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Planta Daninha

Journal of The Brazilian Weed Science Society

ISSN 0100-8358 (print)
1806-9681 (online)

Research Article

Residual herbicides increase the period prior to interference in soybean cultivars

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ARTICLE INFORMATION

Received: April 3, 2019
Accepted: May 25, 2020

Keywords:
interference periods
pre-emergence
competition
weeds

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Cite this article:
Rizzardi MA, Rockenbach AP, Schneider T. Residual herbicides increase the period prior to interference in soybean cultivars. Planta Daninha. 2020;38:e020222194.
https://doi.org/10.1590/S0100-83582020380100091

Conflict of Interest:
The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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HIGHLIGHTS

- Pre-emergence herbicide allows the canopy closure before the critical period of interference prevention.
- The use of pre-emergence herbicide allows the rotation herbicide mechanism of action in the production system.
- The pre-emergence herbicide controls the weeds' new emergence flow at the beginning of soybean development.

ABSTRACT

Background: The pre-emergence herbicides diclosulam and flumioxazin are used to weed control in soybean. We hypothesized management of the new emergence of weeds in the early development stages of the soybean could alter the periods of interference. Thus, the period prior to interference allows and increases the canopy closure spaces before the critical period and disfavors the development of weeds inside the vegetative canopy.
Objective: This study aimed to evaluate whether the period prior to interference of soybean cultivars was altered due to the application of residual pre-emergence herbicides.
Methods: Two experiments were conducted with the soybean cultivars 'NA 5909 RG' and 'P95R51'. One day before sowing in the main plots, the herbicide treatments paraquat (control without residual herbicide), paraquat+diclosulam, and paraquat+flumioxazin were applied. In the sub-plots, the increasing periods of coexistence of soybean with weeds of 0, 7, 14, 21, 28, 35, 42, and 49 days after the emergence of soybean were allocated.
Results: The control without residual herbicide had the lowest period prior to interference and the most considerable reductions in grain yield when compared with residual herbicides in both experiments. The presence of residual herbicide increased the period prior to interference because they controlled the initial emergence of the major weeds in the experimental area.
Conclusions: The use of the herbicides with residual activity diclosulam and flumioxazin increased the period prior to interference of 'NA 5909 RG' and 'P95R51' in areas infested mainly with horseweed and radish.

1 INTRODUCTION

Weeds compete with crops for light, water, and nutrients. The period in which this competition occurs is a determining factor in the degree of interference between species (Radosevich et al., 2007). The ability of weeds to compete with the crop depends on their distinct emergence period, rapid leaf growth and development, high root density, reproductive strategies, high viable seed production, among others (Swanton et al., 2015).

The weed emergence time compared to the crop determines the competition intensity. Depending on how long the emergence of weeds precedes the emergence of soybeans, the greater the negative effect on the variables associated with the crop (Fleck et al., 2004). Thus, most of the interference studies between crops and weeds are designed to identify the critical periods of interference and define the optimal time for weed control to avoid losses in crop yield (Vidal, 2010).

Interference periods are classified in the period prior to interference (PPI), the total period of interference prevention (TPIP), and the critical period of interference prevention (CPIP). According to Pitelli and Durigan (1984), the PPI is at the beginning of the crop development cycle, in which it can coexist with the weed community before its productivity or other characteristics being negatively affected. The TPIP occurs from the emergence, and it must be free from weeds to the productivity not be altered. The CPIP is between the maximum limits of the previously mentioned periods and it is characterized by compulsory weed control.

The TPIP delimits the time in which it is necessary to maintain the residual activity of pre-emergence herbicides, or until which period the control by weeding, cultivation, or application of post-emergent herbicides must be maintained (Vidal, 2010). Changes in soybean cultivars, such as growth and cycle type, and management, such as sowing season and the use of pre-emergent herbicides, characterize the crop's distinct response to competition, which may alter the periods of interference. The use of residual herbicides is an essential management practice to control certain species and avoiding the new emergence of weeds in the early stages of crop development.

Diclosulam and flumioxazin are herbicides used in pre-emergence to weed control in soybean. We hypothesized that the management of the new emergence of weeds in the early development stages of the soybean could alter the periods of interference. Thus, the PPI allows and increases the canopy closure spaces between the crop before the critical period. It also disfavors the development of weeds inside the vegetative canopy. This study aimed to evaluate whether the PPI of soybean cultivars was altered due to the application of residual pre-emergence herbicides.

