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CROP PRODUCTION AND MANAGEMENT - Article

Relative competitiveness of soybean cultivars with barnyardgrass

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ABSTRACT: The aim of this work was to evaluate the competitiveness between soybean cultivars and barnyardgrass, based on morphological and physiological characteristics of species. The experiments were conducted in completely randomized experimental design, with 4 replications. In the first study, for both soybean and barnyardgrass, it was determined the population of plants in which shoot dry matter became constant and independent of the population (16 plants·pot^{-1} or 400 plants·m^{-2}). In the second study, 2 experiments were conducted to evaluate the competitiveness of BMX Apolo RR and BMX Potência RR soybean cultivars with barnyardgrass plants, both carried out in replacement series under different proportions of plants·pot^{-1} (100:0; 75:25; 50:50; 25:75 and 0:100) between the crop and the weed. The analysis of the species competitiveness was determined through diagrams applied to replacement series experiments and use of relative competitiveness indexes. At 44 days after the emergence of species, the physiological and morphological parameters of the crop and the weed were evaluated. The BMX Apolo RR and BMX Potência RR soybean cultivars show similar competitiveness when competing with the barnyardgrass; therefore, the ability of one species to interfere on another is equivalent. For plant height, barnyardgrass displays higher competitiveness compared to BMX Apolo RR, with early cycle and short height. The intraspecific competition is more important to barnyardgrass than interspecific competition with soybean cultivars, resulting in negative effects on the morphological and physiological characteristics of species.

Keys words: *Echinochloa crus-galli*, lowlands, replacement series, competition.

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INTRODUCTION

Barnyardgrass (*Echinochloa crus-galli* L.) is a highly-competitive weed, especially due to C_4 photosynthetic cycle, rapid initial growth combined with high demand for nitrogen, and the fact that it is present in high infestation levels in lowland areas (Kissmann 2007). Soybean crops have expanded in these areas, integrating the crop rotation systems, especially with rice; however, barnyardgrass infestations have become important in soybean crops affecting grain yield when not properly managed.

Competition between plants arises when one (or more) of the resources essential to growth/development is present in limited quantity to meet the requirements of individuals. However, this competition can occur between individuals of the same species (intraspecific) or between individuals of different species (interspecific) (Rigoli et al. 2008). In the environment, plants compete basically for water, light, nutrients, O_2 and CO_2 to a lesser extent (Radosevich et al. 2007).

There are several methods to investigate the competitive relationships between plants; among them, the experiments in replacement series stand out, which have been widely used for studies of different crop/weeds (Aminpanah and Javadi 2011; Bianchi et al. 2006; Galon et al. 2014; Rigoli et al. 2008; Wandscheer and Rizzardi 2013). This method allows the understanding of the competitive process between plants, especially when related to the effect of the population as well as of the crop and weeds proportion (Aminpanah and Javadi 2011).

The replacement or substitutive series experimental model was first proposed by Radosevich (1987), where the plant total density is kept constant, while varying the mixing proportions of the species. This situation is different from that found in field conditions where crop density is constant while weed density is variable. However, the experimental model is important to assess the effects of competition of the 2 species for a total single density and to determine the relative effects of interference within and between species, indicating which one is more competitive.

Studies in substitutive series have found that usually crops have higher competitive ability than weeds (Agostinetto et al. 2013; Galon et al. 2014; Moraes et al. 2009). This behavior is explained by the fact that the negative effect of weeds is not restricted by the largest individual competitive ability, but mainly due to the level of infestation in the area (Vilà et al. 2004).

Research using replacement series studies has shown that soybean crop has competitive advantage in relation to weeds, grasses and broadleaves (Bianchi et al. 2006; Dias et al. 2010; Moraes et al. 2009; Wandscheer and Rizzardi 2013). However, the results for barnyardgrass have shown that this weed usually has competitive advantage in relation to irrigated rice cultivars (Agostinetto et al. 2008; Aminpanah et al. 2012; Gealy et al. 2005), and this response is attributed to the high morphophysiological similarity between the species. Thus, both of them end up exploiting basically the same ecological niche, competing for the same resources in time and/or space (Agostinetto et al. 2008).

