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Article

Interference of Broadleaf Buttonweed and White-Eye in Soybean

Interferência de Erva Quente e Poaia-Branca na Cultura da Soja

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ABSTRACT - Weed species is one of the factors contributing to grain yield losses due to crop-weed competition. Two of the most common weeds of soybean fields in Brazil are from the Rubiaceae family: *Borreria latifolia* and *Richardia brasiliensis*. This study aimed to evaluate the effects of *B. latifolia* and *R. brasiliensis* on plant development, yield components, and soybean productivity. Two assays were conducted in a randomized block design with four replications, using a two-level factorial design, in which the first factor consisted of the species *B. latifolia* and *R. brasiliensis* and the second factor consisted of the densities 0, 2, 4, 6, 8, 10, and 12 plants m^{-2}. Plant height, leaf area and total chlorophyll in the V_6 and R_5 stages, number of pods per plant, number of grains per pod, 1000-grain weight, and grain yield loss were evaluated in both cultivars. Grain yield of both soybean cultivars was negatively affected by the interference with *B. latifolia* and *R. brasiliensis*. The species *B. latifolia* was more competitive with soybean when compared to *R. brasiliensis*, causing higher reductions for all variables. Each *B. latifolia* plant per square meter is able to reduce the yield of soybean by 3 a 4.4%, while each *R.brasiliensis* plant reduces yield by 2 a 2.6%. For both species, the reduction in soybean yield due to competition was caused by a decrease in the number of pods per plant, number of grains per pod, and 1000-grain weight.

Keywords: interspecific competition, *Glycine max*, *Richardia brasiliensis*, *Borreria latifolia*, density.

*RESUMO - Vários fatores determinam as perdas de rendimento de grãos devido à competição com plantas daninhas, entre eles as espécies infestantes. Entre as espécies daninhas de ocorrência comum em lavouras de soja das diferentes regiões do Brasil, destacam-se as da família Rubiaceae, representadas principalmente por **Borreria latifolia** e **Richardia brasiliensis**. O objetivo do presente estudo foi avaliar os efeitos da interferência das espécies **B. latifolia** e **R. brasiliensis** sobre o desenvolvimento das plantas e os componentes do rendimento e produtividade da soja. Dois estudos foram conduzidos em delineamento de blocos ao acaso com quatro repetições. Os tratamentos foram resultantes de um bifatorial, em que o primeiro fator foi constituído pelas espécies **B. latifolia** e **R. brasiliensis**, e o segundo, pelas densidades de 0, 2, 4, 6, 8, 10 e 12 plantas m^{-2}. Em ambos os cultivares de soja, foram avaliados altura de planta, área foliar e clorofila total nos estádios V_6 e R_5 da cultura, número de vagens por planta, número de grãos por vagem, massa de mil grãos e perda de rendimento de grãos. O rendimento de grãos de ambos os cultivares de soja foi negativamente afetado pela interferência com as espécies **B. latifolia** e **R. brasiliensis**. **B. latifolia** foi mais competitiva com a cultura da soja do que **R. brasiliensis**, provocando maiores reduções em todas as variáveis analisadas. Cada planta de **B. latifolia** por m^2 é capaz de reduzir o rendimento de*

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grãos de soja em 3 a 4,4%, enquanto cada planta de ***R. brasiliensis*** *reduz o rendimento em 2 a 2,6%. Para ambas as espécies rubiáceas, a redução do rendimento da soja decorrente da competição foi motivada pelo decréscimo no número de vagens por planta, número de grãos por vagem e massa de mil grãos.*

Palavras-chave: competição interespecífica, *Glycine max*, *Richardia brasiliensis*, *Borreria latifolia*, densidade.

INTRODUCTION

The presence of weeds in farming areas has been pointed out as one of the most important factors since it contributes significantly to reduce crop productivity, thus presenting a great threat to sustainable food production. Its importance is so great that about half the pesticides marketed in the world are represented by herbicides (Theisen and Ruedell, 2004).

Soybean (*Glycine max* (L.) Merrill) has become one of the most important crops in the worldwide economy, providing about half of the world's demand for oils and proteins from plants (Dall'Agnol, 2008). At the global level, soybean grain yield losses due to the presence of weeds in the absence of control (potential) measures are estimated at 37% and losses due to the adoption of control measures are estimated at 7.5%, which means a high degree of effectiveness when compared to measures to control pests and pathogens (Oerke, 2006). In some regions, losses in soybean cultivation caused by weed interference may reach 80% when not properly managed (Gazziero et al., 2004).

The effectiveness of the chemical control of weeds is currently at risk for many reasons. Among them is the process of selection of more tolerant and resistant plants resulting from the high selection pressure exerted by herbicides, the reduced number of new active ingredients of herbicides released in recent years, and the low diversification of weed management methods used by farmers (Christoffoleti and López-Ovejero, 2003).

In the southern region of Brazil, the most common Rubiaceae weeds in soybean areas are *Borreria latifolia* (broadleaf buttonweed) and *Richardia brasiliensis* (white-eye), being considered tolerant to the herbicide glyphosate. Broadleaf buttonweed is an annual herbaceous species with an erect or prostrated stem with branches, which develops throughout the country, vegetating in areas occupied by annual and/or perennial crops (Moreira and Bragança, 2010). White-eye is an annual herbaceous species that develops spontaneously throughout Brazil (Moreira and Bragança, 2010). It has a high vegetative vigor, completely covering the soil like a carpet, causing a higher interference at the beginning of the cycle of summer crops (Lorenzi, 2008).

The intensity of interference between weeds and cultivated plants can be determined by the evaluation of the decreased crop production when under competition. Among the several factors that influence the decrease of production, the time and duration of coexistence and characteristics associated with cultivated and weed species stand out (Pitelli, 1985). Through weed coexistence with crops, critical, competitive, economic threshold levels can be determined (Portugal and Vidal, 2010). These thresholds are considered potentially very useful in integrated weed management (Portugal and Vidal, 2009). The integrated management contributes to the maintenance of weed populations at lower levels for longer periods, reducing the undesirable impacts of herbicides and preserving chemical control tools (Fontes et al., 2003).

The incidence of broadleaf buttonweed and white-eye in soybean crops in southern Brazil has increased substantially in recent years. Therefore, there is a need for research to determine the damage caused by these species. The aim of this study was to evaluate the effects of *B. latifolia* and *R. brasiliensis* on plant development, yield components, and soybean productivity.

