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Periods of interference of Alexandergrass on morphophysiological and productive characteristics of transgenic soybean

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ABSTRACT

Among the weed species infesting soybean, Alexandergrass (*Urochloa plantaginea*) is highlighted as one of the most competitive. The objective of this work was to determine the periods of interference of Alexandergrass, and is effects, on morphophysiology and yield components of soybean. Treatments were pooled into two groups: the group “convivence” comprised soybean growing among Alexandergrass for increasing periods: 0, 7, 14, 21, 28, 35 and 42 days after emergence (DAE), as well as along all the crop cycle. The “control” group comprised soybean free from competition for the same time lapses. Forty-two DAE, soybean morphophysiology was assessed. There was no effect of the time lpse of Alexandergrass “control” or “convivence” on soybean physiological performance. Plant height, stem diameter, plant dry mass, leaf area and grain yield components of soybean were, however, affected by Alexandergrass. The critical period of interference prevention comprises 26-41 DAE; the period prior to interference is 26 DAE; and the total period of interference prevention is 41 DAE.

Highlighted Conclusions

1. The yield components of soybean are negatively affected by Alexandergrass (*Urochloa plantaginea*) interference.
2. The control and coexistence periods of Alexandergrass did not change the physiological traits of soybean plants.
3. The critical periods of interference of Alexandergrass in competition with soybean were 26, 41 and 26 - 41 days, respectively for PAI, PTPI and PCPI.

INTRODUCTION

Soybean productivity is linked to genetic and management factors such as sowing time, soil fertility, plant density and arrangement, and pest control, especially weeds (Almeida et al. 2015; Hammer et al. 2018; Koehler-Cole et al. 2021). Losses caused by the interference of weeds in the soybean crop can be higher than 52% if no management method is adopted (Silva et al. 2008; Soltani et al. 2017; Pagnoncelli et al. 2017).

For the proper growth and development of the crop, it is necessary that the available resources such as water, light, nutrients and CO_2 are not limited, especially by competition with weeds (Lamego et al. 2015; Forte et al. 2017; Hammer et al. 2018). Competition for environmental resources can be determined as intraspecific, which occurs when there is competition between soybean plants, or it can be interspecific, which corresponds to competition between different species, influencing plant architecture, especially in height and branch distribution (Bastiani et al. 2016; Koehler-Cole et al. 2021).

Under competitive conditions, plants tend to increase their stature in order to maximize radiation uptake; with greater crop growth, there will be greater weed shading, with an expected reduction in dry mass accumulation and in leaf area (Silva et al. 2009a). The stress caused by competition can be irreversible, causing morphophysiological changes resulting in a decrease in productivity (Lamego et al. 2004; Nepomuceno et al. 2007; Forte et al. 2017).

Alexandergrass (*Urochloa plantaginea*) is found in the South, Southeast and Center-West regions of Brazil, being an annual grass belonging to the Poaceae family, with C_4 photosynthetic metabolism, very competitive when infesting agricultural crops (Moreira 2011). It has the ability to germinate in different environmental conditions and different soil characteristics (Moreira 2011), demonstrating high efficiency in the exploitation of environmental resources (Silva et al. 2009b). In high populations, the competition exerted by Alexandergrass can decrease soybean grain productivity by up to 50% (Silva et al. 2009b).

To control soybean weeds, farmers have used chemical control, with herbicides recommended for this crop. However, the incorrect use of this tool can favor the appearance of resistant weeds, making management difficult. Considering that competition negatively affects grain yield and quality, the study of the effect of competitiveness and the best time to control weeds becomes essential (Silva et al. 2009b; Pagnoncelli et al. 2017; Koehler-Cole et al. 2021).

To identify the best time to control weeds infesting agricultural crops, periods of interference- especially the period prior to interference (PAI), have often been used-it is the time lapse between crop emergence and the time where weeds start affecting the crop. The total period of interference prevention (PTPI) occurs from emergence to the time lapse where the crop is not affected by weeds anymore; and the crossing of PAI and PTPI allows the estimation of the Critical Interference Prevention Period (PCPI) - which corresponds effectively to the time lapse in which the crop should be free from competition (Nepomuceno et al. 2007; Galon et al. 2018; Franceschetti et al. 2019).

