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Development stages horseweed in soybeans competition

Estádios de desenvolvimento da buva em competição com soja

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ABSTRACT: The objective of this study was to evaluate the relative competitive ability of soybean with different development stages of hairy fleabane. Two experiments were conducted in greenhouse, in a completely randomized design. In the experiment it was tested soybean and hairy fleabane competition at different stage of development (rosette and 15 cm height) at the proportions 100:0, 75:25, 50:50, 25:75 and 0:100, and total plant population was 315 plant m^{-2}. The variables evaluated were plant height, leaf area, and shoot dry matter (leaves and stems). Competitive analysis was performed by diagrams and interpreting the competitiveness index. The soybean has greater competitive ability that horseweed for both development stages. The intraspecific competition is more intense for soybean when in hairy fleabane rosette stage, and the competitive relations are equivalent between soybean and hairy fleabane of 15 cm tall. The both hairy fleabane stages were injured in the soybeans competition.

KEYWORDS: competitivity; *Conyza bonariensis*; *Glycine max*; replacement series.

RESUMO: O objetivo deste trabalho foi avaliar a habilidade competitiva relativa da cultura da soja com buva de diferentes estádios de desenvolvimento. Foram realizados dois experimentos em casa de vegetação, em delineamento inteiramente casualizado. Os experimentos testaram a competição de soja e buva (estádio roseta e plantas com 15 cm de estatura) nas proporções de 100:0, 75:25, 50:50, 25:75 e 0:100, com população equivalente a 315 plantas m^{-2}. As variáveis avaliadas foram estatura, área foliar e matéria seca da parte aérea (folhas e caule). A análise da competitividade foi realizada por aplicação de diagramas e interpretações dos índices de competitividade. Os resultados da competição da soja com buva de diferentes estádios de desenvolvimento evidenciam que o cultivar de soja BRS Estância RR, em geral, possui mais habilidade competitiva que a buva, independentemente do estádio de desenvolvimento. A competição intraespecífica é mais intensa para a cultura quando em competição com buva em estádio de roseta, enquanto para a soja com buva de 15 cm as relações de competição se equivalem. O desenvolvimento da buva é prejudicado na competição com a soja.

PALAVRAS-CHAVE: competitividade; *Conyza bonariensis*; *Glycine max*; série de substituição.

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INTRODUCTION

Soybean crops have become Brazil's main agricultural export. In the 2013/14 harvest, more than 30 million ha were planted, and production exceeded 86 million tonnes (CONAB, 2014).

Owing to the development of agriculture-oriented biotechnology, agricultural production has increased. As a result, there is greater yield with smaller areas in use. One of the factors that contributed to such increase is the development of glyphosate-resistant cultivars, which allowed farmers to simplify weed control in soybean by replacing the use of various herbicides by a single molecule (SHANER, 2000). However, the increased use of glyphosate for weed control in genetically modified soybean has led to selection of resistant biotypes, e.g., hairy fleabane (*Conyza bonariensis*) (VARGAS et al., 2007).

Hairy fleabane has high competitive and dispersive potential, and has emergence flow throughout the year. Thus, different plant growth stages occur during a production cycle, which impacts competition ability.

Because hairy fleabane establishment occurs prior to soybean sowing, the weed has competitive advantage over the crop, and its negative effects increase as its emergence occurs earlier in comparison with that of the crop. Studies in which weed establishment occurs before that of the crop have shown that delay in soybean emergence, compared with the competing weed, increases the negative effects, which can be enhanced as population increases (FLECK et al., 2004; RIZZARDI et al., 2004; SILVA et al., 2005).

Relations of competition between crops and weeds depend on the conditions in which competition is happening, because competition interactions are specific to species and weed population, as well as to environmental conditions. In general, crops are not as efficient when in competition because they are outnumbered by weeds; also, early weed emergency occurs, hence weeds have greater ability to extract the resources from the environment (PROCOPIUS et al., 2005).

