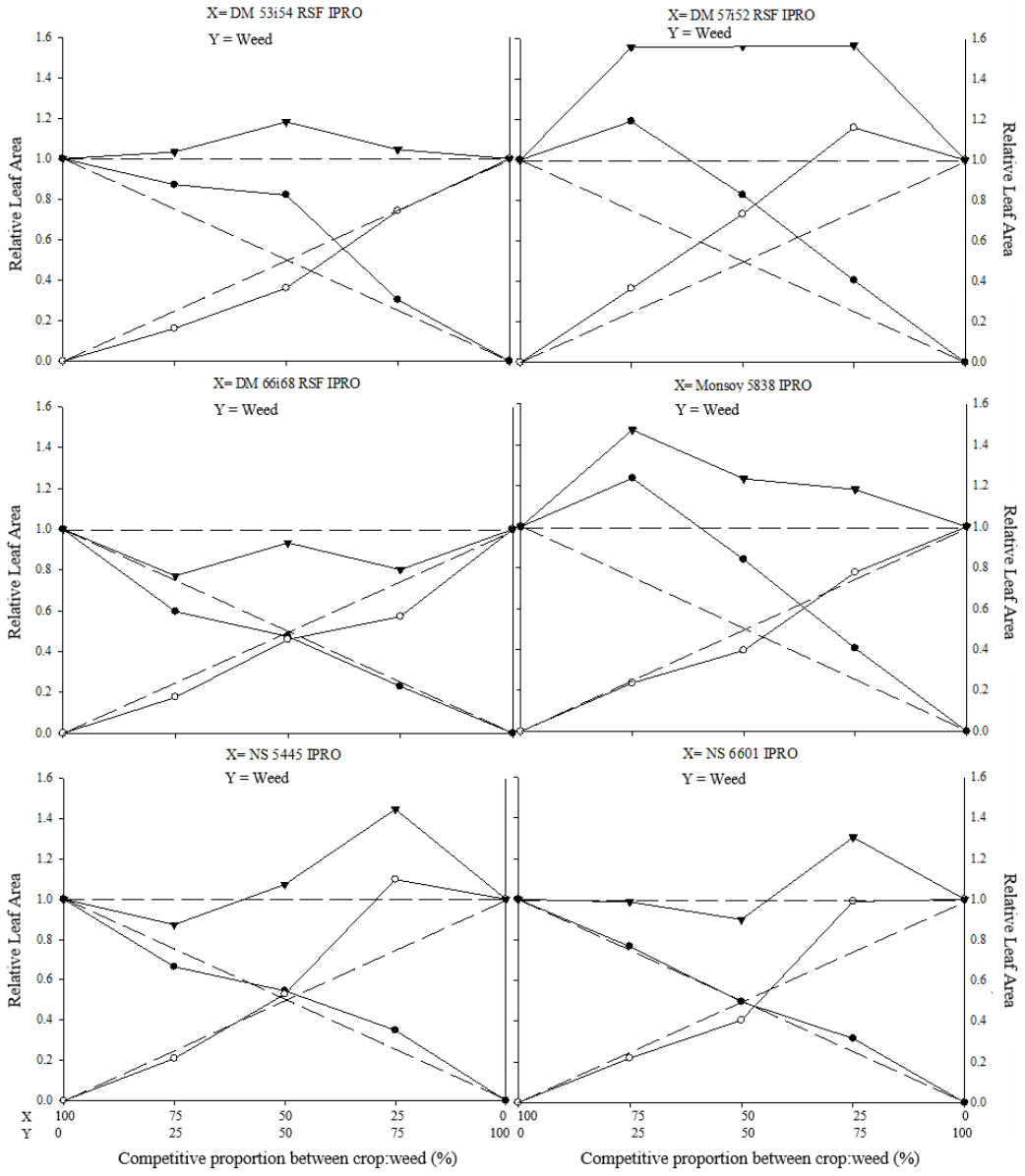

Figure 1. Relative productivity (RP) for leaf area (cm^2 pot^{-1}) of soybean cultivars DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, M 5838 IPRO, NS 5445 IPRO, and NS 6601 IPRO (●) and for *I. indivisa* plants (□), and total relative productivity (TRP) of the community (▼) in different crop:weed proportions. Dashed lines represent the expected values, in the absence of competition; solid lines the values observed when species competed in different plant proportions.

The graphic results indicate that the expected RP values were close to those observed for all variables analyzed when soybean cultivars (Monsoy 5838 IPRO, DM 53i54 IPRO, DM 57i52 IPRO, DM 66i68 IPRO, NS 5445 IPRO, and NS 6601 IPRO) were grown with the competitor (Figures 1 and 2; Table 2). It is also noteworthy that the soybean cultivars showed similarities in terms of competition with *I. indivisa*, with significant differences for LA and DM, in the vast majority of the evaluated plant's proportions (Table 2).