The hypothesis tested in the present study was that there are different morphophysiological and productivity responses of soybean in competition with Alexandergrass related to periods of weed interference on the crop. Furthermore, the objective of this work was to determine the periods of Alexandergrass interference and the effect of this weed on the morphophysiology and grain yield components of the soybean crop.

MATERIAL AND METHODS

The experiment was carried out in the field, in the experimental area of the Universidade Federal da Fronteira Sul (UFFS), Campus Erechim/RS, from October 2018 to February 2019, in a no-tillage system in straw, in soil classified as typical Aluminoferric Red Latosol. (Santos et al. 2018), with the following chemical and physical characteristics: pH_water = 4.8; OM = 3.3%; P = 6.3 mg dm^{-3}; K = 106 mg dm^{-3}; Al^{3+} = 0.9 $cmol_c$ dm^{-3}; Ca^{2+} = 5.1 $cmol_c$ dm^{-3}; Mg^{2+} = 3.3 $cmol_c$ dm^{-3}; $CTC_{(t)}$ = 9.8 $cmol_c$ dm^{-3}; $CTC_{(pH7)}$ = 17.6 $cmol_c$ dm^{-3}; H+Al = 8.7 $cmol_c$ dm^{-3}; SB = 9.2 $cmol_c$ dm^{-3}; V = 51%; and Clay = 62%.

The experimental design adopted was randomized blocks, with four replications. Experimental units were composed of 3 m wide plots (6 rows spaced in 0.5 m) by 5 m long, resulting in a useful area of 15 m^2. Soil fertility correction and other cultural treatments were carried out according to the technical recommendations for soybean cultivation (ROLAS, 2016). For burndown of the present vegetation, composed of black oat (*Avena strigosa*) + vetch (*Vicia sativa*), the herbicide glyphosate was used, formulated on the basis of diammonium salt applied at a dose of 1335 g_{ai} ha^{-1} or 3 L ha^{-1} of Roundup Original®.

The soybean cultivar used was Brasmax Elite IPRO, with indeterminate growth habit, early cycle, maturation group 5.5, insect resistance and herbicide tolerance, sown with a drill, at density of 24 plants m^{-2} or 240,000 plants ha^{-1}, and base fertilization comprised 275 kg ha^{-1} of the formulation N-P-K 02-20-20. Soybean seeds were inoculated one day before sowing with *Bradyrhizobium elkonii* and *B. japonicum*, according to the recommendations. Population surveys were carried out in the experimental area to determine the average density of plants of Alexandergrass (*Urochloa plantaginea*) infesting soybean, with an average of 70 plants m^{-2}. The remaining soybean weeds were removed from the area by hand weeding. Insect and disease management was carried out following the technical recommendations of the research for soybeans (Caraffa et al. 2019).

Treatments were separated into two interference models: in the first, the soybean crop coexisted with Alexandergrass for increasing periods of 0, 7, 14, 21, 28, 35, 42 days after emergence (DAE) and throughout the entire cycle, called the "coexistence" group. In the second group, the culture was kept free from infestation for the same time lapses described above, called "control". In Figure 1, precipitation and average daily temperature can be observed throughout the crop cycle, during the period during which the experiment was conducted (INMET 2018).

The variables related to plant physiology were evaluated 42 DAE, as this is the period in which all the treatments tested would present an effect on the differentiation of soybean yield components, except only those that were carried out throughout the crop cycle. To measure the chlorophyll index, a portable chlorophyll meter model SPAD 502 – Plus was used, taking measurements at five points of each plant in the lower, middle and upper leaves of the canopy. Furthermore, photosynthetic activity (µmol m^{-2} s^{-1}), internal CO_2 concentration (µmol mol^{-1}), transpiration rate (mol H_2O m^{-2} s^{-1}), stomatal conductance (mol m^{-1} s^{-1}), carboxylation efficiency (mol CO_2 m^{-2} s^{-1}) and water use efficiency (mol CO_2 mol H_2O^{-1}) were measured in the middle third of the plants. For this, an infrared gas analyzer (IRGA), brand ADC, model LCA PRO (Analytical Development Co. Ltd, Hoddesdon, UK) was used, and each block was evaluated in one day, between eight and nine o'clock in the morning, so that the environmental conditions were more uniform during the analyses.