It is hypothesized that taller hairy fleabane plants cause greater losses to soybean development compared with shorter plants. Considering it all, the objective of this work was to evaluate the relative ability of soybean crop to compete with hairy fleabane in different growth stages.

MATERIAL AND METHODS

Two experiments were conducted in a greenhouse in a completely randomized block design, with four replications. The tests were placed in 8 L plastic pots, and the soil in use was a clayey, typical Dystrophic Red Latosol with the following physicochemical properties: clay = 53%; organic matter = 2.3 $g.dm^{-3}$; water pH = 7.3; P = 50 $mg.dm^{-3}$; K = 496 $mg.dm^{-3}$; Ca = 82.8 $mmolc.dm^{-3}$; and Mg = 49.4 $mmolc.dm^{-3}$.

The first experiment (Experiment I) was conducted in an additive series to determine plant population; based on the latter, total dry matter (TDM) per unit area becomes independent of the population (RADOSEVICH et al., 1997). The tested populations of soybean and hairy fleabane had 2, 4, 8, 16 and 32 plants per pot (equivalent to 52, 105, 210, 420, 841 plants per m^2). The hairy fleabane seeds were left to germinate in plastic pots. When they had four leaves, they were transplanted to the experimental units, while the soybean seeds were left to germinate directly in the experimental units. The variable TDM of soybean was analyzed at 43 days after emergence (DAE), by weighing the dry material in an oven with temperature of 60ºC for 72 hours. Constant final yield in TDM was calculated with the average population of 12 plants per pot, an amount equivalent to 315 plants m^{-2}. To determine time of competition between the crop and the weeds, we took into consideration the critical period for prevention of interference in the soybean crop, which is between 15 and 45 DAE (VIDAL, 2010).

The experiment was conducted in a replacement series, and it tested the competition between soybean plants and hairy fleabane in the rosette stage (six leaves) and hairy fleabane plants with 15 cm in height (25 leaves). The treatments were arranged in the following proportions (%) of soybean and hairy fleabane: 100:0 (12:0) (soybean monocrop), 75:25 (9:3), 50:50 (6:6), 25:75 (3:9) and 0:100 (0:12) (hairy fleabane monocrop). For this purpose, hairy fleabane plants were collected in the field and transplanted to the experimental units, and the soybean cultivar BRS Estância RR (maturation group 6.1) was used. The plants were equidistantly distributed in the pots.

At 43 days after establishment of the plants, assessments were made of plant height (H), leaf area (LA), leaf dry matter (LDM), stem dry matter (SDM) of soybean plants and TDM of soybean and hairy fleabane plants. Plant height was determined by measuring the distance from the base of the plant until the end of the last fully developed leaf. LA was measured with the help of a LI-COR3100 leaf area meter. LDM and SDM were calculated by weighing the leaves and stem after drying them in an air circulation oven at 60ºC for 72 hours. TDM was determined by the sum of LDM and SDM.

The variables were analyzed through the method of graphical analysis of relative yield. They were analyzed by means of a diagram based on relative yield (RY) and relative yield total (RYT), in the proportions of plants of 0, 25, 50, 75 and 100% of soybean and hairy fleabane.

Relative yield of the evaluated variables was calculated by the ratio of the average of the mixture/average of the monocrop. RYT was represented by the sum of relative yields of the competitors. In these diagrams, the results are compared with the values of the hypothetical straight line, which unites point in stand zero (0:100) and pure stand (100:0) of the diagram, which represent the absence of interference between plants. When RY results in a concave line, it means that there is loss

in the growth of one or both of the plants, or, if the line shown by RY is convex, there is benefit in the growth of one or both species. For RYT, if the value is equal to 1 (straight line), there is competition for the same resources; if the value is greater than 1 (convex), the competition is avoided; if the value is less than 1 (concave line), there is competition and mutual loss to the growth of the species.