2 Material and Methods

Two field experiments were conducted in the agricultural year 2015/2016, at latitude 28° 13' S, longitude 52° 23' W, and an approximate altitude of 700 m above sea level. The soil of the experimental area belongs to the Passo Fundo mapping unit and it was classified as a Humic Dystrophic Red Latosol (Streck et al., 2008).

The climate of the region is subtropical humid with hot summers (Cfa) by the Köppen climatic classification. During the experiment, the rainfall was 1365.2 mm, which was higher than the climatological normal for the period, which is 855.0 mm. The mean air temperature for the period was 21.21 °C and was close to the climatological normal value of 20.50 °C for these months (Figure 1) (Embrapa, 2017).

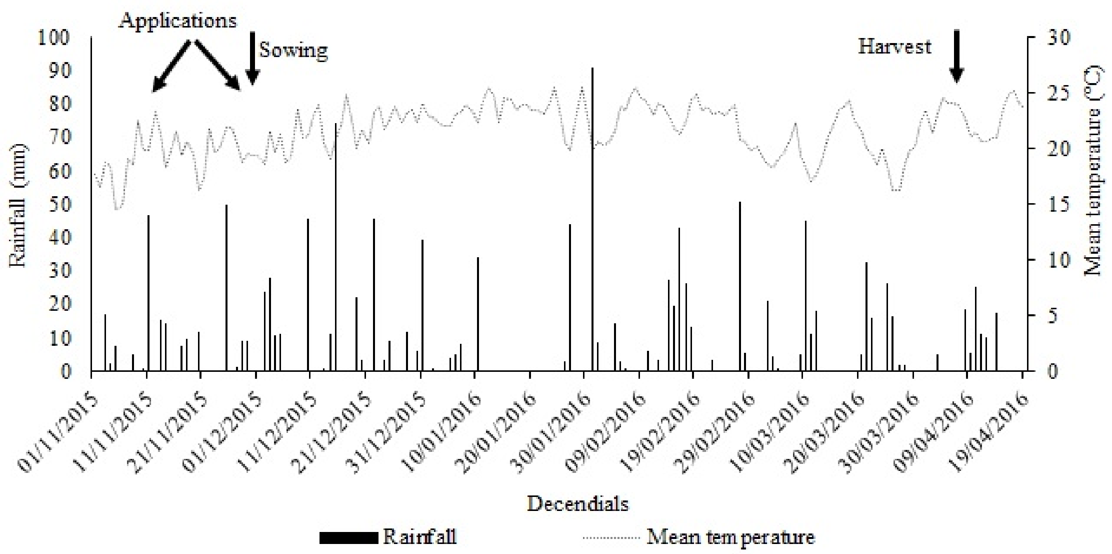


Figure 1 - Rainfall and mean air temperature in Passo Fundo (RS, Brazil) during the experimental period.

The experimental design was a randomized complete block design with four replications. In the main plots, the residual herbicides, diclosulam and flumioxazin, and the control without residual herbicide were allocated. In the subplots, the growing periods of coexistence of soybean with weeds 0, 7, 14, 21, 28, 35, 42, and 49 days after the emergence (DAE) of soybean, which corresponds to the following stages of soybean: sowing, V1, V2, V3, V4, V8, V10 and R2 for cultivar 'NA 5909 RG'; and sowing, V1, V2, V3, V4, R2, R3, and R4 for cultivar 'P 95R51'. The subplots were 5 m long and 3.5 m wide.

Twenty days before sowing, glyphosate + 2,4-D (750 g a.e. ha^{-1} + 670 g a.e. ha^{-1}) was applied in the total area. In the main plots, the herbicide treatments paraquat (400 g a.i. ha^{-1}), paraquat (400 g a.i. ha^{-1}) + diclosulam (25.2 g a.i. ha^{-1}) and paraquat (400 g a.i. ha^{-1}) + flumioxazin (50 g a.i. ha^{-1}), were applied one day before sowing. The herbicide paraquat is a post-emergent product with no pre-emergence effect and was used to ensure weed-free sowing. The herbicides diclosulam and flumioxazin have systemic and residual activity in soil, mainly controlling broad-leaf weeds. Glyphosate applications (750 g a.e. ha^{-1}) were completed at the end of each period, supplemented with manual weeding of glyphosate herbicide-resistant weeds, and then maintained without weeds.