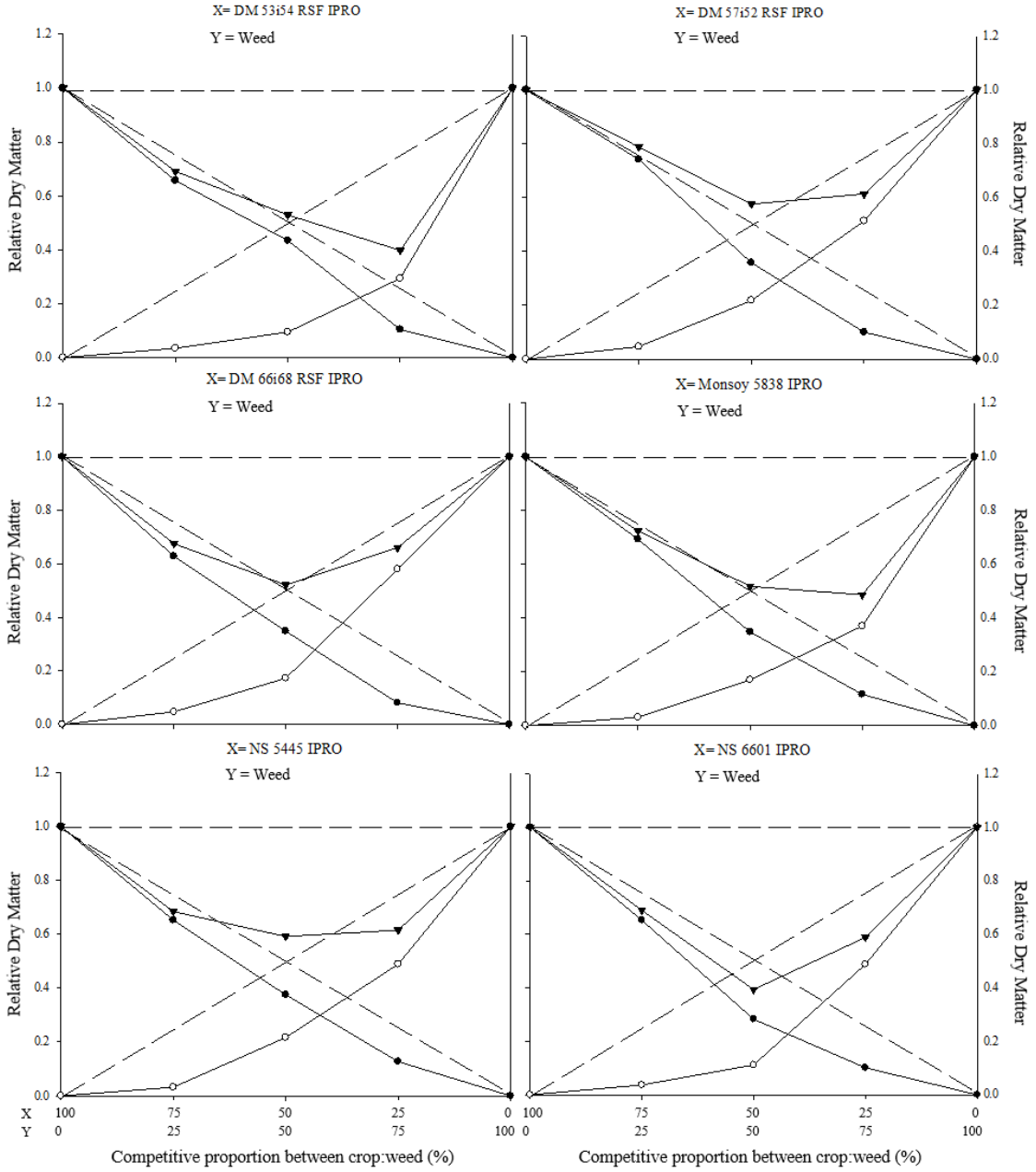

Figure 2. Relative productivity (RP) for dry matter (g pot^{-1}) of soybean cultivars DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, M 5838 IPRO, NS 5445 IPRO, and NS 6601 IPRO (●) and for *I. indivisa* plants (□), and total relative productivity (TRP) of the community (▼) in different crop:weed proportions. Dashed lines represent the expected values, in the absence of competition; solid lines the values observed when species competed in different plant proportions.

Significant differences were observed in at least two proportions in relation to TRP for LA and DM of soybean cultivars DM 53i54, DM 57i52, DM 66i68, M 5838, NS 5445, and NS 6601 when competing with *I. indivisa* (Table 2). The LA of cultivars DM 53i54, DM 57i52, Monsoy 5838, NS 5445, and NS 6601 showed TRP with convex lines and mean greater than 1, mainly above the 50:50 ratio (crop versus weed), and concave lines in all situations and mean less than 1 for DM (Figure 2, Table 2). In addition, there was an increase in LA production and a reduction in DM for both cultivars and weeds, characterizing an interspecific competition, that is, competition for the same resources and damage to both species. A TRP greater than one related to LA suggests changes in the photoassimilate partitioning for leaf area expansion-with thinner