Calculations were made of the indexes of relative competitiveness (RC), relative clustering coefficient (K) and competitiveness (C) in the 50:50 ratio among the plants. RC represents the comparative growth of the crop compared with the weed, K indicates relative dominance of one species over the other, and C indicates which species is more competitive.

For statistical analysis of relative yield, calculations were made of the differences for the values of RY found in the proportions of 25, 50 and 75% of plants compared with the values belonging to the hypothetical straight lines found in the respective proportions. The t test ($p \leq 0.05$) was used to assess differences in the study indexes compared with the hypothetical straight line. The criterion for considering the curves of RY and RYT as different from the hypothetical straight line is that, at least in two proportions, there is a significant difference by the t test ($p \leq 0.05$); the same criterion was applied to the indices RC, K and C (BIANCHI et al., 2006b).

The data collected for H, LA, LDM, SDM, and TDM of soybean and hairy fleabane plants were submitted to ANOVA by the F-test at 5% of significance. The average of the treatments was compared by Duncan's test ($p \leq 0.05$), and the monocrops were considered as control.

RESULTS AND DISCUSSION

The graphic analysis of RY of the height of soybean in competition with hairy fleabane rosette resulted in a concave line; there were significant deviations compared with the hypothetical straight line, as observed for the hairy fleabane rosette, although there was a significant deviation compared with the hypothetical straight line only in the 50:50 ratio (Table 1 and Fig. 1). RYT for the variable height was less than 1, suggesting that both soybean and hairy fleabane rosette show mutual losses in development. By contrast, for the competition between soybean and the 15 cm-tall hairy fleabane, there was no mutual loss in height in RY and RYT, i.e., the height behavior of soybean in competition with taller hairy fleabane was similar to that of intraspecific competition (soybean monocrop).

The response of plant height in competition can vary depending on the type of resource required. In cultivation conditions in which water and nutrients are limiting factors, weed competition can reduce the height of soybean; however, when the resources of soil are not limiting, the height of soybean may be greater in competition. Thus, light has greater influence on the interaction of competition (VOLLMANNA et al., 2010). It should be noted that, in this work, water was not the limiting factor of competition, because the treatments were irrigated daily.

In the soybean crop, plant height is an important morphological feature, because taller plants have greater competitive ability (BIANCHI et al., 2006a; FLECK et al., 2007).

Table 1. Relative yield differences (RYD) and relative yield total (RYT) for the variables plant height and total dry matter of the soybean and hairy fleabane of different growth stages (rosette and 15 cm tall).

Relative yield differences/ relative yield total	Plant proportions (soybean:hairy fleabane)		
	75:25	50:50	25:75
Plant height			
RYD soybean	-0.08 (0.02)*	-0.03 (0.01)*	0.01 (0.01)^{ns}
RYD hairy fleabane rosette	-0.04 (0.02)^{ns}	-0.13 (0.03)*	-0.09 (0.06)^{ns}
RYT	0.88 (0.02)*	0.84 (0.03)*	0.92 (0.04)^{ns}
RYD soybean	0.07 (0.02)*	0.04 (0.01)^{ns}	0.03 (0.03)^{ns}
RYD hairy fleabane 15 cm tall	-0.05 (0.02)^{ns}	0.00 (0.04)^{ns}	0.00 (0.08)^{ns}
RYT	1.03 (0.04)^{ns}	1.04 (0.04)^{ns}	1.03 (0.07)^{ns}
Total dry matter			
RYD soybean	0.02 (0.03)^{ns}	0.22 (0.04)*	0.24 (0.03)*
RYD hairy fleabane rosette	-0.08 (0.03)^{ns}	-0.29 (0.03)*	-0.33 (0.06)*
RYT	0.94 (0.01)*	0.93 (0.02)*	0.90 (0.09)^{ns}
RYD soybean	0.13 (0.03)*	0.13 (0.03)^{ns}	0.02 (0.05)^{ns}
RYD hairy fleabane 15 cm	-0.13 (0.02)*	-0.06 (0.04)^{ns}	0.00 (0.13)^{ns}
RYT	1.00 (0.02)^{ns}	1.07 (0.09)^{ns}	1.02 (0.15)^{ns}

^{ns}Not significant; *significant by the t test ($p \leq 0.05$). Values in parentheses are the standard errors of the means.