This study hypothesizes that barnyardgrass is potentially more competitive than soybean when occurring in similar proportions and with appropriate resource levels, especially due to more efficient photosynthetic cycle and rapid initial growth. Thus, the objective of this study was to evaluate the competitiveness between soybean cultivars and barnyardgrass, based on morphological and physiological characteristics of these species.

MATERIAL AND METHODS

The research was divided into 2 studies (Study 1 and 2). The Study 2 was divided into 2 separate experiments. Both were carried out in greenhouses. Study 1 was conducted from October to December 2013 while Study 2, from December 2013 to February 2014. The experimental units were 8-L plastic pots with 23 cm of nominal diameter, filled with soil, classified as Albaqualf, with sandy loam texture, from mapping unit of Pelotas.

Study 1 consisted of soybean monoculture and barnyardgrass, aiming to determine the population of plants per m^2 in which the shoot dry matter (SDM) per unit area ($g \cdot m^{-2}$) became constant and independent of the population based on the "law of constant final production" (Radosevich et al. 2007). The hypothesis proposed by these authors is that the population per pot when the dry matter weight becomes constant is sufficient to capture all the necessary resources for plant growth.

The experimental design was completely randomized, with 4 replications. In this previous experiment, soybean →

(cv. BMX Potência RR) and barnyardgrass were sown as monocultures to establish the following plant populations: 1; 2; 4; 8; 16; 32; 64 and 128 plants·pot^{-1} (equivalent to 25; 50; 100; 200; 400; 800; 1,600 and 3,200 plants·m^{-2}) for both species. The seeds of the barnyardgrass biotype (*Echinochloa crusgalli* (L.) Beauv. var. crusgalli) were previously collected in the field (lat 31°48′25.4″ and long 52°28′53.4″), shortly after the beginning of the natural dispersion in May 2013. Then, they were manually cleaned and stored in paper bags at room temperature until the beginning of the experiments.

Forty-four days after emergence (DAE), the shoots were harvested, packaged in paper bags and dried in a forced air circulation oven, at 65 °C average, until constant weight of SDM.

For data analysis, reciprocal production was used to determine the plant population in which SDM became constant (Radosevich et al. 2007). The SDM became constant from the population of 16 plants·pot^{-1} onward (data not shown), equivalent to 400 plants·m^{-2}.

Study 2 was conducted based on the replacement series model described by Radosevich (1987), with the number of plants per pot (16 plants·pot^{-1}) established in Study 1. The experimental design was completely randomized, with 4 repetitions. The proportions between BMX Potência RR soybean cultivar and barnyardgrass (Experiment 1) and between BMX Apolo RR soybean cultivar and barnyardgrass (Experiment 2), in each series, were: 100:0 (soybean monoculture), 75:25; 50:50; 25:75 and 0:100 (barnyardgrass monoculture).

The variables evaluated at 44 DAE were: plant height (PH), leaf area (LA), SDM and photosynthetic parameters. The plant height was determined using a millimeter ruler to measure the height from the ground to the apex of the last expanded trifoliate for soybeans and the height from the ground to the end of the last leaf to barnyardgrass. Leaf area (cm^2·plant^{-1}) was determined using a leaf area meter LI 3100C (LI-COR, Lincoln, NE, USA), and SDM (g·plant^{-1}) was quantified as described above.

The photosynthetic parameters were evaluated in the last expanded trefoil of soybean plants and in the middle third of the first fully expanded leaf of the barnyardgrass, using an infrared gas analyzer (IRGA), model LI-6400 (LI-COR, Lincoln, NE, USA). The greenhouse was kept open to allow free air circulation during the measurements. This equipment was also used to determine stomatal conductance (Gs: mol·m^{-1}·s^{-1}), transpiration rate (E: mol H_2O·m^{-2}·s^{-1}), intercellular CO_2 concentration (Ci: μmol·mol^{-1}) and photosynthetic rate (A: μmol·m^{-2}·s^{-1}). The efficiency of carboxylation (EC: mol CO_2·m^{-2}·s^{-1}) and water use efficiency (WUE: mol CO_2·mol H_2O^{-1}) were calculated from the ratio of the variables A/Ci and A/E, respectively.

For the variables plant height, leaf area and SDM of soybean cultivars and weed, it was used the method of graphical analysis of the relative yield (Radosevich 1987). This model involves the construction of a diagram based on the relative yield (RY) and relative total yield (RTY) for the studied plant proportions (0; 25; 50; 75 and 100%).