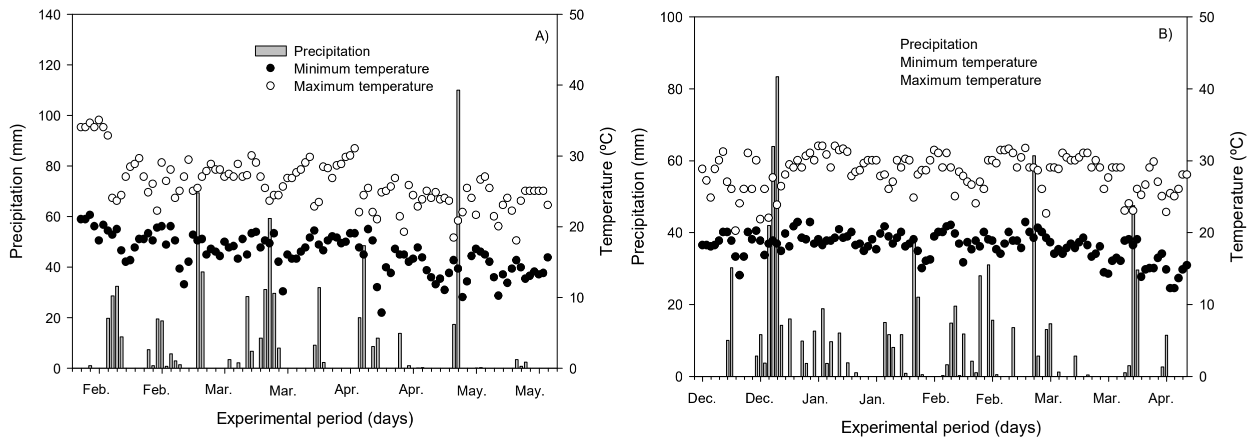
MATERIAL AND METHODS

Two experiments were carried out under field conditions at the experimental area of the Universidade Tecnológica Federal do Paraná (UTFPR), campus of Pato Branco, Paraná, in a soil classified as a dystrophic Red Latosol (Embrapa, 2006), whose characteristics are shown in Table 1. The climate of the region is classified as subtropical humid (Cfa). Climate conditions during the experimental period are shown in Figure 1.

Table 1 **-** Particle size distribution and chemical attributes of the dystroferric Red Latosol

Particle size distribution		Chemical attributes	
Component	%	Component	Value/ Unit
Clay	55.7	MO[(1)]	49.50 g dm^{-3}
Sand	3.0	P_2O_5[(2)]	14.32 mg dm^{-3}
Silt	41.3	K_2O[(3)]	0.70 $cmol_c$ dm^{-3}
		CTC[(4)]	17.63 $cmol_c$ dm^{-3}
		pH[(5)]	5.6
		H+Al[(6)]	5.35 $cmol_c$ dm^{-3}

[(1)] Organic matter; [(2)] Phosphorus; [(3)] Potassium; [(4)] Cation exchange capacity; [(5)] Soil pH; [(6)] Exchangeable acidity.



Source: IAPAR (Instituto Agronômico do Paraná). UTFPR, Pato Branco, PR, 2016.

Figure 1 **-** Precipitation and minimum and maximum temperature during the periods in which the experiments were conducted in the 2013/2014 off-season (A) and 2014/2015 season (B).

The experiments followed very similar procedures and, therefore, are described together. They were carried out in the 2013/2014 off-season (soybean cultivar V-TOP RR) and 2014/2015 season (soybean cultivar BMX Ativa RR) in a randomized block design with four replications. Treatments were the result of a 2 × 7 factorial, with the first factor consisting of two weeds (*B. latifolia* and *R. brasiliensis*) and the second factor consisting of densities (0, 2, 4, 6, 8, 10, and 12 plants m^{-2}).

The soybean cultivars V-TOP RR (February 6, 2014) and BMX Ativa RR (December 15, 2014) were sown at a density of 350,000 plants ha^{-1} in a no-tillage system simultaneously with the sowing of *B. latifolia* and *R. brasiliensis*. Seeds of both soybean cultivars were treated with pyraclostrobin + methyl thiophanate + fipronil (50 g a.i. ha^{-1}). Weed seeds were purchased from Agrocosmos Agrícola (São Paulo, Brazil).

Seeds of *B. latifolia* were submitted to dormancy-breaking by dry heat at 60 ºC in a drying oven with air circulation for 30 min and then immersion in 2% potassium nitrate (KNO_3) for three hours. Seeds of *R. brasiliensis* did not need to overcome dormancy. Seeds were germinated in gerbox boxes with a double germinating paper layer, moistened with distilled water in a proportion of 2.5 times its dry weight. Seedlings were transplanted in the soybean-sowing row at 4 days after sowing, with the number of plants corresponding to each density.

Plots consisted of four sowing rows spaced at 0.45 m from each other and 1.5 m in length (2.7 m^2). An area of 1.0 m^2 was delimited to collect plants for determining yield components and grain yield.

During plant development, a manual weeding was performed to remove other weeds. Four applications of the fungicides trifloxystrobin + prothioconazole (400 mL ha^{-1}) and azoxystrobin + cyproconazole (300 mL ha^{-1}) were carried out to control leaf diseases and an application of the insecticide thiamethoxam (180 mL ha^{-1}) and acephate (750 g ha^{-1}) was carried out for pest control.

Plant height, leaf area, and total chlorophyll were evaluated at the V_6 and R_5 stages of the crop. Moreover, plant height, first pod height, and the number of pods per plant were evaluated at the physiological maturation. These variables were determined in ten plants chosen at random in the useful area of plots. Leaf area was determined using a LI-3100C integrator. Total chlorophyll was measured with a ClorofiLOG® CFL 1030 chlorophyll meter (Falker..., 2008).

Grain yield was determined at harvest maturation by collecting and threshing plants from 1.0 m^2 of the useful area of plots. Grain moisture was corrected to 13%. One thousand-grain weight was obtained by counting and weighing 400 grains from yield determination. The yield obtained at each plot was converted to yield loss in percentage in relation to the control without the presence of *B. latifolia* and *R. brasiliensis*.

The collected data were submitted to analysis of variance by the F-test (p=0.05) using the software Winstat (Machado and Conceição, 2005). The relationship between quantitative factor levels and response variables, except for yield losses, was adjusted by a non-linear regression using the software Sigmaplot 10.0.

The percentage of grain yield loss and its relation to the density of plants of *B. latifolia* and *R. brasiliensis* were adjusted by the linear model proposed by Vidal and Portugal (2010):

$$QR = b \times d$$

where b indicates the impact that each weed under very low densities has on the reduction in yield and d is the independent variable (weed density). Calculations were carried out using the software Excel.

RESULTS AND DISCUSSION

For all response variables, the analysis of variance showed significance for the species × density two-factorial interaction, except for the number of grains per pod of the cultivar V-TOP RR and total chlorophyll of the cultivar BMX Ativa RR, in which there was significance only for the factor density. The three- and four-parameter logistic models had a good fit between densities of *B. latifolia* and *R. brasiliensis* and response variables, with coefficients of determination varying from 0.85 to 0.99 (Tables 2 and 3).