In an experiment conducted by TREZZI et al. (2013) on the competitive ability of soybean cultivars in competition with hairy fleabane, the authors have verified that soybean height can be higher in the presence of the weed, a phenomenon referred to as initialism (VIDAL, 2010).

RY for TDM of soybean in competition with hairy fleabane rosette showed a convex line, which indicates an advantage in growth compared with the estimated straight lines, and hairy fleabane showed a concave line, hence its growth was affected by competition with soybean (Table 1 and Fig. 1). As the ratio of the competitor increases, soybean responds with a relative increase of TDM, indicating that in this interaction between the species the soybean plants are more capable of capturing environmental resources. RYT was less than 1 in the competition between soybean and hairy fleabane rosette, which indicates that both species are affected in their development. However, it can be seen that the hairy fleabane rosette has greater responsibility in such loss, as it shows greater differences in the expected straight lines (Table 1). By comparison, RY and RYT of soybean and the 15 cm-tall hairy fleabane, when associated with soybean, showed no differences between the estimated straight lines and the expected straight lines, indicating that competition occurs for the same environmental resources.

The losses of competition as regards plant height may be attributed to quantity and quality of light that reaches the canopy of plants. It has been reported that, in non-competitive conditions, modifying the quality of light reflected by weeds causes changes in competition interactions with crops (LIU et al., 2009). The increase in height, length of internodes and