The RY values were obtained according to the following equation: RY = mixing average/monoculture average, where "average" represents the average per plant of each species in each experimental unit. The RTY data were represented by the sum of the relative yield of culture and the competitors in the respective plant proportions. When RY is a straight line, there is no effect of one species over the other, or the ability of the species to interfere with one another is equivalent. When RY is a concave curve, the growth of one or both species was negatively affected; however, a convex curve indicates that the growth of one or both species was positively affected. On the other hand, RTY equal to 1 (straight line) means that there was competition for the same resources. However, a value greater than 1 (convex line) means that there was no competition, either because the supply of resources exceed the demand or because the demands for the resources are different for each species. Finally, a value less than 1 (concave) indicates the occurrence of antagonism that harmed the growth of both species (Radosevich 1987).

Relative competitiveness (RC) indices as well as coefficients of relative crowding (K) and of competitiveness (C) were calculated for the 50% proportion (crop and competitor). The RC is the comparative growth of species X in relation to Y; K indicates the relative dominance of one species over another; and C shows which species is more aggressive (Cousens 1991). The joint interpretation of these values (CR, K and C) indicates, with higher certainty, the competitiveness of the species involved. Accordingly, the species X is more competitive than Y when RC > 1; $K_x > K_y$ and C > 0; otherwise, Y will be more competitive than X when RC < 1; $K_x < K_y$ and →

C < 0 (Hoffman and Buhler 2002). These indices were calculated using the following equations: $RC = RY_x/RY_y$; $K_x = RY_x/(1 - RY_x)$; $K_y = RY_y/(1 - RY_y)$; $C = RY_x - RY_y$, according to Cousens and O'Neill (1993).

The differences of RY values for the 25, 50 and 75% proportions were first calculated in relation to the values of the hypothetical straight lines obtained in the respective proportions to analyze the relative yield statistically (Bianchi et al. 2006). The *t*-test at 5% probability was used to test differences in the studied indices in relation to the hypothetical straight line (Hoffman and Buhler 2002; Roush et al. 1989). The null hypotheses used to test differences of RY and C were made on the assumption that, if they were equal to zero ($H_0 = 0$), for RTY and RC, the averages would be equal to 1 ($H_0 = 1$); for the K index, the mean differences between K_x and K_y were equal to zero: $H_0 = (K_x - K_y) = 0$.

The results obtained for the morphological (PH, LA, SDM) and photosynthetic (A, Gs, Ci, E, EC and WUE) characteristics of soybean and barnyardgrass were expressed as average values per plant. Firstly, the data were tested for normality by the Shapiro-Wilk's test ($p \geq 0.05$), without the need for data transformation. Later, analysis of variance was performed by the F-test ($p \leq 0.05$) and, in the case of significant difference between the treatments, the means were compared by the Dunnett's test ($p \leq 0.05$), considering monocultures as untreated check in such comparisons. For photosynthetic parameters, the Duncan's test ($p \leq 0.05$) was also applied to analyze the differences between the species proportions.

RESULTS AND DISCUSSION

The graphical analysis of the proportions of soybean (BMX Apolo RR and BMX Potência RR) and the competitor, barnyardgrass, showed that, in general, the expected RY values were close to those observed, revealing that the 2 cultivars responded similarly to the weed competition (Figure 1; Table 1). For the difference to be significant, at least 2 plant proportions should differ significantly (Bianchi et al. 2006). Thus, based on the RY, only the height of BMX Apolo RR soybean cultivar was different for at least 2 plant proportions (75:25 and 50:50), represented by a concave curve (Figure 1a; Table 1). In this case, it was demonstrated that barnyardgrass used the available resources more efficiently than the soybean, without changing the RY, while, for the BMX Apolo RR, RY decreased as crop population increased.

RTY and RY behaved similarly since the expected straight lines had values very close to the unit (1), with no statistical difference ($p \leq 0.05$). The exception was the plant height of BMX Potência RR, which, in the 50:50 and 25:75 proportions, had RTY equivalent to less than 1, represented by a concave curve (Figure 1d; Table 1). For this, according to Harper (1977), there was antagonism between species since RTY decreased due to the lower contribution of both species, i.e. the 2 species competed for the same resources.