Soybean sowing was performed on 01/12/2015 in the absence of weeds, with 0.45 m inter-row spacing and a population of 280 thousand plants ha^{-1}. In experiment I, the 'NA 5909 RG' soybean cultivar was used, and in experiment II, the 'P 95R51' soybean cultivar was used, with cycles of 110-135 and 115-120 days, respectively. Both cultivars were tolerant to glyphosate herbicide and had indeterminate growth. Weed infestation consisted mainly of horseweed (*Conyza* spp.), radish (*Raphanus* spp.), beggarticks (*Bidens pilosa*), and morning glory (*Ipomoea* spp.). The control of weed grasses was performed with clethodim herbicide (96 g a.i. ha^{-1}).

Before harvest, ten plants were collected in the center of each plot and the yield components the total number of pods, the total number of grains, and the mass of one thousand grains were evaluated. Grain yield was determined by harvesting three 5 m long central rows in the plot area using a harvester, totaling 6.75 m^2. After the weighing and determination of the sample humidity, the moisture was corrected to 13%.

For analysis of the PPI, a regression analysis was performed for the sigmoidal equation (three parameters), with the mathematical models obtained using the statistical software Sigma PlotTM v.10.0. Regression analysis was performed for the mass of one thousand grains.

3 Results and Discussion

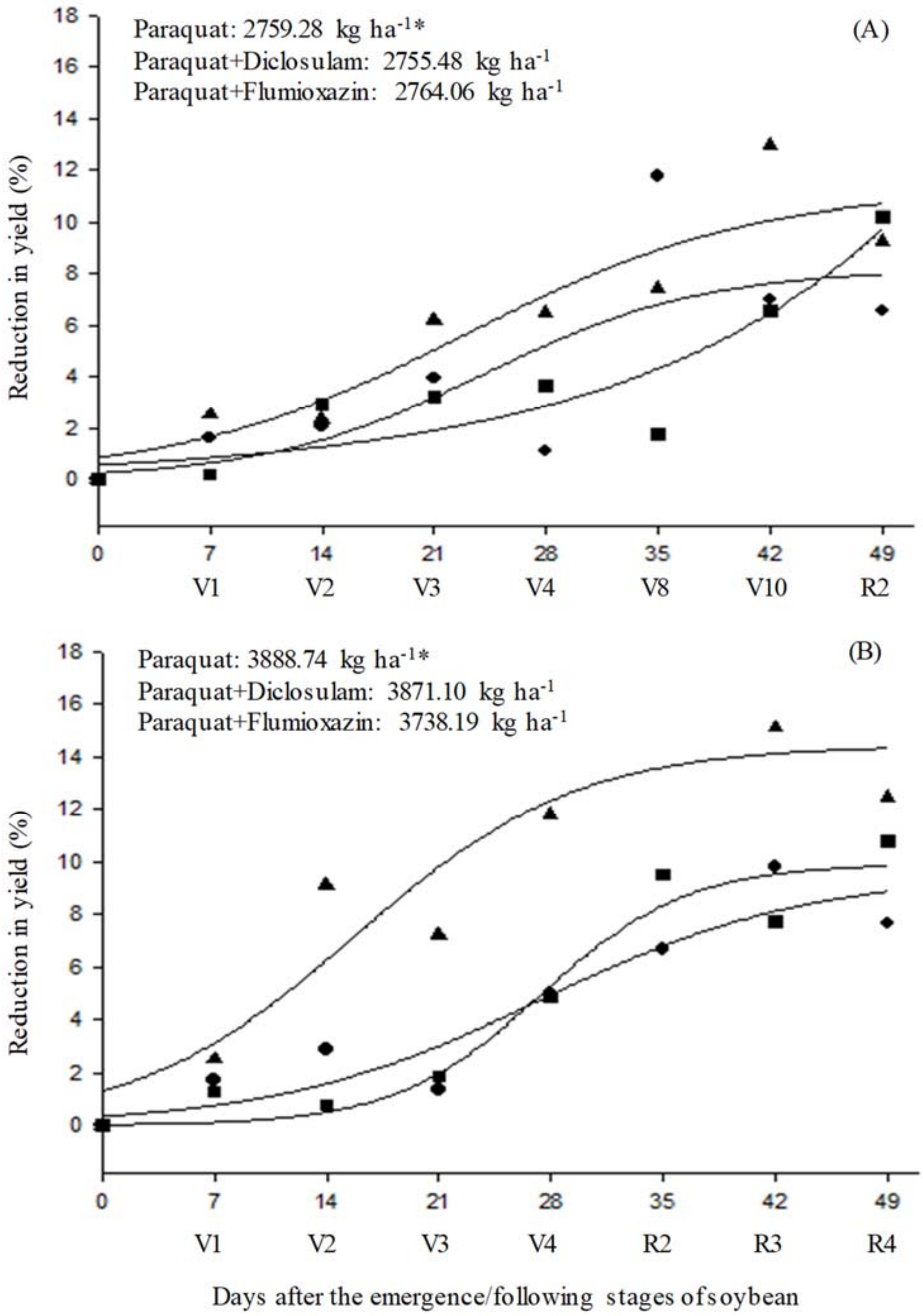
The treatment without residual herbicide showed the lowest PPI and the largest reductions in grain yield when compared with residual herbicides in both experiments (Figure 2). Paraquat acts on contact and has no soil residual (Senseman, 2007), which allows weeds to emerge soon after application, which could be well developed when the crop was in the CPIP, resulting in potential competition. One of the possibilities to avoid this situation, which is currently very common, is to use herbicides with residual activity in the soil.