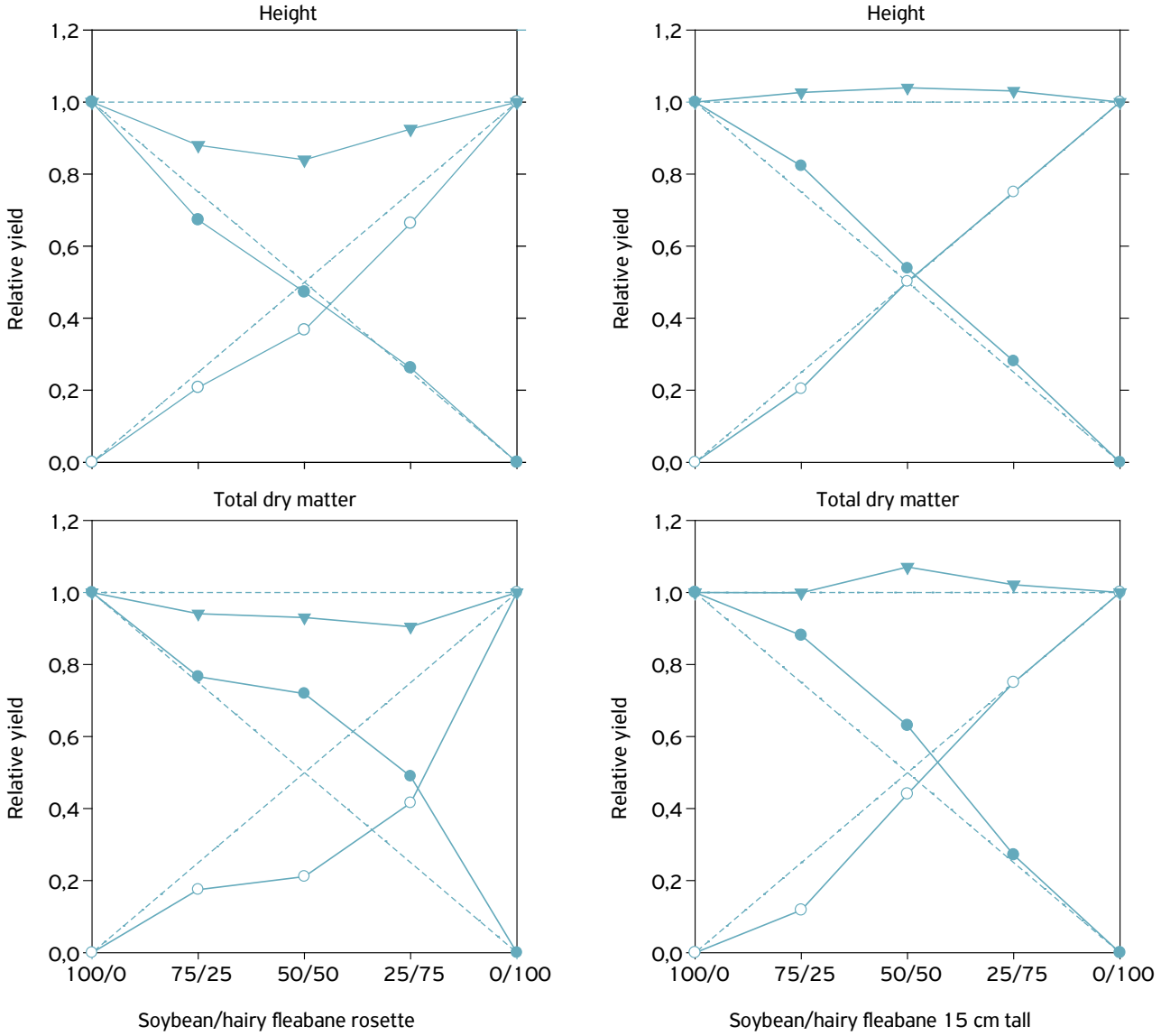

Figure 1. Relative yield (RY) and relative yield total (RYT) for height and total dry matter of soybean and hairy fleabane of different growth stages (rosette and 15 cm tall). (●) RY for soybean, (○) RY for hairy fleabane and (▼) RYT. The dashed line represents the hypothetical relatives yields whenever there is no interference between one specie over another.

in the shoot:root ratio are morphological changes that indicate competition for light, or a change in the ratio of quality of light that reaches plants (GREEN-TRACEWICZ et al., 2011). Thus, it can be inferred that there was no change in the ratio of quantity and quality of light received by soybean plants in competition with hairy fleabane rosette, unlike what might have happened in the relations of competition with the 15cm-tall hairy fleabane, in which the soybean plants grew taller to compete for light. In non-competitive conditions, the low red:far-red light ratio causes plants to express greater height, greater leaf area and a greater shoot:root ratio (RAJCAN et al., 2004).

Before interference relations occur, plants detect early responses from the environment, especially with respect to light that is reflected from other plants, and change their metabolism to avoid shade from other plants. Soybean crops have the ability to occupy spaces with increased branching, and such plasticity gives them a competitive advantage. Although there may not be differences in biomass of soybean in competition with hairy fleabane, yield may be reduced as found by SILVA et al. (2014). According to the authors, the coexistence of soybean with hairy fleabane in the first 21 days caused yield loss of approximately 5 kg of grain ha^{-1}. day^{-1}.

The increase of biomass of soybean plants is due to increased grain yield. However, when plants are in the presence of weeds, plant response varies widely as regards biomass increase, which reflects variability in yield (GREEN-TRACEWICZ et al., 2011).

In the absolute growth of soybean, the plant height was reduced in the 75:25 ratio, when hairy fleabane rosette is compared with the soybean monocrop, while there were no changes in the other ratios (Table 2). However, there was an increase in the height of soybean in the 75:25 and 50:50 ratios when in competition with the 15 cm-tall hairy fleabane and when in competition with the hairy fleabane rosette; this shows that the crop grew to prevent the shade from the weeds. By contrast, the height of the hairy fleabane rosette did not change in competition with soybean; however, the height of the 15 cm-tall hairy fleabane was withdrawn when soybean had a greater ratio in the competition, indicating greater ability of the crop to acquire environmental resources for its growth, thus restricting the growth of the weed (Table 3). As expected, the hairy fleabane plants showed differences in their height among themselves in all competition conditions.