The analysis of the RY and RTY figures shows that the observed and expected lines are very close to the unit (1), with no differences in most cases (Figure 1; Table 1). Generally, it is possible to infer that the effect of one species over another in the competition for environmental resources was low, and probably the ability of one species to interfere with the other was equivalent (Radosevich 1987).

Similar results were reported for the competition between corn and *Chloris distichophylla*, where the observed and hypothetical values did not differ. The authors inferred that, even with weed interference, corn maintained yield equivalent to monoculture condition (Wandscheer and Rizzardi 2013). Likewise, it was observed that the competitive ability of *Commelina benghalensis* and soybeans were equivalent, with no effect on overall yield of either species (Dias et al. 2010).

It is noteworthy that, for all variables tested in both cultivars, for the proportion of 75:25 (soybean/competitor-weed), the RY soybean values were always below the hypothetical straight line, while RY weed values were, in general, higher than expected (Figure 1). On the other hand, these values were not always significantly different ($p \leq 0.05$) (Table 1). However, this trend is a result of increased intraspecific competition for both soybean and barnyardgrass. Soybean has lower relative yield at higher proportions, but it is not affected by the increase of competitor population, while the competitor yield is higher than expected at lower proportions.

The relative growth of soybean cultivars and barnyardgrass analyzed by the morphological variables (PH, LA and SDM) showed that both cultivars did not differ ($p \leq 0.05$) from the untreated check (monoculture – 100:0) for all studied proportions (Table 2).

The lowest proportion of barnyardgrass, combined with BMX Apolo RR cultivar, had the highest SDM. On the other hand, when competing with BMX Potência RR in the same proportion, the competitor presented