2013/2014 off-season

The variables plant height and total chlorophyll of soybean plants in the V_6 stage were not affected by the variation in plant density of *R. brasiliensis* (Figure 2A, C). A different effect was observed in *B. latifolia*, whose increase in density resulted in a decrease in plant height and total chlorophyll in soybean leaves, whose maximum percentages were 13.1 and 10.8%, respectively. Soybean plant height at R_5 (Figure 2B) was reduced with an increasing infestation of both weeds, with few differences in impact between them. However, as in the V_6 stage, the height reduction of the cultivated plant was of low magnitude.

The increased density of both weed species caused a reduction in the leaf area of soybean plants at V_6, but the magnitude of the effect was higher in *B. latifolia* than in *R. brasiliensis* (Figure 2D). At the maximum density, the reduction of leaf area caused by the former species was 21.7% and that caused by the latter one was 6.7%.

Plant height and dry matter at physiological maturation decreased in response to an increase in the densities of *B. latifolia* and *R. brasiliensis*. However, *B. latifolia* was more competitive, causing a higher reduction (Figure 3A, B). The increase in weed density resulted in an increase in the first pod height of soybean (Figure 3C). For this variable, no differences were observed in the effect produced between the species up to a density of 4 plants m^{-2}, from which there was a more expressive increase in treatments with the interference of *B. latifolia*. The increase in height relative to the control reached a maximum value of 27% (Figure 3C).

Table 2 **-** Equations parameters and coefficient of determination (R^2) for the variables in response to the interference with the species *B. latifolia* and *R. brasiliensis* in the soybean cultivar V-TOP RR

Stage	Variable	Species	Parameter				
			a	b	x0	y0	R^2
V_6	Height	*B. latifolia*	58.65	0.34	2449.32	-	0.98
		R. brasiliensis ns	-	-	-	-	-
	Total chlorophyll	*B. latifolia*(1)	45.49	0.29	23.91	-	0.92
		*R. brasiliensis*ns	-	-	-	-	-
	Leaf area	*B. latifolia*(1)	429.72	0.92	44.19	-	0.98
		R. brasiliensis(1)	426.24	0.70	504.38	-	0.99
R_5	Height	*B. latifolia*(1)	76.97	0.82	111.80	-	0.97
		R. brasiliensis(1)	75.21	0.73	349.85	-	0.99
Physiological maturation	Dry matter	*B. latifolia*(1)	653.55	0.69	124.53	-	0.98
		R. brasiliensis(1)	654.11	1.20	85.23	-	0.96
	Height	*B. latifolia*(1)	86.95	0.79	143.71	-	0.92
		R. brasiliensis(1)	84.51	0.64	773.01	-	0.95
	No. pods/plant	*B. latifolia*(1)	24.24	1.02	18.13	-	0.94
		R. brasiliensis(1)	24.02	1.03	32.19	-	0.91
	No. grains/pod	*B. latifolia*(1)	2.47	3.04	13.76	-	0.98
		R. brasiliensis(1)	2.54	2.69	17.79	-	0.97
	First pod height	*B. latifolia*(1)	3.36	1.84	7.91	-	0.99
		R. brasiliensis(2)	-1.26	-1.45	6.73	12.40	0.98
	1000-grain weight	*B. latifolia*(1)	149.43	0.82	29.42	-	0.99
		R. brasiliensis(1)	148.82	1.01	30.13	-	0.99
	Yield loss	*B. latifolia*(3)	-	2.99	-	-	0.93
		R. brasiliensis(3)	-	2.01	-	-	0.94

(1) Three-parameter logistic. (2) Four-parameter logistic. For logistic equations: a = mean response of the control; b = slope of the curve; x0 (D_{50}) = density representing the 50% reduction of the analyzed variable; y0 = mean response at high densities. (3) Equation of the linear segment with densities close to zero. ns = not significant.

As for biometric variables, *B. latifolia* had a higher impact on the components of soybean yield when compared to *R. brasiliensis*. Both weed species produced led to significant losses in the number of pods per plant, number of grains per pod, and one thousand-grain weight (Figure 4A, B, C), but the highest losses were caused by *B. latifolia*, totaling 35, 41, and 31% of maximum loss for these three variables when compared to *R. brasiliensis*, which showed losses of 22, 25, and 26%, respectively.

Soybean yield loss increased as a result of increasing weed density, reaching maximum values of 24 and 19%, respectively, for *B. latifolia* and *R. brasiliensis* (Figure 4D). The adjustment of a rectangular hyperbola equation for this variable was not satisfactory and thus yield losses was estimated using the slope of the first linear segment that passes through the origin (Vidal and Portugal, 2010) (Figure 4D and Table 4).

The critical threshold levels (Vidal and Portugal, 2010) were 2.99 and 2 (Table 4), i.e. in the 2013/2014 off-season, each plant of *B. latifolia* and *R. brasiliensis* per square meter with a density close to zero that emerged close to soybean plants was able to reduce their productivity by approximately 3 and 2%, respectively.

2014/2015 season

The variables plant height, total chlorophyll, and leaf area (Figure 5A, B, C) at the V6 stage of the cultivar BMX Ativa RR were negatively affected by the variation in the plant density of *B. latifolia* and *R. brasiliensis*. For plant height (Figure 5A), a significant difference was observed between both species from a density of 6 plants m^{-2}, reaching a maximum reduction of 15 and 10% for *B. latifolia* and *R. brasiliensis*, respectively.

The species *B. latifolia* had a higher reduction in the total chlorophyll content in soybean leaves of the cultivar BMX Ativa RR, but differences among species were of very low magnitude

Table 3 **-** Equations parameters and coefficient of determination (R^2) for the variables in response to the interference with the species *B. latifolia* and *R. brasiliensis* in the soybean cultivar BMX Ativa RR