Intraspecific competition was more harmful to soybean when in coexistence with hairy fleabane rosette. I.e., when the ratio of hairy fleabane rosette was increased, there was an increase of the variables leaf area, LDM, SDM, and TDM of soybean (Table 2). In the 50:50 and 25:75 ratios, soybean showed greater leaf area, LDM, SDM, and TDM, compared with the soybean growing in the 75:25 ratio and as a monocrop (100:0). The competition of soybean with red rice also showed the same trend in the increase of the variables leaf area and dry matter of soybean when in interspecific competition (MORAES et al., 2009).

Interspecific competition was more detrimental to the growth of the hairy fleabane rosette; in all ratios with soybean, TDM of the hairy fleabane rosette was lower compared with the monocrop, and there was a reduction in TDM for the 15 cm-tall hairy fleabane in the 50:50 and 75:25 ratios (Table 3). TDM among hairy fleabane plants showed no differences when in competition with the highest ratio of soybean; this is an indicative that soybean suppressed the growth of the taller plant, which could prove to be an advantage in competition for the weed that is already established. However, soybean

Table 3. Plant height and total dry matter of hairy fleabane of different stages of development (rosette and 15 cm tall) in competition of proportions with soybean.

Plant proportions (Soybean: hairy fleabane)	Plant height		Total dry matter	
	Rosette	15 cm	Rosette	15 cm
0:100	*21a	82a	*0.39a	1.12a
25:75	*21a	83a	*0.24b	0.99a
50:50	*18a	67a	*0.19b	0.53b
75:25	*20a	51b	^{ns}0.27b	0.37b

^{ns}Not significant; *significant compared between hairy fleabane of different growth stages, and mean followed by same letter not differ statically form each other proportions, both by Duncan test ($p \leq 0.05$).

Table 2. Plant height (H), leaf area (LA), leaf dry matter (LDM), stem dry matter (SDM) and total dry matter (TDM) in different proportions of soybean and hairy fleabane of different growth stages (rosette and 15 cm tall).

Plant proportions (soybean:hairy fleabane)	Plant height		Leaf area		LDM		SDM		TDM	
	Rosette	15 cm	Rosette	15 cm	Rosette	15 cm	Rosette	15 cm	Rosette	15 cm
100:0	^{ns}97a	97a	^{ns}418c	418b	^{ns}1.12c	1.12a	^{ns}1.46c	1.46a	^{ns}2.57c	2.57a
75:25	*87b	107a	^{ns}464c	450ab	^{ns}1.15c	1.35a	^{ns}1.48c	1.67a	^{ns}2.63c	3.02a
50:50	*92a	105a	^{ns}580b	611a	^{ns}1.63b	1.48a	^{ns}2.08b	1.77a	^{ns}3.70b	3.25a
25:75	^{ns}102a	109a	*926a	543ab	*2.36a	1.33a	*2.68a	1.46a	*5.04a	2.79a

^{ns}Not significant; *significant compared between hairy fleabane of different growth stages, and mean followed by same letter not differ statically form each other proportions, both by Duncan test ($p \leq 0.05$).

Table 4. Competitiveness indices of soybean and hairy fleabane of different growth stages (rosette and 15 cm tall), expressed by their relative competitiveness index (RC), coefficients of relative clustering (K) and competitiveness (C).