leaves-in the detriment of DM production. A larger soybean leaf area has been associated with smaller leaf thickness and higher stomata density (HIDAYAT et al. 2021). Leaf growth prioritizes a larger area for higher light capture and photosynthetic activity (NAGASUGA 2019, HIDAYAT et al. 2021). Thus, changes in morphophysiological characteristics in response to competition are expected (SANTOS & CURY 2011). This study observed higher TRP for LA of soybean and lower TRP for DM, especially when there is higher competitor density with soybean cultivars. This demonstrates that there was competition for the same resources between soybean and *I. indivisa*, mainly due to the concave lines for TRP and values less than 1 for DM. When TRP < 1 there is a mutual antagonism between species that are competing in the same proportion, without affecting the final productivity (COUSENS 1991, RUBIN et al. 2014). Similar results were observed when soybean was cultivated with *Digitaria ciliaris* (AGOSTINETTO et al. 2013), *Bidens pilosa* and/or *Euphorbia heterophylla* (FORTE et al. 2017), and *Sida rombifolia* (KONZEN et al. 2021).

Table 2. Relative differences for the variables leaf area and shoot dry mass of soybean cultivars DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, Monsoy 5838 IPRO, NS 5445 IPRO, and NS 6601 IPRO or morning glory (*Ipomoea indivisa*) 35 days after emergence.

	Plants proportions (soybean:weed)		
	75:25	50:50	25:75
Leaf area soybean x *I. indivisa*			
DM 53i54 RSF IPRO	0.12 (±0.06)	0.32 (±0.04)*	0.05 (±0.05)
I. indivisa	-0.09 (±0.01)*	-0.14 (±0.06)	-0.01 (±0.06)
Total	1.03 (±0.07)	1.18 (±0.08)	1.05 (±0.08)
DM 57i52 RSF IPRO	0.44 (±0.04)*	0.33 (±0.08)*	0.16 (±0.0001)*
I. indivisa	0.12 (±0.01)*	0.23 (±0.06)*	0.41 (±0.06)*
Total	1.56 (±0.03)*	1.56 (±0.07)*	1.57 (±0.06)*
DM 66i68 RSF IPRO	-0.15 (±0.04)*	-0.03 (±0.03)	-0.02 (±0.02)
I. indivisa	-0.07 (±0.0001)*	-0.04 (±0.001)	-0.18 (±0.03)*
Total	0.77 (±0.04)*	0.93 (±0.03)	0.80 (±0.01)*
Monsoy 5838 IPRO	0.49 (±0.05)*	0.34 (±0.05)*	0.16 (±0.01)*
I. indivisa	-0.01 (±0.02)	-0.10 (±0.06)	0.03 (±0.06)
Total	1.47 (±0.004)*	1.23 (±0.11)	1.18 (±0.06)*
NS 5445 IPRO	-0.09 (±0.03)	0.05 (±0.05)	0.10 (±0.02)*
I. indivisa	-0.04 (±0.02)	0.03 (±0.09)	0.35 (±0.06)*
Total	0.87 (±0.03)*	1.07 (±0.12)	1.45 (±0.08)*
NS 6601 IPRO	0.02 (±0.06)	0.004 (±0.01)	0.07 (±0.0001)*
I. indivisa	-0.03 (±0.02)	-0.09 (±0.02)*	0.24 (±0.09)
Total	0.99 (±0.06)	0.90 (±0.03)*	1.31 (±0.09)*
Dry matter soybean x *I. indivisa*			
DM 53i54 RSF IPRO	-0.09 (±0.04)	-0.07 (±0.04)	-0.15 (±0.01)*
I. indivisa	-0.22 (±0.01)*	-0.41 (±0.01)*	-0.46 (±0.04)*
Total	0.40 (±0.05)*	0.53 (±0.04)*	0.40 (±0.05)*
DM 57i52 RSF IPRO	-0.01 (±0.02)	-0.14 (±0.02)*	-0.15 (±0.0001)*
I. indivisa	-0.20 (±0.0001)*	-0.28 (±0.01)*	-0.24 (±0.03)*
Total	0.79 (±0.03)*	0.58 (±0.03)*	0.61 (±0.04)*
DM 66i68 RSF IPRO	-0.12 (±0.02)*	-0.15 (±0.0001)*	-0.17 (±0.0001)*
I. indivisa	-0.20 (±0.01)*	-0.33 (±0.04)*	-0.17 (±0.11)
Total	0.68 (±0.03)*	0.52 (±0.05)*	0.66 (±0.12)
Monsoy 5838 IPRO	-0.06 (±0.03)	-0.15 (±0.03)*	-0.13 (±0.01)*
I. indivisa	-0.22 (±0.0001)*	-0.33 (±0.02)*	-0.38 (±0.03)*
Total	0.72 (±0.03)*	0.52 (±0.02)*	0.49 (±0.03)*
NS 5445 IPRO	-0.10 (±0.03)*	-0.12 (±0.02)*	-0.12 (±0.02)*
I. indivisa	-0.22 (±0.01)*	-0.28 (±0.07)*	-0.26 (±0.04)*
Total	0.69 (±0.03)*	0.59 (±0.06)*	0.62 (±0.05)*
NS 6601 IPRO	-0.10 (±0.04)	-0.22 (±0.01)*	-0.15 (±0.0001)*
I. indivisa	-0.21 (±0.01)*	-0.39 (±0.03)*	-0.26 (±0.06)*
Total	0.69 (±0.04)*	0.39 (±0.04)*	0.59 (±0.06)*

*Significant difference by the *t* test (p≤0,05). Values in parentheses represent the standard error of the mean.