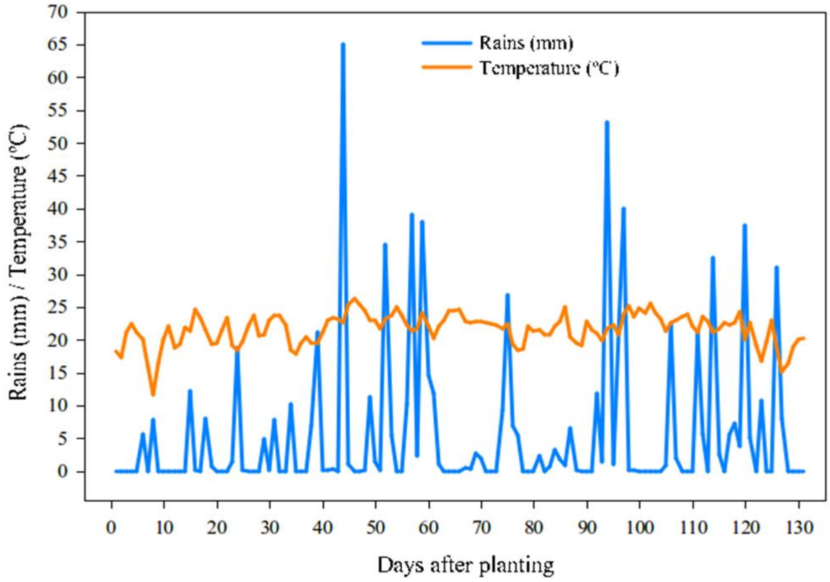

Figure 1. Rains and daily mean temperature along the soybean cropping cycle.
Source: Inmet (2018)

The morphological variables of soybean were also evaluated 42 DAE, namely: plant height, with a ruler graduated in centimeters, from the base of the plant to the apical meristem; stem diameter with the aid of a digital caliper, approximately 5 cm above the ground; the quantification of the leaf area with the aid of a portable leaf area meter model CI-203 BioScence, measuring the leaves of the plants in an area of 0.5 x 0.5 m (0.25 m^2) in the center of each experimental unit. After determining the leaf area, the plants were placed in kraft paper bags and taken for drying in an oven with forced air circulation, at a temperature of 60 ± 5 ºC, until the material reached a constant mass to measure the aboveground dry mass (Carvalho et al. 2011).

Two days before soybean harvest, five plants were randomly collected to count the number of grains per pod and number of pods per plant. In the harvest of the culture, the productivity of the soybean grains was determined. When it reached 18% humidity, it was harvested manually in an area of 3 m^2 per plot. Eight samples of 100 grains each were counted to determine the mass of one thousand grains (g). Grain moisture was determined and the values were corrected to 13%, both for grain yield and for the weight of 1000 grains. After moisture correction, grain yield was extrapolated to kg ha^{-1} (Franceschetti et al. 2019).

The collected data were submitted to analysis of variance, and if significant, the Scott-Knott grouping test was applied to evaluate the periods of interference, within each modality/treatment (coexistence or control), with the exception of the grain yield. To evaluate the effects of the coexistence and/or control periods between the Alexandergrass and the culture, within each evaluation (DAE), Student's t-test was applied. All data were analyzed at $p \leq 0.05$.