Competitive conditions	CR	K (soybean)	K (hairy fleabane)	C
Plant height				
Soybean *vs.* rosette	1.32 (0.13)^{ns}	0.89 (0.03)*	0.59(0.07)	0.10 (0.03)^{ns}
Soybean *vs.* 15 cm tall	1.09 (0.08)^{ns}	1.18 (1.00)^{ns}	1.04(1.15)	0.04 (0.04)^{ns}
Total dry matter				
Soybean *vs.* rosette	2.77 (0.10)*	3.34 (0.04)*	0.27(0.06)	0.51 (0.08)*
Soybean *vs.* 15 cm tall	1.45 (0.15)*	1.99 (0.08)^{ns}	0.81(0.02)	0.19 (0.06)*

^{ns}Not significant; *significant by the t test ($p \leq 0.05$). Values in parentheses are the standard errors of the means.

showed greater ability to capture the environmental resources in these ratios. Weed development has a direct relationship with the negative effects of competition with crops, in which it can be observed that weeds emerged prior to soybean cause a delay in the development of this crop (SILVA et al., 2005). Earlier emergence of weeds beggar-ticks and sidas, compared with soybean, increases the negative effects on crop, causing a decrease in the morphological features and yield of soybean (FLECK et al., 2004).

In the competition between soybean and the 15 cm-tall hairy fleabane, leaf area response was variable and did not show a trend as the other variables did. Competition with an equal ratio for number of plants showed greater leaf area accumulation by the soybean crop while in the other ratios it showed an intermediate value between the control and the ratio with the greatest leaf area (Table 2). Variations in the morphological response of soybean in competition were also found by GREEN-TRACEWICZ et al., (2011). According to the authors, the plasticity of the soybean crop causes the plant to adapt the different environmental conditions, and hence it can express a greater increase in leaf area, however with great variability among plants. By contrast, the effect of the competition of 15 cm-tall hairy fleabane on LDM, SDM, and TDM of soybean was the same as in intraspecific competition, i.e., there was no effect on dry matter accumulation by the crop with variation of the ratios of the competitor (Table 2).

When soybean growth is compared through the variables leaf area, LDM, SDM, and TDM, in competition with hairy fleabane plants of different sizes, it can be seen that only in the lowest soybean ratio there was an increase in growth when the crop competed with the shortest hairy fleabane, as opposed to the 15 cm-tall hairy fleabane (Table 2). In the other ratios and in competition with the different sizes of hairy fleabane, soybean development has not been changed as a function of the growth stage of the competitor.

When analyzing the indices of competitiveness (RC, K and A) of soybeans with hairy fleabane, it appears that there was no difference in competitiveness for plant height, and only the K indicated that the soybean was more competitive than hairy fleabane rosette (Table 4). Now, for DTM, the growth of the crop has surpassed that of hairy fleabane, regardless of development stage, in which there were at least two higher indices for the crop. For the competition between soybean and hairy fleabane rosette, CR, K and A were significantly higher, while for the competition of soybean with 15 cm-tall hairy fleabane only K was not significant. The analysis of all these indices combined corroborates the results found in the graphical analysis, and shows that the crop has greater competition ability compared with the weeds regardless of plant height.

Replacement experiments show that crop is usually more competitive than the weed species, under appropriate levels of resources, because the effect of weeds is not due only to greater individual competitive ability, but also to degree of infestation (VILÀ et al., 2004). A similar result was found with respect to competition between soybean and *Digitaria ciliaris* (AGOSTINETTO et al., 2013). However, weeds can be more competitive than soybean, as observed for the competition with *Euphorbia dentata* (JUAN et al., 2003), with *Euphorbia heterophylla* and *Ipomoea ramosissima* (MOLIN et al., 2004) and with oilseed radish (BIANCHI et al., 2006a).

CONCLUSIONS

In general, the soybean cultivar BRS Estância RR has greater competitive ability than the hairy fleabane plants regardless of the development stage of the latter.

Intraspecific competition is more intense for the crop when it is in competition with hairy fleabane in the rosette stage.

In coexistence between soybean and 15 cm-tall hairy fleabane, interspecific and intraspecific competition relations are equivalent. Hairy fleabane development is impaired in competition with soybean.

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