The LA of soybean cultivars (DM 53i54, DM 57i52, Monsoy 5838, NS 5445, and NS 6601) showed deviations from the RP lines close to the expected lines, and convex lines in most of the tested proportions

(Figure 1; Table 2). On the other hand, *I. indivisa* showed convex lines for the RP related to the LA when it had higher plants proportions (75:25, weed:crop). It was observed that the RP for both soybean and weed plants, which showed a good contribution for the TRP to be greater than 1 for LA. This result indicates that the crop showed less damage than *I. indivisa*, and, consequently, greater competitiveness. This may be related to the weeds density since weeds have greater competitive ability when at high densities and not individually (AGOSTINETTO et al. 2013, FORTE et al. 2017, KONZEN et al. 2021).

The soybean cultivar DM 66i68 showed concave lines for RP and TRP, both for LA and DM, and values less than 1 in all simulations performed, which demonstrates its genetic differentiation in relation to the other cultivars (Table 1). Differentiation in competitive ability when involving soybean cultivars with weeds was also observed in early-cycle and late-cycle soybean cultivars (SOUZA et al. 2019), and between soybean cultivars V-TOP RR and BMX Ativa RR (DIESEL et al. 2020). Furthermore, HAMMER et al. (2018) found that, among 40 soybean cultivars, the most modern and with the highest production capacity were more competitive in relation to older cultivars in a highly competitive environment.

For the variable DM, concave lines were observed for the deviations of the RP lines in relation to the expected lines in all plants proportions for the six soybean cultivars and *I. indivisa*, (Figure 2), with significance occurring in at least two proportions of plants, for both crop and weed (Table 2). This indicates the interaction between soybean and *I. indivisa* and their similar demands for the environment resources, causing competition and damage to both species. Furthermore, there were significant differences between the estimated and expected lines in all proportions of plants for both RP and TRP (Figures 1 and 2; Table 2). As observed in the present study, soybean cultivars (BMX Alvo RR and Fundacep 55RR) coexisting with *B. pilosa* and *E. heterophylla* (FORTE et al. 2017), and soybean cultivars (Brasmax Ativa, DM 5958 RSF IPRO, Brasmax Elite, Nidera 5445 IPRO) with *Sida rhombifolia* (KONZEN et al. 2021) also showed competition and damage between species in relation to leaf area and dry matter variables.

On the other hand, soybean cultivars showed greater relative growth than *I. indivisa* in all proportions of plants for the variables LA and DM, with the highest RP for the crop and the lowest RP for the weed (Figures 1 and 2; Table 2). The greater relative growth of soybean plants may be related to the competitive plants' densities, since weeds have greater competitive ability when at high densities, as previously reported (BIANCHI et al. 2006a, 2006b, CARVALHO & CHRISTOFFOLETI 2008, AGOSTINETTO et al. 2013, FORTE et al. 2017).

Increases in the TRP were observed with increasing proportion of competing plants, with statistical significance for all variables (Figures 1 and 2; Table 2). This behavior shows that the species are competitive and that one does not contribute more than expected to the total productivity of the other. As they belonged to distinct botanical families, it was expected that soybean and *I. indivisa* cultivars would explore different ecological niches and not competing with each other for environmental resources. However, recent studies have reported the occurrence of differentiation in plant competition even between distinct families, such as soybean infested with *D. ciliaris* (AGOSTINETTO et al. 2013), and TRP loss in the community involving soybean and weeds such as *B. pilosa* and/or *E. heterophylla* (FORTE et al. 2017) and *S. rhombifolia* (KONZEN et al. 2021), demonstrating that losses occur both to weeds and to the crop when in competition.

The relative growth of soybean cultivars DM 53i54, DM 57i52, DM 66i68, Monsoy 5838, NS 5445, and NS 6601 showed, in general, similar values in the same plants proportion for LA and DM (Figures 1 and 2; Table 2). Despite the different characteristics of cultivars in terms of height and developmental cycle, there was no difference in their competition with *I. indivisa*. These results allow us to infer that there is no accentuated effect of the intrinsic characteristics of the cultivar on the weed and that the ability of soybean cultivars to interfere on *I. indivisa* was equivalent.