Stage	Variable	Species	a	b	x0	y0	R²
V_6	Height	*B. latifolia*(1)	58.74	1.05	60.41	-	0.97
		R. brasiliensis(1)	58.28	1.11	77.66	-	0.97
	Total chlorophyll	*B. latifolia*(1)	32.33	0.76	130.11	-	0.91
		R. brasiliensis(1)	32.21	0.64	281.57	-	0.85
	Leaf area	*B. latifolia*(1)	937.72	1.36	134.43	-	0.99
		R. brasiliensis(1)	937.67	1.43	206.48	-	0.97
R_5	Height	*B. latifolia*(1)	74.69	1.94	24.05	-	0.99
		R. brasiliensis(1)	73.99	2.35	37.79	-	0.97
	Total chlorophyll	*B. latifolia*(1)	46.99	1.07	50.98	-	0.97
		*R. brasiliensis*ns	-	-	-	-	-
	Leaf area	*B. latifolia*(1)	2091.09	1.79	20.26	-	0.94
		R. brasiliensis(1)	2028.94	1.43	53.51	-	0.99
Physiological maturation	Dry matter	*B. latifolia*(1)	540.56	0.99	66.67	-	0.99
		R. brasiliensis(1)	548.42	1.63	57.83	-	0.99
	Height	*B. latifolia*(1)	81.88	0.89	72.48	-	0.95
		R. brasiliensis(1)	82.48	2.39	36.84	-	0.98
	No. pods/plant	*B. latifolia*(1)	34.58	1.09	26.44	-	0.98
		R. brasiliensis(1)	34.65	0.95	89.59	-	0.95
	No. grains/pod	*B. latifolia*(1)	2.85	1.29	15.41	-	0.98
		R. brasiliensis(1)	2.67	0.75	52.44	-	0.99
	First pod height	*B. latifolia*(2)	3.60	4.79	7.68	10.98	0.98
		R. brasiliensis(2)	-0.65	-1.52	7.78	12.21	0.99
	1000-grain weight	*B. latifolia*(1)	240.84	0.73	83.93	-	0.95
		R. brasiliensis(1)	239.41	0.90	94.20	-	0.96
	Yield loss	*B. latifolia*(3)	-	4.41	-	-	0.89
		R. brasiliensis(3)	-	2.63	-	-	0.90

(1) Three-parameter logistic. (2) Four-parameter logistic. For logistic equations: a = mean response of the control; b = slope of the curve; x0 (D_{50}) = density representing the 50% reduction of the analyzed variable; y0 = mean response at high densities. (3) Equation of the linear segment with densities close to zero. ns = not significant.

(Figure 5B). At the studied densities, the maximum reductions in leaf area due to the interference of *B. latifolia* and *R. brasiliensis* were only 4 and 2%, respectively (Figure 5C).

The relationship between heights of soybean plants at the R_5 stage as a function of the increment of plant density of both weed species was adjusted to the three-parameter logistic model (Figure 6A and Table 3). The interference with *B. latifolia* caused more significant reductions in plant height at this stage than in V_6, reaching 20% at the highest evaluated density, while for *R. brasiliensis* the reduction was 7%.

The effects on total chlorophyll content at the R_5 stage were contrasting with those verified at the V_6 development stage (Figure 6B). At R_5, the population growth of *R. brasiliensis* plants did not change the total chlorophyll content of soybean leaves, but this variable presented an inverse response to the density of *B. latifolia* plants. Both weed species caused significant reductions in leaf area at the R_5 stage, with a differential effect between species from 8 plants m^{-2} (Figure 6C), totaling maximum losses of 27 and 11% for *B. latifolia* and *R. brasiliensis*, respectively.

The presence of both weed species during the cycle negatively influenced soybean plant height at the physiological maturation. The interference of *B. latifolia* exceeded that caused by *R. brasiliensis*, reaching a reduction of 15% in the former species and 6% in the latter species (Figure 7A) at the highest density. The higher interference of *B. latifolia* also resulted in higher losses of soybean dry matter in relation to *R. brasiliensis*, as observed at all studied densities (Figure 7B). First pod height increased as weed species density increased, but without differences between *B. latifolia* and *R. brasiliensis* up to 4 plants m^{-2} (Figure 7C). From this density, the interference with *B. latifolia* resulted in a much more expressive increase in the first pod height, reaching maximum differences of 17% in relation to the control and a 5% increase caused by *R. brasiliensis*.

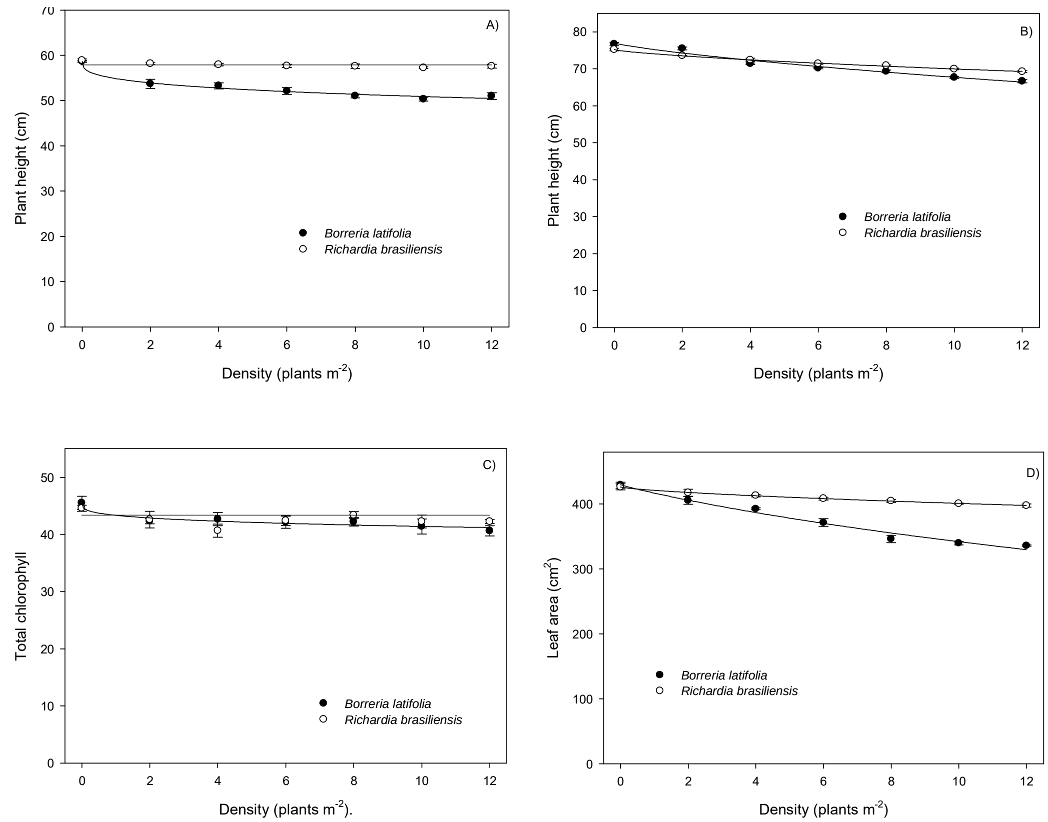


Figure 2 **-** Plant height at the physiological stages V_6 (A) and R_5 (B) and total chlorophyll (C) and leaf area (D) at the stage V_6 of the soybean cultivar V-TOP RR in response to the interference of different densities of the species *B. latifolia* and *R. brasiliensis*.