The presence of the residual herbicide increased the PPI because they controlled the emergence flow of the main weeds in the plot (Figure 2). This allowed the crop canopy closure before the occurrence of CPIP, increasing the cultural control of weeds by soybean through shading the weed seedlings and soil.

At 42 DAE, the interference in the treatment with no residual activity in the soil showed a reduction on the mean of 15% in the yield of both cultivars, compared to a reduction on the mean of 8% in the other treatments (Figure 2). Residual herbicide is a relevant aspect of weed management because weeds (especially the perennials) are often not fully controlled in the desiccation and pre-emergence applications due to current agricultural practices. They will compete with the crop from the initial phase, increasing yield losses, as observed for the treatment without residual herbicide.

Studies that define the periods of interference are used to determine the best time to control weeds in the crop (Silva et al., 2015), and this time varies according to weed management, cultivar, species, and density. For the soybean cultivar 'P98Y12', the PPI was 7 DAE (Pereira et al., 2015). However, the cultivar 'BRS Estância RR' had a PPI of 24 DAE when competing with glyphosate-resistant horseweed (Silva et al., 2014).

The 'BRS Querencia' cultivar had a PPI of 23 DAE when competing with crabgrass (*Digitaria horizontalis*) (Agostinetto et al., 2014). Green-Tracewicz et al. (2012) characterized the period of greater sensitivity of soybean to the changes in light caused by the presence of weeds between the V1 and V3 stages,



* Yield on the ausence of weed

NA 5909 RG
Paraquat: $Y= 11.3093/(1+\exp(-x-23.0220)/9.0929))$ $R^2= 0.86$*
Paraquat + Diclosulam: $Y= 17059.5078/(1+\exp(-x-177.0850)/17.1483))$ $R^2=0.84$*
Paraquat + Flumioxazin: $Y= 8.1972/(1+\exp(-x-24.1260)/6.9072))$ $R^2= 0.58$*
P 95R51
Paraquat: $Y= 14.4382/(1+\exp(-x-15.8693)/6.8708))$ $R^2= 0.88$*
Paraquat + Diclosulam: $Y= 9.9145/(1+\exp(-x-27.4131)/4.5791))$ $R^2= 0.94$*
Paraquat + Flumioxazin: $Y= 9.5350/(1+\exp(-x-27.4627)/8.3458))$ $R^2= 0.88$*

* Significant

Figure 2 - Reduction in grain yield of the soybean cultivars ‘NA 5909 RG’ (A) and ‘P95R51’ (B) in response to the pre-emergence herbicides Diclosulam and Flumioxazin and growing periods of weed coexistence.

which can be characterized as CPIP. For the soybean cultivars ‘Fundacep 63RR’ and ‘59RR’, interferences of 10 and 30 plants m^{-2} of volunteer corn were tolerated for 28 and 42 DAE or 14 and 28 DAE, respectively (Schneider et al., 2014).