Regarding the morphological variables of LA and DM, differential responses were also observed between soybean cultivars. The LA of cultivars DM 53i54, DM 57i52, Monsoy 5838, NS 5445, and NS 6601 showed an increase when competing with *I. indivisa* in all analyzed proportions (Table 3), which suggests a response of crops to invest in light capture for a possible greater growth in height when in the presence of weeds. The translocation of photoassimilates to the leaf area caused a reduction in DM accumulation in soybean cultivars, with increasing competitor density. With the exception of the cultivar DM 66i68 which showed a reduction in LA with an increase in competitor density, possibly due to a genetic differentiation that exists between the cultivars. ULGUIM et al. (2017) reported that one of the determining factors for greater competitive capacity is the increase in light interception for chemical energy production by the photosynthetic process. Thus, RP and TRP related to LA prove to be important characteristics in soybean cultivars with greater competitive capacity, when associated with *I. indivisa*.

Table 3. Leaf area and dry matter between in different proportions of soybean cultivars (DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, Monsoy 5838 IPRO, NS 5445 IPRO e NS 6601 IPRO) and morning glory (*Ipomoea indivisa*), at 35 days after plant emergence.

Plant proportion (%)		Leaf area (cm^2 pot^{-1})		Dry matter (g pot^{-1})	
		DM 53i54 RSF IPRO x *I. indivisa*			
Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)		1292.95	515.31	55.40	31.97
75:25 ou 25:75		1502.88	509.54	48.54	12.51*
50:50 ou 50:50		2121.56*	371.91	48.15	6.06*
25:75 ou 75:25		1569.77	332.14*	23.14*	4.40*
		DM 57i52 RSF IPRO x *I. indivisa*			
Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)		1156.19	515.31	62.87	31.97
75:25 ou 25:75		1836.07*	796.89*	62.21	21.28*
50:50 ou 50:50		1914.18*	754.91*	45.00*	13.95*
25:75 ou 75:25		1875.43*	752.48*	25.25*	5.93*
		DM 66i68 RSF IPRO x *I. indivisa*			
Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)		1744.29	515.31	75.90	31.97
75:25 ou 25:75		1386.07	393.18*	63.64*	24.71
50:50 ou 50:50		1654.49	473.35	52.91*	11.05*
25:75 ou 75:25		1600.79	362.36*	24.51*	6.00*
		Monsoy 5838 IPRO x *I. indivisa*			
Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)		1040.65	515.31	71.00	31.97
75:25 ou 25:75		1716.90*	533.60	65.69	15.66*
50:50 ou 50:50		1746.98*	407.25	49.45*	11.23 *
25:75 ou 75:25		1688.36*	486.29	33.07*	3.91*
		NS 5445 IPRO x *I. indivisa*			
Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)		1938.23	515.313	74.32	31.97
75:25 ou 25:75		1718.20	754.27*	64.70	20.83*
50:50 ou 50:50		2115.07	544.32	55.84*	13.85*
25:75 ou 75:25		2707.86*	431.18	37.74*	4.11*
		NS 6601 IPRO x *I. indivisa*			
Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)		1340.64	515.31	67.09	31.97
75:25 ou 25:75		1373.39	679.89*	58.34	20.76*
50:50 ou 50:50		1329.44	417.63	37.89*	7.11*
25:75 ou 75:25		1691.79*	451.00	27.13*	4.70*

*Mean differs from control (T) by Dunnett's test ($p \leq 0.05$).

Regarding *I. indivisa*, there wasa reduction in LA and DM with the same or lower proportion of plants with soybean cultivars DM 53i54, DM 57i52, DM 66i68, Monsoy 5838, NS 5445, and NS 6601. Competition affects production as it modifies the environmental resources efficiency uses such as water, light, CO_2, and nutrients (BIANCHI et al. 2006a), establishing itself between the crop and plants of other species existing on-site. Plants that establish first in each community benefit from the competition process (CRAINE & DYBZINSKI 2013), or even due to morphological characteristics such as greater height (TREZZI et al. 2013), root system (RIZZARDI et al. 2016), leaf area index, and dry matter production, as observed in the present study. These characteristics indicate the competitive ability of the plants in association.

Studies show that damage to the growth of crops and weeds can occur when they are in competition in a given community (AGOSTINETTO et al. 2013, FORTE et al. 2017, KONZEN et al. 2021). The lowest DM demonstrated high interspecific competition, where both species compete for the same resources, as observed in studies with association of soybean and *Raphanus sativus* (BIANCHI et al. 2006a), *B. pilosa* and/or *E. heterophylla* (FORTE et al. 2017), and *S. rhombifolia* (KONZEN et al. 2021). In the present study, the crop was well distributed, which increases its competitive ability; while the distribution in lines, generally used in the field, increases the damage caused by the infesting community (DUSABUMUREMYI et al. 2014).

The growth of all soybean cultivars surpassed the growth of *I. indivisa*, as indicated by the RC index (greater than 1) for both LA and DM (Table 4). It was also observed the relative dominance of soybean over the weed expressed by K indices ($K_{soybean} > K_{I.\ indivisa}$). This indicates that the crop is more competitive than the weed according to the aggressiveness index (positive AG). In all comparisons, there were significant differences in at least two indices (BIANCHI et al. 2006b), which demonstrates that soybean and *I. indivisa* are not equivalent, and the crop was more competitive than weed.