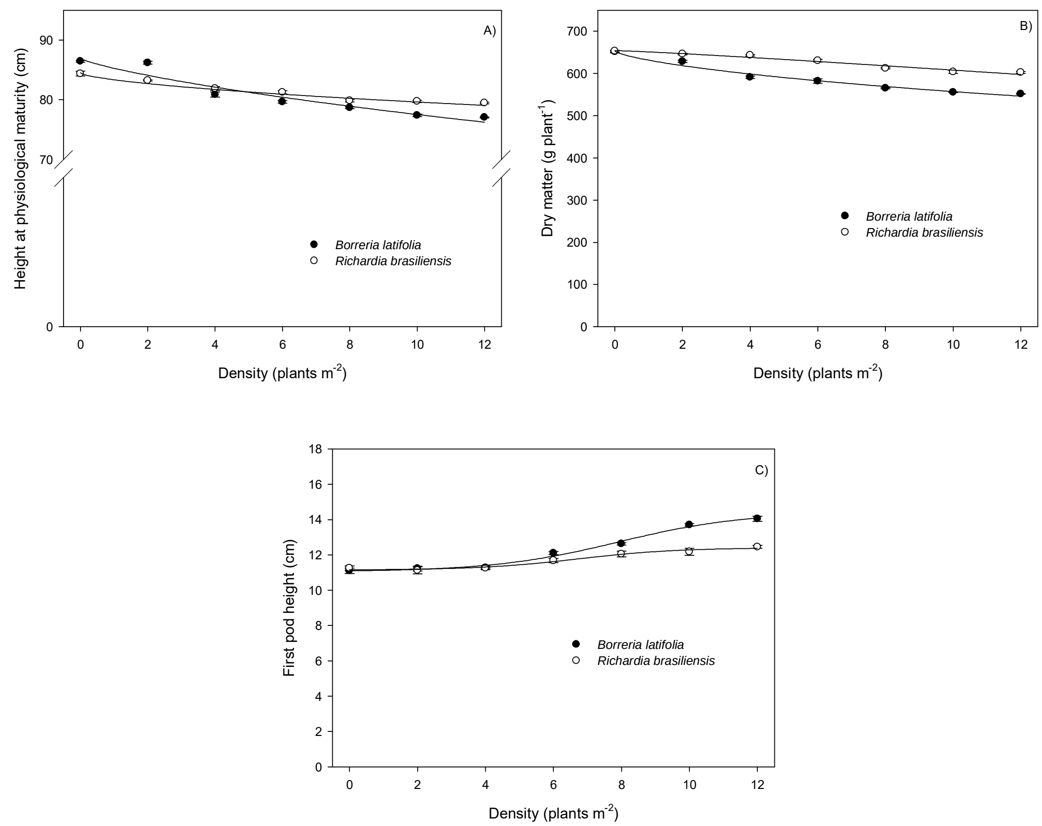


Figure 3 **-** Plant height at physiological maturity (A), shoot dry matter (B), and first pod height (C) at physiological maturation of the soybean cultivar V-TOP RR in response to the interference of different densities of the species *B. latifolia* and *R. brasiliensis*.

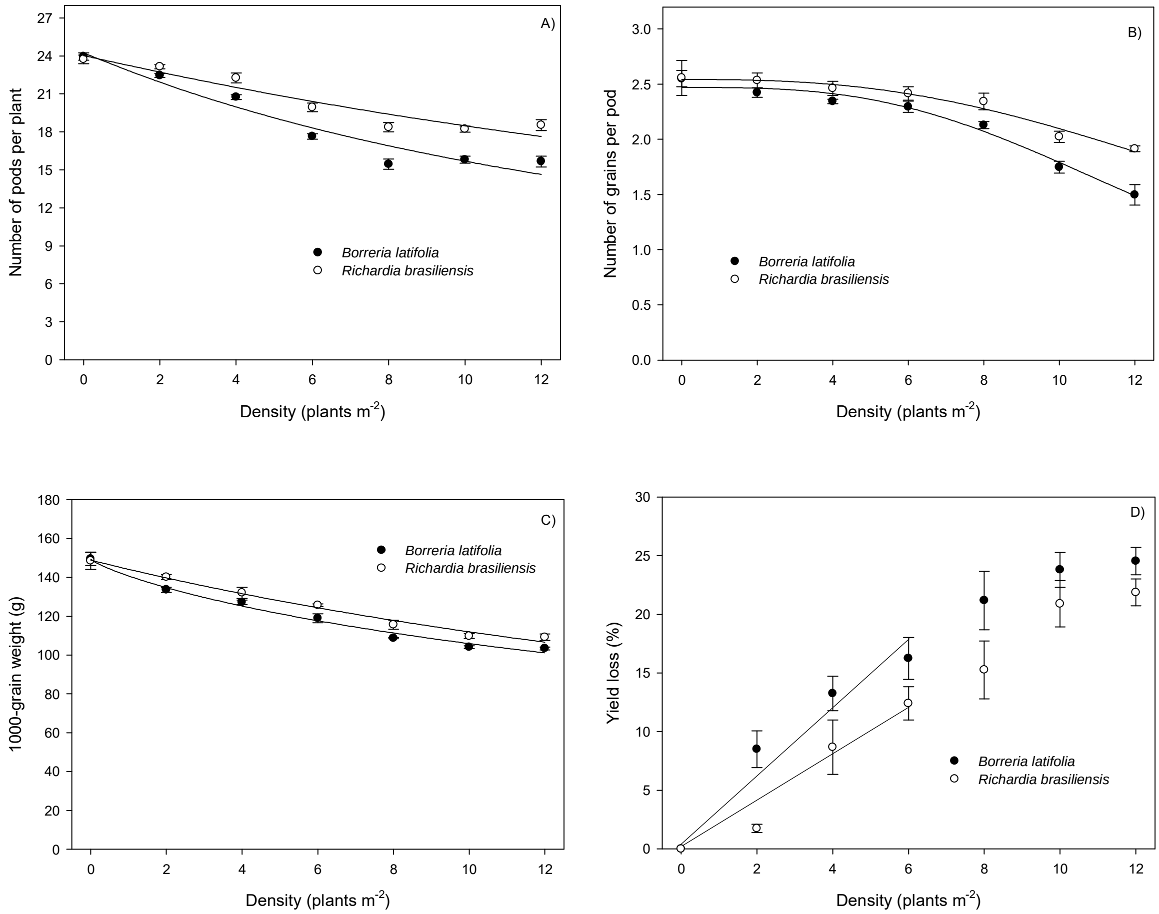


Figure 4 - Number of pods per plant (A), number of grains per pod (B), one thousand-grain weight (C), and yield loss (D) of the soybean cultivar V-TOP RR in response to the interference of different densities of the species *B. latifolia* and *R. brasiliensis*.