In the present study, a similar response was observed for PPI, with the cultivars responding differently. However, the tendency for the period to increase with the use of residual herbicide was similar for both. For the cultivar ‘NA 5909 RG’ in the treatment without residual herbicide, the PPI was 21 DAE, which was equivalent to the V3 vegetative stage.

The flumioxazin and diclosulam residual herbicides resulted in PPI of 35 and 42 DAE, equivalent to the V8 and V10 stages, respectively (Figure 3). For the cultivar ‘P95R51’ in the treatment without residual herbicide, the PPI was at 14 DAE (V2 stage) and with residual herbicides were at 28 DAE (V4 stage) (Figure 4). Considering a 5% reduction in grain yield as the determinant to define the PPI, the residual herbicide resulted in extending this period to 19 and 14 DAE in the ‘NA 5909 RG’ and ‘P95R51’ cultivars, respectively for the mean of the residual herbicide treatments, compared to the treatment without residual herbicide (Figure 3 and 4).

In addition to using residual herbicides to increase PPI, crop rotation is also important and is beneficial to minimize difficulties in the control of weeds. Crop rotation also alters the PPI and reduces the sizes and number of weeds, providing greater flexibility in application times for post-emergence herbicide (Lopes Ovejero et al., 2013). Therefore, crop rotation systems promote the installation of the crop free of competition since the emergence, which allows the crop to have early access to the environmental resources until the canopy closure (Piasecki and Rizzardi, 2016).

Given the above information, residual herbicides become essential strategies for current weed management. Their benefits have already been elucidated for some species. For sunflowers, the use of pre-emergence herbicide increased the PPI in 10 DAE on average (Knezevic et al., 2013). For soybean, the PPI was 43 DAE when pre-emergence of glyphosate + chlorimuron-ethyl was applied, compared to 29 DAE when treated with glyphosate alone (Carvalho et al., 2009). The increase in the PPI occurs because residual herbicides have a considerable impact on the initial weed emergence in crops. Using them in pre-emergence, an average of 20 plants m^{-2} was observed, whereas in its absence, the average density was 63 plants m^{-2} (Santos et al., 2016).

Benefits related to weed control are observed by using herbicides with different mechanisms of action and with residual soil activity for the desiccation and