Regarding the three indices evaluated (RC, K and AG) there were differences when soybean coexisting with *I. indivisa.* There was no significant effect for LA involving soybean cultivars DM 57i52, DM 66i68, and NS 5445 with *I. indivisa* (Table 4). This is probably due to the specific characteristics of the cultivars, such as determined growth habits, early cycle, short stature plants, lower leaf area index. In most situations, the culture showed greater competitive ability than *I. indivisa* alone. This was expected since the greatest competitive ability of weeds occurs mainly when they are in higher density (VILÀ et al. 2004).

Table 4. Competitiveness indexes between soybean cultivars (DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, Monsoy 5838 IPRO, NS 5445 IPRO e NS 6601 IPRO) and morning glory (*Ipomoea indivisa*) in equal proportions of plants (50:50), expressed by relative competitiveness (RC), relative clustering (K) and aggressiveness (AG) coefficients for leaf area and shoot dry mass at 35 days after plant emergence.

Variable	RC	Kx (soybean)	Ky (*I. indivisa*)	AG
	Leaf area (LA)			
DM 53i54 RSF IPRO x weed	2.46 (± 0.44)*	5.47 (± 1.31)*	0.60 (± 0.15)*	0.46 (± 0.06)*
DM 57i52 RSF IPRO x weed	1.17 (± 0.20)	3.61 (± 0.67)	3.54 (± 1.28)	0.10 (± 0.12)
DM 66i68 RSF IPRO x weed	1.03 (± 0.07)	0.92 (± 0.11)	0.85 (± 0.0005)	0.01 (± 0.03)
Monsoy 5838 IPRO x weed	2.27 (± 0.34)*	3.89 (± 0. 47)*	0.71 (± 0.18)*	0.44 (± 0.04)*
NS 5445 IPRO x weed	1.09 (± 0.15)	1.27 (± 0.22)	1.49 (± 0.70)	0.02 (± 0.08)
NS 6601 IPRO x weed	1.23 (± 0.05)*	0.99 (± 0.05)*	0.69 (± 0.06)*	0.09 (± 0.02)*
	Shoot dry matter (DM)			
DM 53i54 RSF IPRO x weed	4.91 (± 1.07)*	0.80 (± 0.15)*	0.11 (± 0.01)*	0.34 (± 0.05)*
DM 57i52 RSF IPRO x weed	1.64 (± 0.08)*	0.56 (± 0.05)*	0.28 (± 0.02)*	0.14 (± 0.02)*
DM 66i68 RSF IPRO x weed	2.55 (± 0.78)	0.54 (± 0.01)*	0.22 (± 0.06)*	0.18 (± 0.04)*
Monsoy 5838 IPRO x weed	2.14 (± 0.30)*	0.54 (± 0.06)*	0.21 (± 0.03)*	0.18 (± 0.04)*
NS 5445 IPRO x weed	2.30 (± 0.64)	0.61 (± 0.05)	0.31 (± 0.13)	0.16 (± 0.08)
NS 6601 IPRO x weed	2.96 (± 0.64)*	0.40 (± 0.03)*	0.13 (± 0.04)*	0.17 (± 0.02)*

*Significant difference by the *t* test (p≤0,05). Values in parentheses represent the standard error of the mean. K_x and K_y are the relative clustering coefficients of soybean cultivars and competitor *I. indivisa*, respectively.

Taken the data together, considering the graphic analyzes of relative variables and their significance in relation to equivalent values (Figures 1 and 2), morphological variables (Table 2), and competitiveness indices (Table 4), it was found, in general, that there is a negative interaction effect between species, where soybean cultivars (DM 53i54, DM 57i52, DM 66i68, Monsoy 5838, NS 5445, NS 6601) and *I. indivisa* were affected.

There was an increase in chlorophyll index (CI) for the soybean cultivars DM 53i54, DM 66i68, NS 5445, and NS 6601, according to the increase in the weed proportion (Table 5). The other soybean cultivars (DM 57i52 and Monsoy) showed no significant effect for CI in the presence of *I. indivisa*, regardless of the proportion. On the other hand, for the competitor, it was observed, in general, a lower CI with the increase in the density of soybean plants. The reduction in chlorophyll can compromise the photosynthetic activity of plants, normally observed in situations of abiotic (MANGENA 2018, IQBAL et al. 2019) or biotic stress (GALON et al. 2015). As a result, plants with a higher concentration of chlorophyll throughout their cycle usually obtain a higher dry matter (FREITAS FILHO 2014, GABARDO et al. 2020).

Table 5. Chlorophyll index (CI), photosynthetic rate (*A,* µmol m^{-2} s^{-1}), and internal CO_2 concentration (Ci, µmol mol^{-1}) in different proportions of soybean cultivars (DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, Monsoy 5838 IPRO, NS 5445 IPRO e NS 6601 IPRO) and morning glory (*Ipomoea indivisa*), at 35 days after plant emergence.