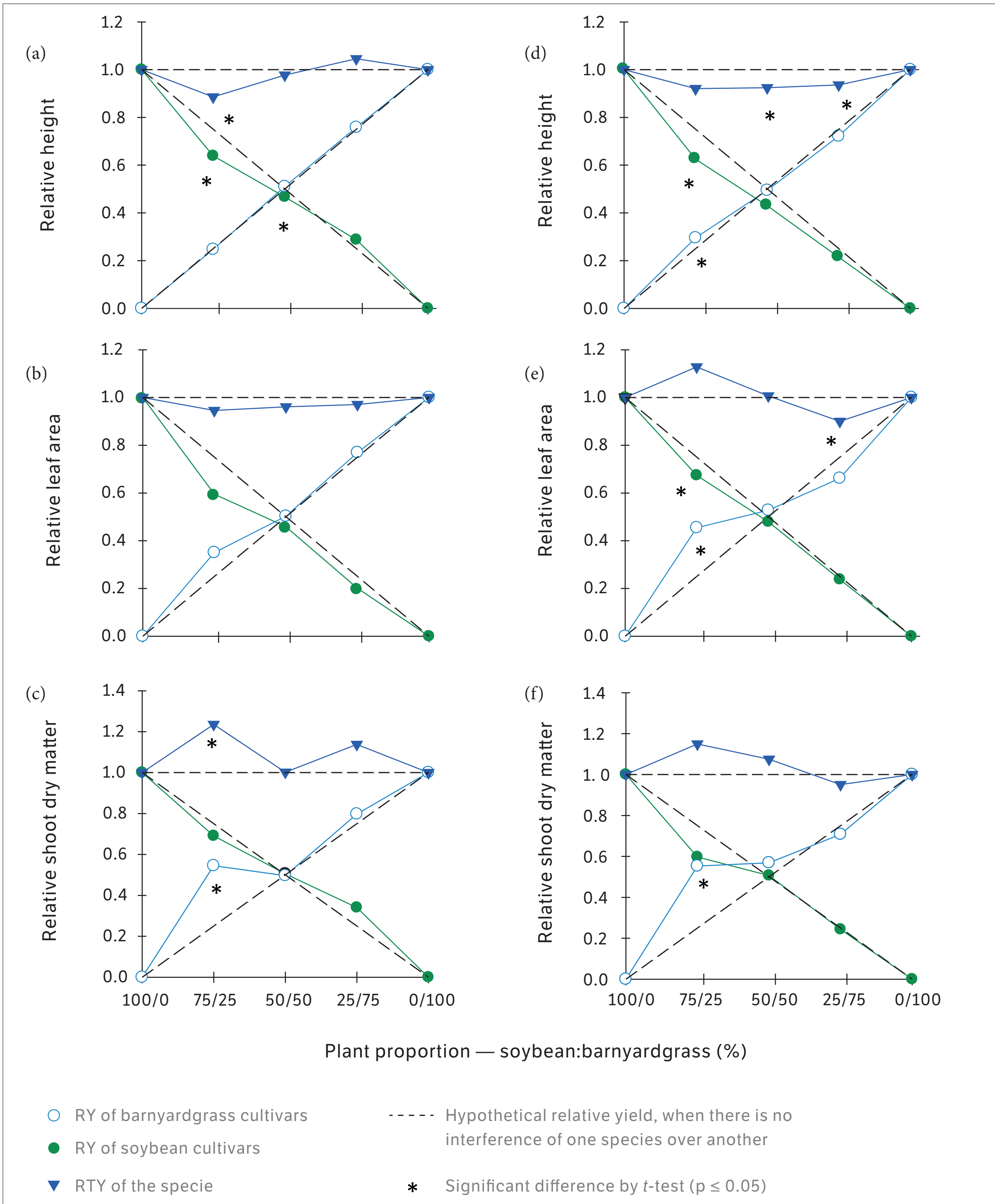

Figure 1. Relative production diagram for plant height, leaf area and shoot dry matter of BMX Apolo RR (a; b; c) and BMX Potência RR (d; e; f) soybean cultivars and barnyardgrass (*Echinochloa crus -galli*) as a function of the proportion between the 2 species.

Table 1. Relative yield differences and relative total yield for the variables plant height, leaf area and shoot dry matter of soybean cultivars (BMX Apolo RR or BMX Potência RR) and barnyardgrass (*Echinochloa crus-galli*) at 44 days after emergence.

Variable	Plant proportion (soybean:barnyardgrass)		
	75:25	50:50	25:75
		Plant height	
RYD BMX Apolo RR	−0.11 (± 0.02)*	−0.03 (± 0.01)*	0.04 (± 0.02)^{ns}
RYD barnyardgrass	0.00 (± 0.01)^{ns}	0.01 (± 0.01)^{ns}	0.01 (± 0.01)^{ns}
RTY	0.89 (± 0.01)*	0.98 (± 0.02)^{ns}	1.05 (± 0.03)^{ns}
RYD BMX Potência RR	−0.12 (± 0.03)*	−0.07 (± 0.03)^{ns}	−0.04 (± 0.02)^{ns}
RYD barnyardgrass	0.05 (± 0.00)*	−0.01 (± 0.02)^{ns}	−0.03 (± 0.03)^{ns}
RTY	0.92 (± 0.03)^{ns}	0.92 (± 0.02)*	0.94 (± 0.01)*
		Leaf area	
RYD BMX Apolo RR	−0.15 (± 0.09)^{ns}	−0.04 (± 0.02)^{ns}	−0.05 (± 0.04)^{ns}
RYD barnyardgrass	0.10 (± 0.06)^{ns}	0.00 (± 0.04)^{ns}	0.02 (± 0.02)^{ns}
RTY	0.95 (± 0.06)^{ns}	0.96 (± 0.04)^{ns}	0.97 (± 0.05)^{ns}
RYD BMX Potência RR	−0.08 (± 0.01)*	−0.02(± 0.08)^{ns}	−0.01 (± 0.04)^{ns}
RYD barnyardgrass	0.20 (± 0.05)*	0.03 (± 0.05)^{ns}	−0.09 (± 0.04)^{ns}
RTY	1.13 (± 0.06)^{ns}	1.01 (± 0.05)^{ns}	0.90 (± 0.01)*
		Shoot dry matter	
RYD BMX Apolo RR	−0.06 (± 0.08)^{ns}	0.01 (± 0.04)^{ns}	0.09 (± 0.06)^{ns}
RYD barnyardgrass	0.29 (± 0.06)*	0.00 (± 0.05)^{ns}	0.05 (± 0.09)^{ns}
RTY	1.24 (± 0.07)*	1.00 (± 0.08)^{ns}	1.14 (± 0.05)^{ns}
RYD BMX Potência RR	−0.15 (± 0.08)^{ns}	0.01 (± 0.10)^{ns}	−0.01 (± 0.07)^{ns}
RYD barnyardgrass	0.30 (± 0.06)*	0.07 (± 0.06)^{ns}	−0.04(± 0.07)^{ns}
RTY	1.15 (± 0.14)^{ns}	1.07 (± 0.07)^{ns}	0.95 (± 0.06)^{ns}