To determine the periods of interference, the grain yield (kg ha^{-1}) of the crop was used, according to the methodology by Nepomuceno et al. (2007). Grain yield data, standardized to 13% humidity on a dry basis were submitted to regression analysis using the sigmoidal model. This model obeys the following logistic equation: $Y= a/(1+e(-(x-x0\ )/b))$, where: Y= grain yield, a= initial value of the equation, x= number of days after soybean crop emergence, x0= number of days in which 50% of grain yield reduction occurs and b= slope of the curve. Based on the regression equations, the periods of Alexandergrass interference on the soybean crop were determined, subtracting 5% from the maximum productivity estimated in the regression equations in relation to the treatment maintained in the absence of infestation, a value considered as the cost of adoption of chemical control.

RESULTS AND DISCUSSION

The variables related to physiological traits of soybean plants, such as chlorophyll index, photosynthetic activity, stomatal conductance, internal CO_2 concentration, water use and carboxylation efficiencies did not present a significant effect of coexistence or control with Alexandergrass (data not presented). For discussions, the physiological variables need due care, as the IRGA equipment reflects the physiological status of the plant at the time of evaluation, that is, an interval of approximately 2 minutes. Considering the importance for competitiveness, the physiological variables provide only evidence of the reaction of the plants, imposed by the stress of competition. A result similar to that found in the present study was also reported by Ferreira et al. (2011) when working with the soybean cultivar BRS 243 RR in competition with *Bidens pilosa* and *Brachiaria decumbens* at different stages of weed development, also did not find differences in variables related to the physiology of the evaluated plants.

There was decrease in stem diameter and plant height of the culture as the time of coexistence between the species increased (Table 1). For the control, there was no differentiation in relation to the time when the crop was cleaned, with the elimination of Alexandergrass plants, both for the height of soybean plants and for the diameter. This result can be explained by the interspecific competition that occurs in the environment, considering that plants that establish themselves first in the environment prevail over the others, due to the greater use of water, light, CO_2 and nutrients (Ferreira et al. 2011; Pagnoncelli et al. 2017; Hammer et al. 2018).

Table 1. Effects of periods of coexistence and control of Alexandergrass (*Urochloa plantaginea*) on soybean plant height (cm) and stem diameter (mm) of cv. Brasmax Elite IPRO, UFSS, Erechim/RS, 2018.

Period (DAE)	Soybean plant height (cm)		Soybean stem diameter (mm)	
	Coexistence	Control	Coexistence	Control
0	81.75 aA[1]	76.83 aA[1]	9.85 aA	7.04 aB
7	77.58 aA	73.73 aA	9.16 aA	7.47 aB
14	79.52 aA	73.91 aA	9.57 aA	9.32 aA
21	66.14 bA	69.58 aA	7.56 bA	7.15 aA
28	72.75 bA	66.17 aA	7.58 bA	8.19 aA
35	70.50 bA	70.33 aA	7.90 bA	7.89 aA
42	68.58 bA	70.99 aA	7.70 bA	8.56 aA
Mean	72.74		8.21	
C.V(%)	7.37		13.17	

[1] Means followed by the same lowercase letter in the column, and uppercase letter in the row, do not differ according to Scott-Knott's and T-tests ($p \leq 0.05$), respectively.

The height of soybean plants did not differ when comparing the coexistence and control periods (Table 1). The fact that there is no difference in the height of soybean plants when comparing each period with each other may be associated with the vast availability of light when weeding was carried out on the crop. This fact can be explained by the growth and development of weeds, especially those that emerged at the beginning of the cycle, suppressing the development of the following ones and reducing the intensity of competition on the crop (Galon et al. 2018). These results corroborate those found by Nepomuceno et al. (2007) who did not observe significant differences in plant height of soybean cultivars M-SOY-6101 and CD 201 when evaluating the periods of coexistence and control of several weed species, when submitting the crop to no-tillage and no-tillage systems.