Plant proportion (%)	CI		*A*		Ci	
	DM 53i54 RSF IPRO x *I. indivisa*					
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	33.65	26.80	14.18	6.14	304.00	309.00
75:25 ou 25:75	35.57	35.20*	14.87	11.05*	316.00	296.25
50:50 ou 50:50	36.20*	26.97	12.71	6.61	306.00	308.00
25:75 ou 75:25	34.07	27.90	12.94	6.38	293.00	277.63
	DM 57i52 RSF IPRO x *I. indivisa*					
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	35.65	26.73	16.17	6.14	281.00	309.00
75:25 ou 25:75	35.17	31.77*	17.36	7.14	275.00	339.00
50:50 ou 50:50	35.55	24.60	16.97	4.99	260.50	344.25
25:75 ou 75:25	35.70	23.90	18.69	7.14	264.33	324.75
	DM 66i68 RSF IPRO x *I. indivisa*					
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	32.07	26.55	14.83	6.14	291.33	309.00
75:25 ou 25:75	34.33*	29.37	15.88	11.82*	289.00	306.33
50:50 ou 50:50	32.93	28.03	17.76	6.27	272.67	318.67
25:75 ou 75:25	36.37*	22.23*	17.27	8.23	291.00	303.00
	Monsoy 5838 IPRO x *I. indivisa*					
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	35.97	26.73	17.08	6.14	264.33	309.00
75:25 ou 25:75	36.03	26.78	17.80	4.37*	257.33	327.33
50:50 ou 50:50	34.80	25.87	17.71	3.92*	256.00	333.00
25:75 ou 75:25	35.50	26.10	19.02	6.59	263.33	326.33
	NS 5445 IPRO x *I. indivisa*					
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	31.08	26.80	14.19	6.14	306.33	309.00
75:25 ou 25:75	35.63*	27.00	15.75	5.92	283.00	311.00
50:50 ou 50:50	37.60*	22.60*	17.81*	3.65*	274.50	323.00
25:75 ou 75:25	37.50*	21.33*	17.01	5.84	278.50	323.00
	NS 6601 IPRO x *I. indivisa*					
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	34.70	26.80	16.91	6.14	277.25	309.00
75:25 ou 25:75	34.43	30.05	18.13	6.94	279.50	312.25
50:50 ou 50:50	34.68	26.15	17.10	7.98	280.25	307.00
25:75 ou 75:25	35.05	25.28	14.72	6.22	290.75	322.75

*Mean differs from control (T) by Dunnett's test (p≤0.05).

For the photosynthetic rate (*A*) only the cultivar NS 5445 increased significantly with the increase in *I. indivisa* density (Table 5). In relation to the weed, it was observed, in general, an increase in *A* with the increase in crop density. Competition can compromise water and nutrient plant availability, affecting stomata aperture and, consequently, photosynthetic rates (FERREIRA et al. 2015).

The internal concentration of CO_2 (Ci) did not differ statistically for soybean cultivars or for *I. indivisa*, regardless of the plants' proportions (Table 5). This demonstrates that there was no limitation of CO_2 assimilation and fixation (BASTIANI et al. 2016).

The association between soybean cultivar NS 5445 IPRO and *I. indivisa*, in the proportion of 75:25, promoted higher stomatal conductance (g_S) (Table 6) and higher photosynthetic rate (Table 5) in soybean plants. For the other cultivars tested, there was no significant effect in the presence of different proportions of *I. indivisa*. The greater stomatal conductance allows the CO_2 influx to the substomatal cavity and become it available to be fixed by Rubisco in the Calvin Cycle, increasing photosynthesis. In relation to the weed, a higher stomatal conductance was observed when its growth with the soybean cultivars DM 53i54 RSF IPRO,

DM 57i52 RSF IPRO, and DM 66i68 RSF IPRO, in the proportion of 25:75.

Water use efficiency did not have a significant effect for soybean cultivars in competition with *I. indivisa* (Table 6). This occurs due to the difference in the competitive ability of cultivars to compete with a certain population of weeds. For *I. indivisa*, smaller WUE was observed when associated with the cultivar DM 53i57 RSF IPRO in proportions of 50:50 e 25:75; and a greater WUE was observed in association with the cultivar DM 57i52 RSF IPRO in the proportion of 75:25 (competitor versus weed). The data corroborate FERREIRA et al. (2015), who reported that soybean competition with weeds, such as *Urochloa brizantha*, reduces the crop WUE, requiring more water to maintain photosynthetic rates (FERREIRA et al. 2015).

Table 6. Stomatal conductance (g_S, mol m^{-2} s^{-1}), transpiration (*E*, mol m^{-2} s^{-1}), water use efficiency (WUE, mol CO_2 mol^{-1} H_2O), and carboxylation efficiency (CE) in different proportions of soybean cultivars (DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, Monsoy 5838 IPRO, NS 5445 IPRO e NS 6601 IPRO) and morning glory (*Ipomoea indivisa*), at 35 days after plant emergence.