*Significant difference by *t*-test at p ≤ 0.05; Values in parentheses are the standard errors. RYD = Relative yield diferences; RTY = Relative total yield.

increased values for PH, LA and SDM (Table 2). This behavior is again the result of increased intraspecific competition, especially for barnyardgrass. Thus, several replacement series studies have reported that, in some cases, the intraspecific competition seems to be more important than the interspecific one, because plants of the same species basically exploit the same ecological niche, competing for the same resources in time and/or space (Dias et al. 2010; Moraes et al. 2009; Rigoli et al. 2008).

The analysis of the physiological parameters shows that the higher relative growth of the weed at the lowest proportion (25%), previously presented by morphological variables (Figure 1; Table 1,2), is due, in part, to the increased photosynthetic activity and related variables (Table 3). In this sense, there was a higher photosynthetic rate (A) of barnyardgrass when soybean proportion was higher, regardless of the cultivar tested (Table 3). For the same proportion, the effects were more pronounced when the competitor was competing with BMX Potência RR cultivar. In addition to increased photosynthetic rate, the values for stomatal conductance (Gs), transpiration rate (E) and efficiency of carboxylation (EC) also increased. At this proportion (75:25), the plants differed from the untreated check, and the values were also higher compared to the other proportions (50:50 and 25:75). On the other hand, both soybean cultivars were not different regarding the physiological variables in relation to the competitor presence (Table 3).

The results indicate a connection between morphological and physiological variables that allows us to better understand the behavior of the studied species (Table 2,3). Thus, in proportion with less intraspecific competition (75:25) by the barnyardgrass, further opening →

Table 2. Soybean (BMX Apolo RR and BMX Potência RR cultivars) responses to the interference of barnyardgrass (*Echinochloa crus-galli*) for the variables plant height, leaf area and shoot dry matter, in experiments conducted in substitutive series at 44 days after emergence .

Plant proportion (soybean:competitor)	Plant proportion (soybean:barnyardgrass)		
	Plant height (cm)	Leaf area ($cm^2 \cdot plant^{-1}$)	SDM ($g \cdot plant^{-1}$)
		BMX Apolo RR	
100:0 (T)	56.68	569.28	3.91
75:25	48.27	451.75	3.60
50:50	52.93	521.91	3.95
25:75	65.19	457.57	5.33
CV (%)	**10.1**	**23.6**	**27.0**
		Barnyardgrass	
0:100 (T)	79.68	354.73	3.47
25:75	80.54	364.02	3.69
50:50	81.35	356.53	3.44
75:25	78.75	497.28	7.55*
CV (%)	**5.5**	**22.8**	**21.4**
		BMX Potência RR	
100:0 (T)	75.06	583.17	4.32
75:25	62.59	524.08	3.44
50:50	64.52	559.20	4.38
25:75	64.38	555.80	4.21
CV (%)	**10.2**	**23.4**	**28.9**
		BMX Potência RR	
0:100 (T)	79.68	359.40	3.47
25:75	76.67	317.22	3.27
50:50	78.85	379.16	3.94
75:25	94.13*	653.00*	7.66*
CV (%)	**6.0**	**18.9**	**22.4**

*Means differ from the control (T) by the Dunnett's test ($p \leq 0.05$).

of stomatal pores enabled the plant to incorporate more atmospheric CO_2 into the cells and, consequently, to lose more water to atmosphere resulting in increasing transpiration rate (E). Probably, these CO_2 molecules incorporated into the interior of mesophyll cells were not stored for a long time, because the internal CO_2 concentration (Ci) did not change regardless of the plant's proportions. Thus, it is proposed that CO_2 was quickly carboxylated and transformed into glucose, confirmed here by the increase in photosynthetic activity (A) and efficiency of carboxylation (EC).

The increase in transpiration rate by barnyardgrass was not enough to result in lower water use efficiency. The greatest water loss may result from the need of the plant to incorporate CO_2 by photosynthetic activity and carboxylation efficiency (Concenço et al. 2009). These authors reported similar results, where rice plants under lower intensity competition, in addition to greater dry matter accumulation, also displayed higher values of stomatal conductance and transpiration rate. However, the water use efficiency remained unchanged for different competition intensities.