Table 4 - Equations parameters to determine the relationship between the species *B. latifolia* and *R. brasiliensis* and the percentage of yield loss of the soybean cultivar V-TOP RR

Season	Variable	Species	Parameter*	
			B	SE
2013/2014	Yield loss (%)	*B. latifolia*	2.99	1.65
		R. brasiliensis	2.00	1.26
2014/2015	Yield loss (%)	*B. latifolia*	4.41	2.92
		R. brasiliensis	2.63	0.59

* Linear equation *QR* = b × based on normalized data for percentage of loss in relation to non-infested control, where b indicates the impact of each weed on yield reduction only at low infestations (%) and d is the independent variable (weed density). SE = standard error.

weed species resulted in a negative effect on all response variables evaluated for both soybean cultivars used in the studies, except for the variable first pod height, which showed an increase as the densities of *B. latifolia* and *R. brasiliensis* increased.

As weed species density increased, the dispute over resources essential to the development of the cultivated species increased. Among the essential resources are solar radiation, water, and nutrients, as well as CO_2 (Casaroli et al., 2007; Pimentel, 2011). The morphological development of plants depends on the intensity and spectral quality of radiation; when adequate, they ensure higher efficiency of the photosynthetic machinery in the capture and use of radiant energy (Martins et al., 2009). Solar radiation is one of the essential factors in the photosynthesis process, i.e. only through solar radiation light energy is converted into chemistry (Vieira et al., 2010). Although the species *B. latifolia* may present both erect and prostrate stem (Moreira and Bragança, 2010), it presented an erect behavior and higher height when compared to plants of

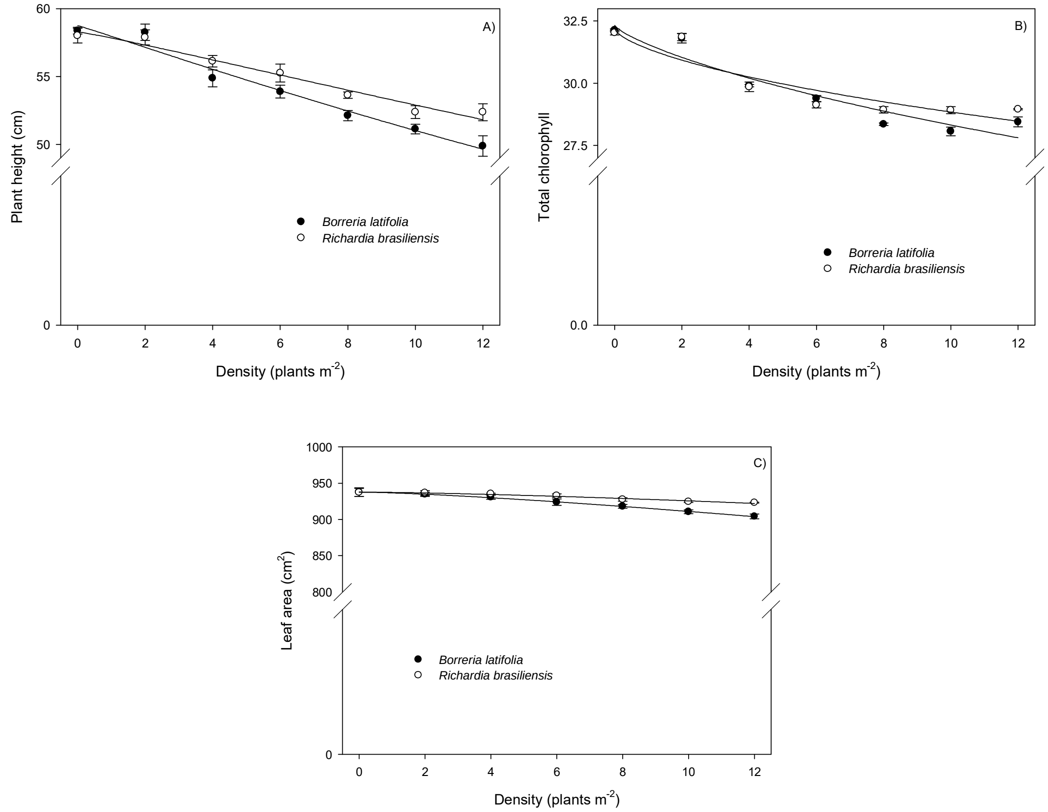


Figure 5 - Plant height (A), total chlorophyll (B), and leaf area (C) at the physiological stage V_6 of the soybean cultivar BMX Ativa RR in response to the interference of different densities of the species *B. latifolia* and *R. brasiliensis*.

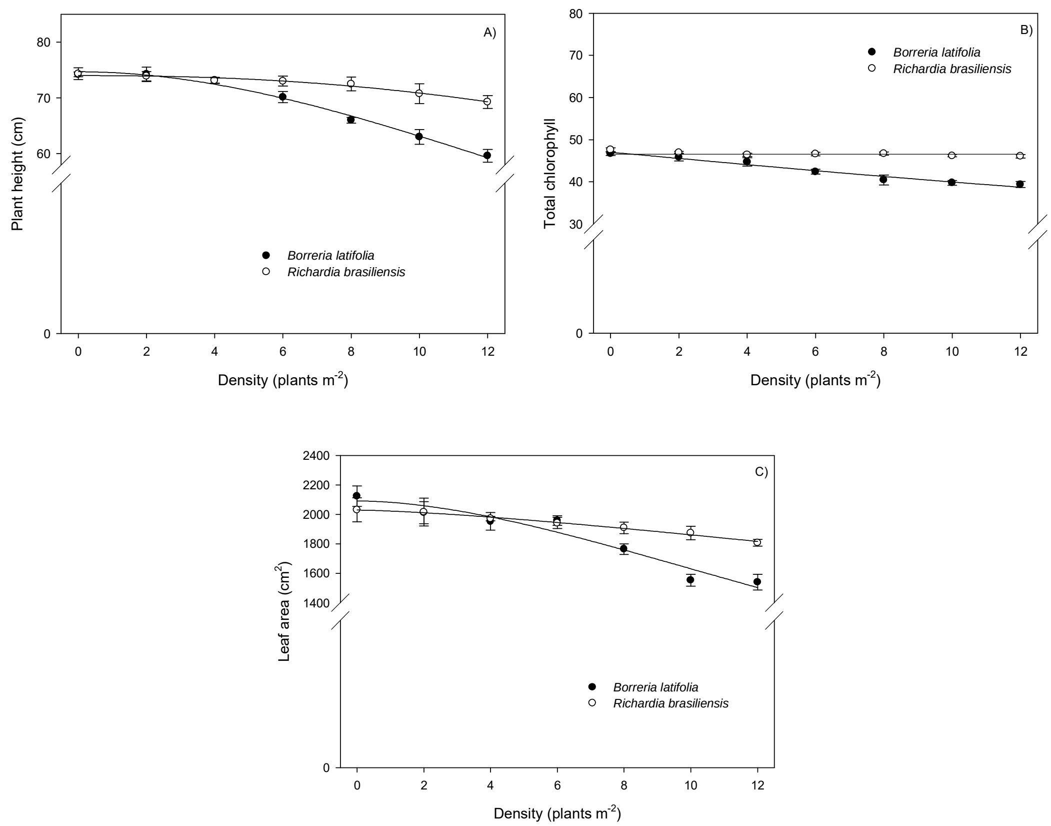


Figure 6 - Plant height (A), total chlorophyll (B), and leaf area (C) at the physiological stage R_5 of the soybean cultivar BMX Ativa RR in response to the interference of different densities of the species *B. latifolia* and *R. brasiliensis*.