Plant proportion (%)	*g*s		*E*		WUE		CE	
	DM 53i54 RSF IPRO x *I. indivisa*							
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	0.37	0.12	2.47	1.90	4.25	3.35	0.043	0.019
75:25 ou 25:75	0.35	0.26*	3.31	3.68*	4.65	3.10	0.053	0.044*
50:50 ou 50:50	0.33	0.16	3.25	2.75	4.06	2.50*	0.040	0.029
25:75 ou 75:25	0.31	0.13	3.41	2.50	3.91	2.55*	0.045	0.023
	DM 57i52 RSF IPRO x *I. indivisa*							
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	0.41	0.12	4.34	1.90	3.84	3.35	0.058	0.019
75:25 ou 25:75	0.40	0.20*	4.23	2.48	4.25	5.24*	0.060	0.020*
50:50 ou 50:50	0.42	0.14	4.910	1.80	3.79	2.79	0.069*	0.014*
25:75 ou 75:25	0.42	0.18*	4.330	2.63	5.24	2.86	0.064	0.025*
	DM 66i68 RSF IPRO x *I. indivisa*							
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	0.39	0.12	3.53	1.90	4.22	3.35	0.057	0.019
75:25 ou 25:75	0.39	0.32*	3.44	3.70*	4.59	3.21	0.053	0.034*
50:50 ou 50:50	0.40	0.17	3.62	2.77	4.93	2.39	0.067*	0.014*
25:75 ou 75:25	0.34	0.20	3.33	3.03	4.05	2.72	0.059	0.027*
	Monsoy 5838 IPRO x *I. indivisa*							
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	0.37	0.12	4.5	1.90	4.11	3.35	0.060	0.019
75:25 ou 25:75	0.39	0.11	4.82	1.60	3.80	2.71	0.070*	0.013*
50:50 ou 50:50	0.40	0.08	5.23	1.31	3.43	3.03	0.070*	0.011*
25:75 ou 75:25	0.45	0.20	4.85	2.59	4.12	3.21	0.070*	0.027*
	NS 5445 IPRO x *I. indivisa*							
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	0.28	0.12	3.82	1.90	3.59	3.35	0.046	0.019
75:25 ou 25:75	0.40*	0.12	3.84	1.83	4.17	3.20	0.055	0.016*
50:50 ou 50:50	0.39	0.09	3.75	1.33	4.46	2.73	0.064	0.014*
25:75 ou 75:25	0.38	0.13	3.78	1.71	4.16	3.48	0.061	0.018
	NS 6601 IPRO x *I. indivisa*							
Soybean Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed	Soybean	Weed
100:0 (T)/0:100 (T)	0.43	0.12	4.11	1.90	4.19	3.35	0.060	0.019
75:25 ou 25:75	0.43	0.16	4.18	2.21	4.07	3.29	0.064	0.022*
50:50 ou 50:50	0.43	0.18	3.70	2.60	4.70	3.26	0.061	0.025*
25:75 ou 75:25	0.40	0.18	3.83	2.27	3.88	2.99	0.050	0.017*

*Mean differs from control (T) by Dunnett's test ($p \leq 0.05$).

Greater carboxylation efficiency (CE) was observed for soybean cultivars DM 57i52 RSF IPRO and DM 66i68 RSF IPRO in the proportion of 50:50 (crop versus weed), and also for the cultivar Monsoy 5838 in all associations (25:75, 50:50 and 75:25) (Table 5). The transpiration rate (*E*) was increased in cultivar DM

53i54 RSF IPRO in proportions 75:25 and 75:25, and in cultivar Monsoy 5838 in all proportions evaluated (25:75, 50:50 and 75:25). The competition between plant species can influence water, light, and nutritional availability, resulting in a lower gas exchange for both species (CRAINE & DYBZINSKI 2013, FERREIRA et al. 2015).

Experiments in substitutive series allow the identification of crop cultivars with better competitive performance to be recommended for areas with a high *I. indivisa* seed bank. The identification of the proportion of the weed that allows a greater crop competitiveness is also important to adequate weed management in the field, and smaller herbicide application. This makes it possible to reduce the cost of production, besides reducing the environmental impact caused by these pesticides. In addition, this information is important for breeding programs that aim to evaluate the characteristics of the most competitive cultivars.

CONCLUSIONS

I. indivisa negatively modifies the morphophysiological variables of soybean cultivars (DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, Monsoy 5838 IPRO, NS 5445 IPRO, and NS 6601 IPRO) demonstrating the superior competitive ability for the resources of the environment.

Competition between soybean cultivars (DM 53i54 RSF IPRO, DM 57i52 RSF IPRO, DM 66i68 RSF IPRO, Monsoy 5838 IPRO, NS 5445 IPRO, and NS 6601 IPRO) occurs in the presence of *I. indivisa*, being negatively affected, regardless of the proportion of plants, causing reductions mainly in the dry matter for both species. Cultivar DM 66i68 showed greater losses in leaf area and dry matter in the presence of the weed when compared to the other cultivars.

Interspecific competition caused greater damage to the evaluated species than intraspecific competition.

Competition for the same environmental resources was observed between soybean and *I. indivisa*.

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