In general, it was observed that, when competing with BMX Apolo RR, barnyardgrass had higher relative growth only for plant height, as shown by RC index (Table 4). However, the dominant competitor was observed for both soybean cultivars, as indicated by the index K. For plant height, barnyardgrass was more competitive →

Table 3. Soybean (BMX Apolo RR and BMX Potência RR cultivars) responses to the interference of barnyardgrass (*Echinochloa crus-galli*) for the variables photosynthetic rate, stomatal conductance of water vapor, internal CO_2 concentration, transpiration rate, efficiency of carboxylation and water use efficiency of the plants in experiments conducted in substitutive series at 44 days after emergence.

Plant proportion (Soybean:competitor)	Physiological variables					
	A	Gs	Ci	E	EC	WUE
	BMX Apolo RR					
100:0 (T)	21.03	0.47	263.8	5.95	0.07	3.85
75:25	24.50 ns	0.98 ns	298.5 ns	7.54 ns	0.08 ns	3.32 ns
50:50	25.65	0.70	272.3	6.74	0.09	3.94
25:75	27.81	1.19	299.8	8.05	0.09	3.47
CV (%)	**19.4**	**65.1**	**9.1**	**28.9**	**13.4**	**12.6**
	Barnyardgrass					
0:100 (T)	25.75	0.27	198.3	4.87	0.13 ns	5.34
25:75	27.95 ns	0.29 ns	196.9 ns	5.17 ns	0.14 ns	5.44 ns
50:50	30.48	0.33	198.1	5.51	0.16	5.59
75:25	*32.80	0.33	189.4	5.57	0.17	5.85
CV (%)	**12.1**	**24.8**	**10.9**	**10.2**	**12.4**	**7.7**
	BMX Potência RR					
100:0 (T)	22.13	0.85	303.8	7.03	0.07	3.28
75:25	19.35 ns	0.45 ns	276.0 ns	5.66 ns	0.07 ns	3.58 ns
50:50	22.26	0.56	275.1	6.02	0.08	3.95
25:75	22.57	0.59	288.5	6.54	0.07	3.48
CV (%)	**16.8**	**60.6**	**6.9**	**23.8**	**12.9**	**14.6**
	Barnyardgrass					
0:100 (T)	25.75	0.27	198.25	4.87	0.13	5.34
25:75	26.75 b	0.25 b	181.65 ns	4.91 b	0.15 b	5.53 ns
50:50	27.65 b	0.30 b	201.50	5.24 b	0.14 b	5.28
75:25	*37.17 a	*0.38 a	184.63	*6.54 a	*0.20 a	5.77
CV (%)	**8.8**	**21.2**	**11.9**	**12.4**	**10.2**	**10.4**

*Significantly different from the control (T) by Dunnett's test ($p \leq 0.05$); Means followed by different letters, for different plant proportions, differ by Duncan's test ($p \leq 0.05$); nsThe mixing proportions of plants do not differ by Duncan's test ($p \leq 0.05$). A = Photosynthetic rate ($\mu mol \cdot m^{-2} \cdot s^{-1}$); Gs = Stomatal conductance of water vapor ($mol \cdot m^{-1} \cdot s^{-1}$); Ci = Internal CO_2 concentration ($\mu mol \cdot mol^{-1}$); E = Transpiration rate ($mol\ H_2O \cdot m^{-2} \cdot s^{-1}$); EC = Efficiency of carboxylation ($mol\ CO_2 \cdot m^{-2} \cdot s^{-1}$); WUE = Water use efficiency ($mol\ CO_2 \cdot mol\ H_2O^{-1}$).

than BMX Apolo RR cultivar as shown by the A index (Table 4). This is based on the assumption that species Y is more competitive than X when RC < 1; $K_x < K_y$ and C < 0 (Hoffman and Buhler 2002). Another assumption to demonstrate competitive advantage is that at least 2 indices must have statistical significance (Bianchi et al. 2006). According to this, barnyardgrass was more competitive than BMX Apolo RR only regarding plant height.