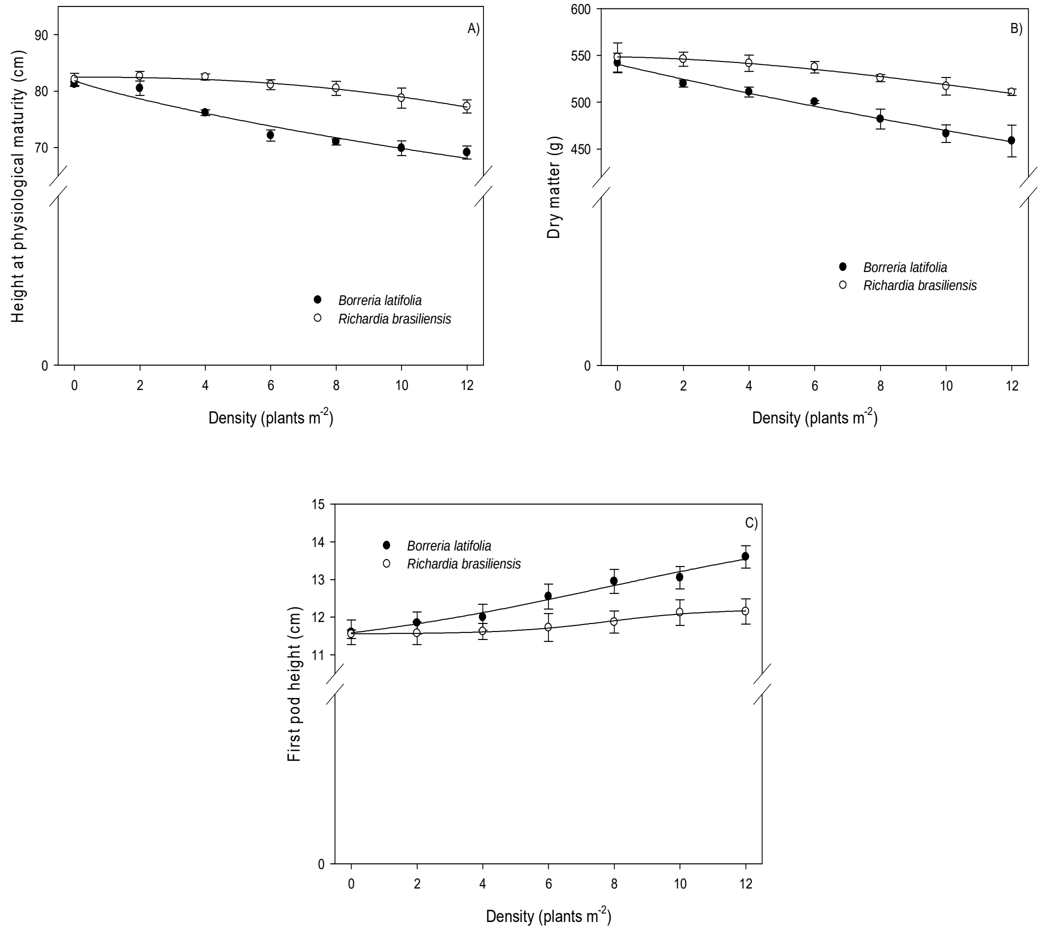


Figure 7 **-** Plant height at physiological maturity (A), shoot dry matter (B), and first pod height (C) at physiological maturity of the soybean cultivar BMX Ativa RR in response to the interference of different densities of the species *B. latifolia* and *R. brasiliensis*.

The variables number of pods per plant, number of grains per pod, one thousand-grain weight, and soybean yield loss (Figure 8A, B, C, D) were negatively affected by the interference of both weed species. However, the damage caused by interference with *B. latifolia* was higher.

Differential effects of both weed species on the number of pods per plant occurred from the density of 4 plants m^{-2}, reaching a maximum reduction of 11 and 7% for *B. latifolia* and *R. brasiliensis*, respectively (Figure 8A). An increase in weed density interfering with crop increased the number of pods, with a maximum value of 27 and 12% for *B. latifolia* and *R. brasiliensis*, respectively. The number of grains per pod was influenced by a density of 6 plants m^{-2}, reaching maximum reductions of 26 and 16% for *B. latifolia* and *R. brasiliensis*, respectively (Figure 8B). The species *B. latifolia* was also responsible for the highest reductions in the one thousand-grain weight, leading a maximum reduction of 17% for this species and 12% for *R. brasiliensis* (Figure 8C).

The species *B. latifolia* showed a higher interference with the soybean cultivar BMX Ativa RR, resulting in a maximum grain yield loss of 39%, while *R. brasiliensis* determined a maximum loss of 30% (Figure 8D).

The critical threshold level (Vidal and Portugal, 2010) showed that each plant per square meter of *B. latifolia* was responsible for a 4.4% grain yield loss, a value higher than the percentage of grain yield loss caused by *R. brasiliensis*, which was 2.6% (Table 4).

Both seasons presented precipitation conditions and maximum and minimum temperatures favorable to the growth and development of both crop and weeds (Figure 1).

Among the evaluated factors (weed species and density), the impact generated by density on response variables of soybean was higher. The results show that the increased population of