When comparing the coexistence with the control for the stem diameter of soybean plants in competition with Alexandergrass, a greater value was observed when soybean coexisted with the weed for 0 and 7 DAE (Table 1). According to Galon et al. (2011), cultivated plants when in competition for light, increase the investment of photoassimilates in the formation of longer stems, that is, etiolation occurs in an attempt to capture more light, with less energy investment for tillering, leaf area development, growth and root elongation; even grain yield can be affected, as the plant invests more energy in the organ which will help it to escape competition and have access to the highest level of the scarce resource, in contrast to the others. Corroborating with Galon et al. (2011), in the present study there was also a greater investment of soybean in stem diameter (Table 1), leaf area and aboveground dry mass of the crop plants (Table 2) when in coexistence with Alexandergrass, compared to the control periods.

The results show that soybean leaf area accumulation rate decreased proportionally to the time the crop lived with the weed, reaching a 48% reduction when comparing 0 (always clean plot) against 42 coexistence DAE (Table 2). Regarding the control, it was observed that the largest accumulations of leaf area occurred 14 and 35 DAE compared to the others.

When comparing the coexistence and control groups, a 56% reduction in leaf area was observed when coexistence with Alexandergrass is maintained throughout the cycle (Table 2). This fact is due to the competition that exists for resources present in the environment (Forte et al. 2017). As already reported, the culture under competition will invest more energy in the organ that will most contribute to it having greater access to the scarce resource.

A proportional decrease in the accumulation of aboveground dry mass can be observed with the increase in the time of coexistence of soybean with Alexandergrass (Table 2). These results may be related to the high competitive capacity of Alexandergrass plants, especially due to their C_4-type carbon metabolism, thus demonstrating high efficiency in the exploitation of environmental resources, as demonstrated by other sudies (Moreira 2011; Ferreira et al. 2011; Galon et al. 2018).

Table 2. Effect of the periods of coexistence and control of Alexandergrass (*Urochloa plantaginea*) on the leaf area and aboveground dry mass of soyean cv. Brasmax Elite IPRO. UFFS, Erechim/RS, 2018.

Period (DAE)	Soybean leaf area (cm^2 $plant^{-1}$)		Soybean aboveground dry mass (g $plant^{-1}$)	
	Coexistence	Control	Coexistence	Control
0	3159.49 aA[1]	1783.28 bB	19.49 aA1	11.70 aB
7	2033.88 bA	1379.54 bB	12.79 bA	8.44 bB
14	2187.25 bA	2178.78 aA	12.29 bA	15.01 cB
21	1894.24 bA	1633.56 bA	12.74 bA	12.44 aA
28	1991.86 bA	1798.56 bA	12.04 bA	10.44 aA
35	1738.56 cA	2015.11 aA	10.27 bA	14.40 cB
42	1505.96 cA	1556.17 bA	11.05 bA	11.07 aA
Mean	1918.51		12.44	
C.V (%)	14.02		13.32	

[1] Means followed by the same lowercase letter in the column, and uppercase letter in the row, do not differ according to Scott-Knott's and T-tests ($p \leq 0.05$), respectively.

Similarly to leaf area, also for aboveground dry mass the highest values were reported 14 and 35 DAE for the treatments of the “control” group (Table 2). It is noteworthy that the decrease in the shading capacity of the crop plants confers greater competitive capacity to the weeds; in cultures with rapid initial development, or where the weed emerges after the culture, a great competitive advantage is given to the cultivated species. If the weed emerges together with the cultivated species, it may be affected by competition (Tironi et al. 2014). Shading, in addition to the benefits mentioned above, inhibits the germination of positively photoblastic weeds, which is advantageous for the crop (Lamego et al. 2004).

For both groups, “coexistence” and “control”, there was a difference in the number of pods per plant among treatments. In coexistence, from 28 DAE onwards there was an increase in the number of pods per plant, and in the control at 0, 7, 21, 28 and 42 DAE, the lowest numbers of pods were reported (Table 3). When comparing coexistence and control, in general it was observed that the control of Alexandergrass plants increased the number of pods per plant throughout the evaluated period, except at 7 and 28 DAE, which was attributed to chance and to limitations of the proposed statistical method. According to Agostinetto et al. (2010), when evaluating the effect of barnyardgrass plant densities on irrigated rice at different row spacings, there were limitations of the statistical model used in the analyses, where it did not present adequate values for estimating some parameters. Lamego et al. (2004) when evaluating different soybean cultivars in competition with weeds simulating competition, also observed a reduction in the number of pods per plant when soybean was in the presence of different competitors. However, Nepomuceno et al. (2007) when testing the periods of coexistence and control of different weed species in cropping systems (no-tillage and conventional) of two soybean cultivars (M-SOY-6101 and CD 201) did not find significant differences in seedling height, insertion of the first pod, nor in the number of pods per plant. Thus, it can be seen that there is variation in the responses of the studies of periods of weed interference in soybean in relation to climate, soil type, cultivar and sowing systems (no-till or conventional), in addition to management and cultural treatments adopted.