Plant height is an important trait for the growth and development of species in the environment because it is directly related to the light capture efficiency (Fleck et al. 2008). Thus, it is possible that the experimental period (44 DAE) was relatively short to show differences in other variables such as the expansion of leaf area and SDM. However, Saccol and Estefanel (1995) reported that the competition period of barnyardgrass, from which soybean height and leaf area is significantly reduced, is about 20 to 22 days, respectively.

The competitiveness indices showed greater values for barnyardgrass compared to BMX Apolo RR concerning plant height, probably due to the small height of the cultivar, which

Table 4. Competitiveness indices between soybean (BMX Apolo RR and BMX Potência RR cultivars) and barnyardgrass (*Echinochloa crus-galli*) for the variables relative competitiveness, coefficients of relative crowding and of competitiveness obtained in experiments conducted in substitutive series.

Variables	RC	K_x	K_y	C
	Plant height			
BMX Apolo RR × Barnyardgrass	0.92 (± 0.02)*	0.88 (± 0.02)*	1.05 (± 0.05)	−0.04 (± 0.01)*
BMX Potência RR × Barnyardgrass	0.88 (± 0.08)	0.76 (± 0.08)*	0.99 (± 0.06)	−0.06 (± 0.04)
	Leaf area			
BMX Apolo RR × Barnyardgrass	0.94 (± 0.10)	0.85 (± 0.05)	1.06 (± 0.18)	−0.04 (± 0.05)
BMX Potência RR × Barnyardgrass	0.98 (± 0.24)	1.06 (± 0.30)	1.20 (± 0.24)	−0.05 (± 0.12)
	Shoot dry matter			
BMX Apolo RR × Barnyardgrass	1.04 (± 0.10)	1.06 (± 0.14)	1.04 (± 0.19)	0.01 (± 0.04)
BMX Potência RR × Barnyardgrass	0.97 (± 0.27)	1.31 (± 0.47)	1.51 (± 0.43)	−0.06 (± 0.15)

*Significant difference by *t*-test at $p \leq 0.05$; Values between parentheses are the standard errors. K_x and K_y = Relative crowding coefficients for soybean and barnyardgrass, respectively. RC = Relative competitiveness; K = Relative crowding coefficient; C = competitiveness coefficient.

facilitated weed growth and greater SDM accumulation. On the other hand, the characteristics of BMX Potência RR contributed to higher relative growth of barnyardgrass, expressed mainly by increasing photosynthetic activity and carbon sequestration efficiency, which directly contributed to increase plant height, leaf area and dry matter accumulation. The BMX Potência RR cultivar has average development cycle (6.7), and, consequently, emergence and growth rates are lower compared to the super-early-cycle cultivars such as BMX Apolo RR (5.8). These features facilitate the growth of weeds, especially barnyardgrass, which has high growth rate at the early developmental stages (Kissmann 2007).

A study diagnosed that plant height soybean plants with late cycle have greater competitive ability than early-maturing, shorter cultivars (Lamego et al. 2004). However, environmental conditions (biotic and abiotic factors) can interfere with the expression of competitive ability in different ways in each cultivar. Therefore, characteristics such as development cycle and plant height may not have much effect on the competitive ability of plants in experiments conducted under controlled conditions, as in a greenhouse (Agostinetto et al. 2008), which is the case in this study.

Based on morphological and physiological variables, it is emphasized that the intraspecific competition was more harmful than interspecific competition for barnyardgrass. This can be explained mainly by the high demand for nitrogen of barnyardgrass (Kissmann 2007), so that, in the weed monoculture, intraspecific competition for nitrogen is greater, but without discarding the competition for other environmental resources. In contrast, the highest growth rate of the weed, both in plant height and leaf area production, makes it capture the light more efficiently and, consequently, at more advanced growth stages, it may shade the crop and reduce its growth (Place et al. 2011). From this study, it is not possible to conclude that barnyardgrass is more competitive than soybean crop because the main negative effect of the competitor on the cultivars was to decrease plant height, especially for BMX Apolo RR, while all other morphophysiological parameters remained virtually unchanged.

CONCLUSION

The BMX Apolo RR and BMX Potência RR cultivars show equivalent relative competitiveness with barnyardgrass, which exhibits higher competitiveness to the BMX Apolo RR soybean cultivar, regarding to plant height. Intraspecific competition is more important for barnyardgrass since it affected negatively morphophysiological characteristics of the species.

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