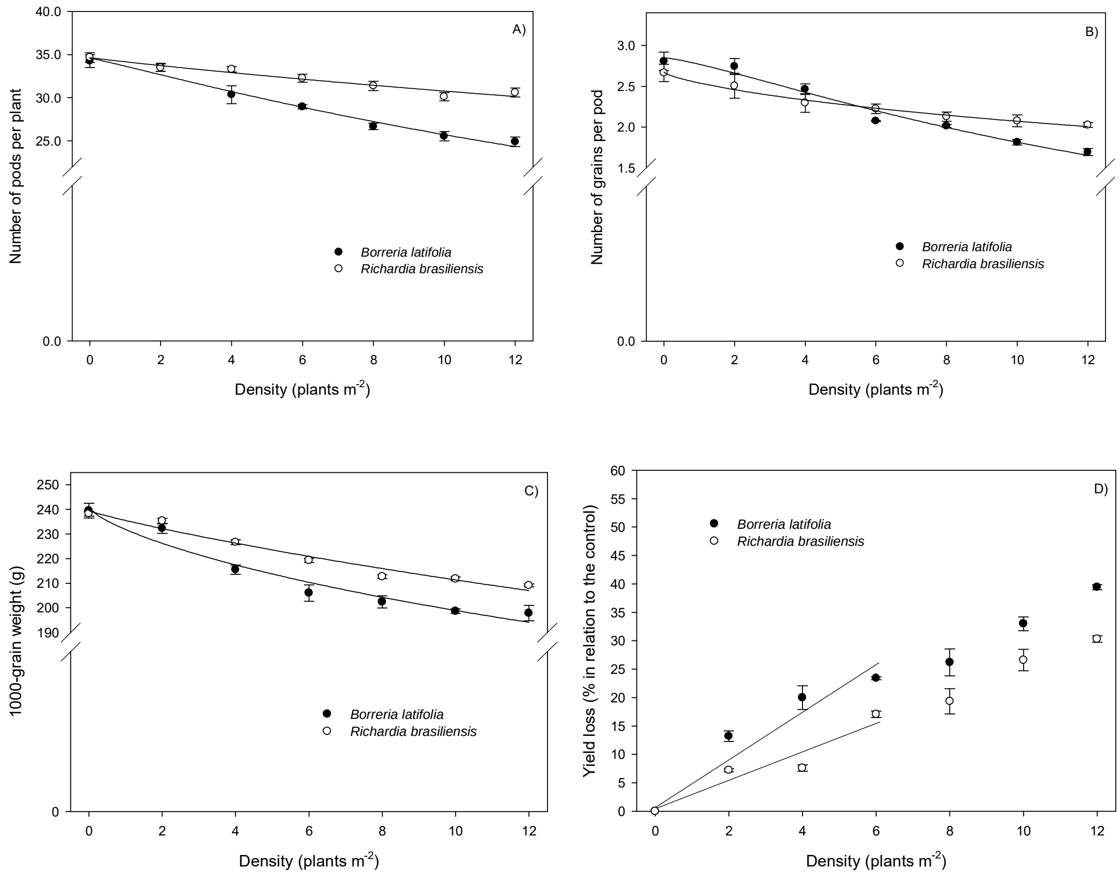


Figure 8 - Number of pods per plant (A), number of grains per pod (B), one thousand-grain weight (C), and yield loss (D) of the soybean cultivar BMX Ativa RR in response to the interference of different densities of the species *B. latifolia* and *R. brasiliensis*.

R. brasiliensis, reaching a development equal to or higher than soybean crop, contributing to its higher interference with the crop. Therefore, shading of soybean plants, determined by the presence of *B. latifolia*, reduced the radiation in the visible light spectrum (400 and 700 cm), reducing the energy available for photosynthesis. Many studies have reported differential plasticity between cultivated and weed species in response to an interspecific interference (Sattin et al., 1994; Gibson et al., 2004; Fleck et al., 2008). Increased height favors competition for light, which was confirmed in a study carried out by Stoller and Woolley (1985), in which *Abutilon theophrasti* and *Datura stramonium* grew higher than soybean, intercepting 44 and 56% of solar radiation, leading to a decrease in soybean grain yield of 19 and 25%, respectively.

In addition, because of the shading of soybean plants, especially in the cultivar BMX Ativa RR, the total chlorophyll contents in the leaves showed a marked decrease for *B. latifolia*, which is in accordance with the results of Victório et al. (2007). Chlorophylls, as well as carotenoids, are pigments present in plants able to capture visible radiation, triggering the photochemical reactions of photosynthesis (Seiferman-Harms, 1987). The type, amount, and incorporation of chlorophyll and carotenoids within the photosynthetic apparatus depend on the quality and quantity of light (Macmahon et al., 1991).

The reduction of biometric characteristics and biomass of soybean plants can be explained in terms of both quantity and quality of incident radiation. In soybean, the increase in extreme red radiation (Ve) can also result in a decrease in the shoot dry matter of soybean plants at 16 days after emergence (La Rosa et al., 1999). Other organs and plant parts, such as leaf area (Pyke and Lopez-Juez, 1999) and internode length (Pausch et al., 1991), can also be modified by light quality.

As densities of *B. latifolia* and *R. brasiliensis* increased, the number of pods per soybean plant reduced, which could be justified by a lower emission of inflorescences and flower abortion caused by the competition for environmental resources. The increase in the first pod height with the increased interference may have been an effect of both the reduction of radiation quality (higher extreme red to red ratio) and the abortion of flowers and pods in the basal area of plants. Studies carried out in Brazil also reported negative effects of weeds on soybean regarding the reduction in the number of pods per plant (Durigan 1983; Lamego et al., 2004) and first pod height.

The species *B. latifolia* showed to be more competitive with soybean when compared to *R. brasiliensis*. Each plant of *B. latifolia* that emerged together with the soybean crop was responsible for 3 to 4.4% of yield reduction. It is possible to compare these losses with those imposed by other weeds implanted on the same day of soybean sowing. As an example, the weed plants *Bidens pilosa* and *Sida rhombifolia* reduced soybean yield by 1.58 and 0.69%, respectively (Rizzardi et al., 2003). In another study, each plant of *Conyza bonariensis* resulted in a 0.97% yield loss (Trezzi et al., 2014). However, each *Ipomoea* plant implanted on the same day of soybean reduced its productivity by 26.0% (Pagnoncelli et al., 2017).

This loss of grain yield due to the interference with weed species may be related to a high reduction in the leaf area of soybean plants, which resulted in a decrease in the capture of solar radiation, with negative reflections on photosynthesis. In addition, the reduction of shoot biomass with the interference indicates a reduction in leaf weight and number of branches in dicotyledonous plants, variables that directly influence the number of flowers and pods (Schmitt and Wulff, 1993), corroborating the results of the present study.

Considering the high potential losses of *B. latifolia* and *R. brasiliensis* in modern soybean cultivars, the results of this study indicate the importance of their adequate management. Management practices that aim to reduce the emergence of these weed species may be beneficial as they would prevent early interference with the cultivated plant. In this context, tank mixtures of residual herbicides with glyphosate or sequential applications with herbicides of other mechanisms of action represent an important strategy for their control. Crop rotation is a valuable tool to reduce infestations and improve weed control efficiency in arable areas since it allows soil coverage for a large part of the time, as well as rotation of herbicide mechanisms of action.

The species *B. latifolia* was more competitive with the soybean crop, causing higher losses in all analyzed variables when compared to *R. brasiliensis*. Each plant of *B. latifolia* per square meter is able to reduce soybean grain yield by 3 to 4.4%, while each plant of *R. brasiliensis* reduced yield by 2 to 2.6%, respectively. For both weed species, yield reduction is motivated by a decrease in the number of pods per plant, number of grains per pod, and one thousand-grain weight.

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