Table 3. Effects of the periods of coexistence and control of *Urochloa plantaginea* (Alexandergrass) on the number of pods per plant, grains per pod and mass of 1000 grains (g) of soybean cv. Brasmax Elite IPRO. UFFS, Erechim/RS, 2018.

Period (DAE)	Pods per plant		Grains per pod		Mass of 1000 grains (g)	
	Coexistence	Control	Coexistence	Control	Coexistence	Control
0	43 bB[1]	49 bA	2.05 bB	2.30 aA[1]	138.97 bB	153.21 bA[1]
7	43 bA	48 bA	2.40 aA	2.40 aA	151.56 aB	160.92 aA
14	41 bB	57 aA	2.27 bA	2.15 bA	152.71 aA	157.38 aA
21	40 bB	50 bA	2.52 aB	2.20 bA	154.68 aA	161.95 aA
28	51 aA	54 bA	2.25 bB	1.82 cA	152.94 aB	163.72 aA
35	50 aB	60 aA	2.17 bA	2.12 bA	156.70 aB	147.83 bA
42	54 aB	45 cA	2.12 bB	2.42 aA	149.50 aB	158.43 aA
Mean	49.14		2.23		154.32	
C.V.(%)	7.89		7.26		3.62	

[1] Means followed by the same lowercase letter in the column, and uppercase letter in the row, do not differ according to Scott-Knott's and T-tests ($p \leq 0.05$), respectively.

Regarding the components of grain yield, there was an increase in the number of grains per pod when the control of Alexandergrass was carried out later, contrary to what was observed in the coexistence group in which the management carried out 7 and 21 DAE were lower than those applied later. When comparing the periods with each other, it was observed that for the control group, all weeding performed between 0 and 42 DAE provided a greater number of grains per pod when compared to the coexistence group (Table 3).

The coexistence of soybean with Alexandergrass at 0 DAE negatively affected the mass of a thousand grains when compared to the other treatments, since this time was statistically different with lower mass production (Table 3). From 7 to 42 DAE there was no differentiation between treatments for the coexistence group. The control group provided the smallest masses of a thousand soybean grains at 0 and 35 DAE, with the other periods being equal to each other. The mass of one thousand grains was higher for all treatments when comparing the control group against the coexistence group, thus demonstrating that the soybean presents higher productivity when kept free from the Alexandergrass infestation. Similar data were reported by Pagnoncelli et al. (2017) who found found that the mass of a thousand soybean grains was reduced with the increase in the density of rapeseed plants when in competition with the crop.

Considering the data presented in Figure 2, the need to carry out the control of Alexandergrass until 41 DAE is reported. The period before interference (PAI) is 26 DAE; the interval between 26 and 41 DAE corresponds to the critical interference prevention period (PCPI), and the total interference prevention period (PTPI) is 41 DAE. Weeds emerged after this period are prone not to interfere with grain yield of soybean. The interference caused by weeds on crops causes irreversible damage, compromising the development of reproductive structures and consequently affecting the components of grain yield (Silva et al. 2008). In high populations, the competition exerted by Alexandergrass can reduce soybean grain productivity by up to 50% (Silva et al. 2009b).

In the present study, when comparing the control treatments with those that remained in coexistence with the crop, a loss of grain productivity of 35.71% or 2,250 kg ha^{-1}, was observed (Figure 2). In view of the above, it is evident that the management of Alexandergrass in the soybean crop must be carried out within the range recommended by the results, which is from 26 to 41 DAE, that is, for a period of 15 days.

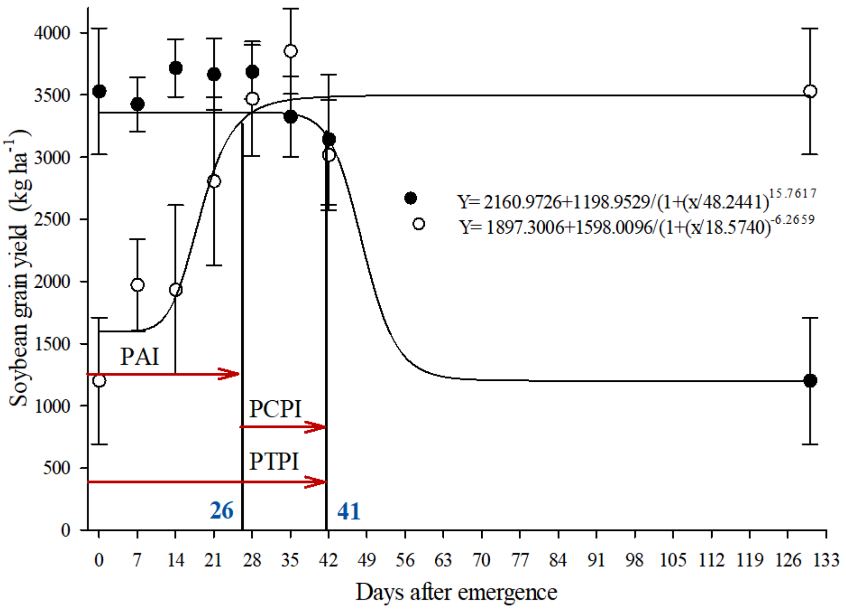

Figure 2. Soybean grain yield (kg ha^{-1}), cv. Brasmax Elite, as a function of periods of coexistence (●) and control (○) of Alexandergrass (*Urochloa plantaginea*). PAI: period prior to interference; PTPI: total period of prevention of interference; and PCPI: critical period of prevention of interference. Vertical bars correspond the sample standard deviation. * Significant at p ≤ 0.05. UFFS, Erechim/RS, 2018.

Results found by Nepomuceno et al. (2007) showed that the period before the interference of weeds in the soybean crop for the direct and conventional sowing systems is 33 and 34 days, respectively. The decrease in the PAI of the present experiment may be related to a good correction of soil fertility, the optimal distribution of rainfall and adequate temperature (Figure 1), or even the soybean cultivar, which favored greater growth and development of Alexandergrass. Or even, the lower tolerance of the cultivar in the competition with the weed. Assessing different levels of infestation, Silva et al. (2009b) found the PAI for soybean competition with weeds at 17 and 11 days for high and low infestation, respectively. Thus, it is evident that there are differences in the periods of interference according to the climate and soil conditions, in addition to the management and cultural practices adopted in each soybean producing region in Brazil.

The definition of the PCPI in soybean and other crops is an extremely important tool for the adoption of integrated weed management, in order to avoid losses and unnecessary use of herbicides or even other control methods. However, the precise determination of this period is complex, as factors such as sowing time and plant density of the crop; dose and timing of fertilizer application; weed species and densities present in the area; and edaphoclimatic characteristics can considerably influence the results, causing differences between locations and cropping seasons.

In conclusion, due to the competition for resources exerted by Alexandergrass, it is noticed that the height of plants, number of pods per plant, number of grains per pod, dry mass and mass of one thousand grains are negatively influenced, resulting in low productivity of the soybean crop.

There was no significant effect of Alexandergrass competition on the physiological characteristics of soybean plants. The effect of competition on crop plants appears to be more morphological, while the effects on plant physiology and metabolism appear to be transient.

The periods of interference of Alexandergrass in competition with soybean were 26, 41 and 26 to 41 days, for PAI, PTPI and PCPI, respectively.

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