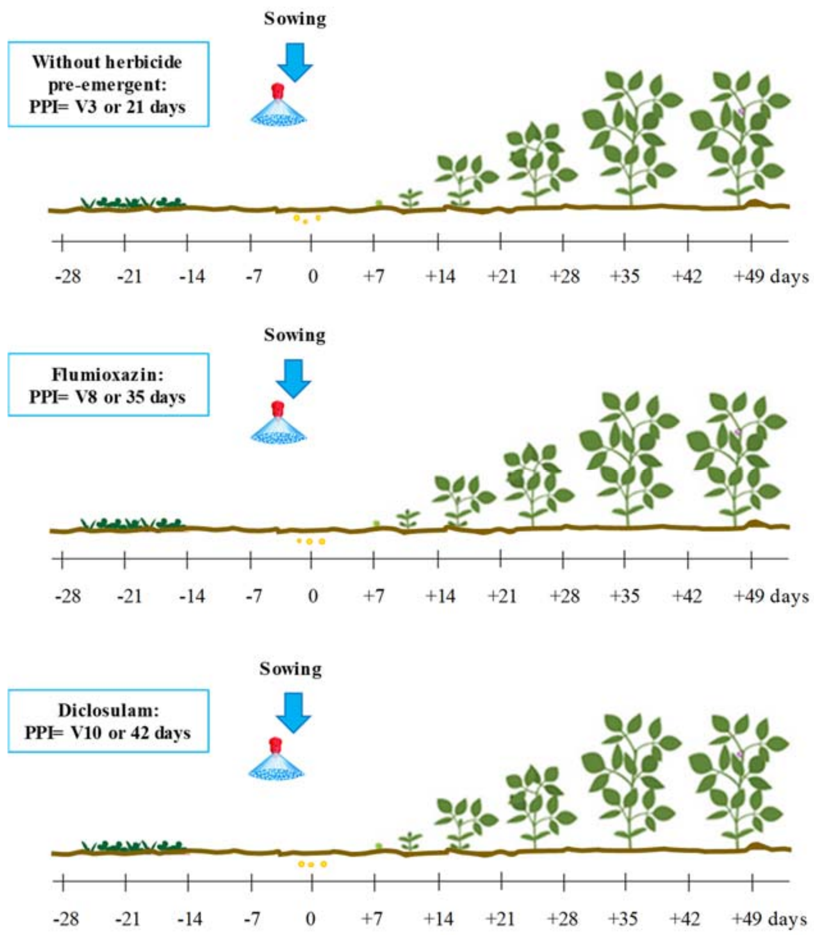


Figure 3 - Period prior to interference (PPI) of soybean cultivar ‘NA 5909 RG’ submitted to the pre-emergence application of herbicides with and without residual activity.

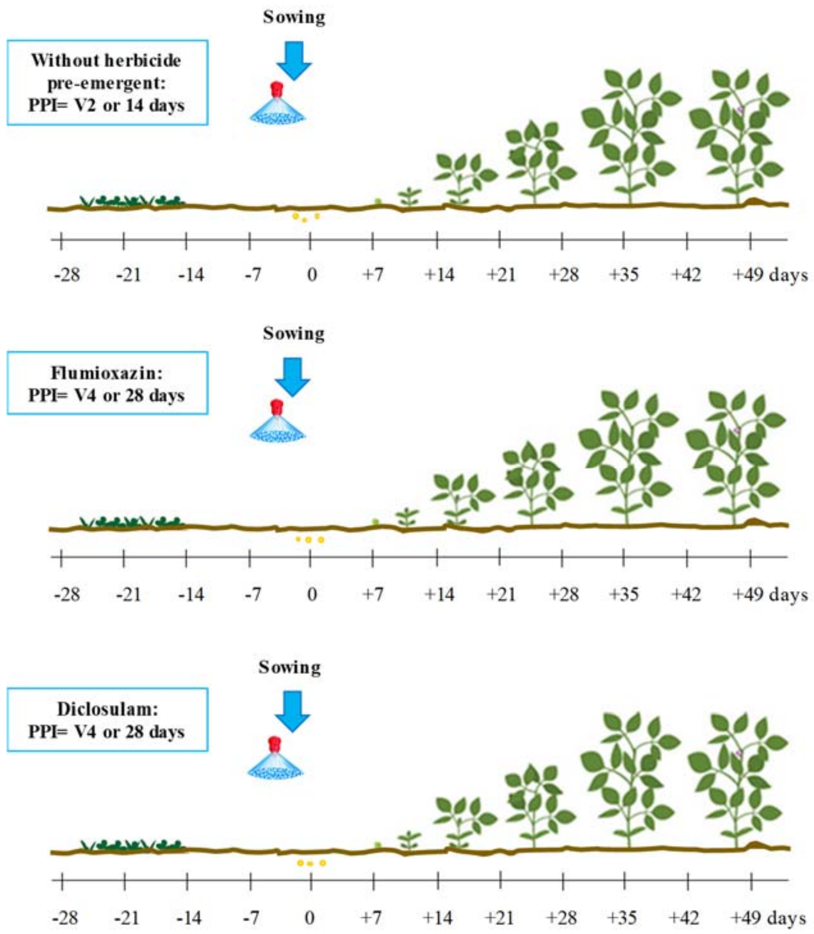


Figure 4 - Period prior to interference (PPI) of soybean cultivar 'P95R51' submitted to the pre-emergence application of herbicides with and without residual activity.

pre-emergence applications. These herbicides promote the best conditions for the crop by controlling the weed emergence, increasing the PPI, and avoiding the damages of competition for the environmental resources.

The total number of pods and the total number of grains were not significant for both cultivars and herbicide treatments (data not shown). On the other hand, the mass of one thousand grains increased for both cultivars on the mean of the herbicide treatments, when weed coexistence. It was increased in 0.07 and 0.31 g with the addition of one day of coexistence for 'NA 5909 RG' (Figure 5A) and 'P 95R51' (Figure 5B), respectively.

It is believed that with the plasticity of the soybean crop, many of the interferences imposed by the weeds were masked in the final results of yield components, since this crop is very adaptable.

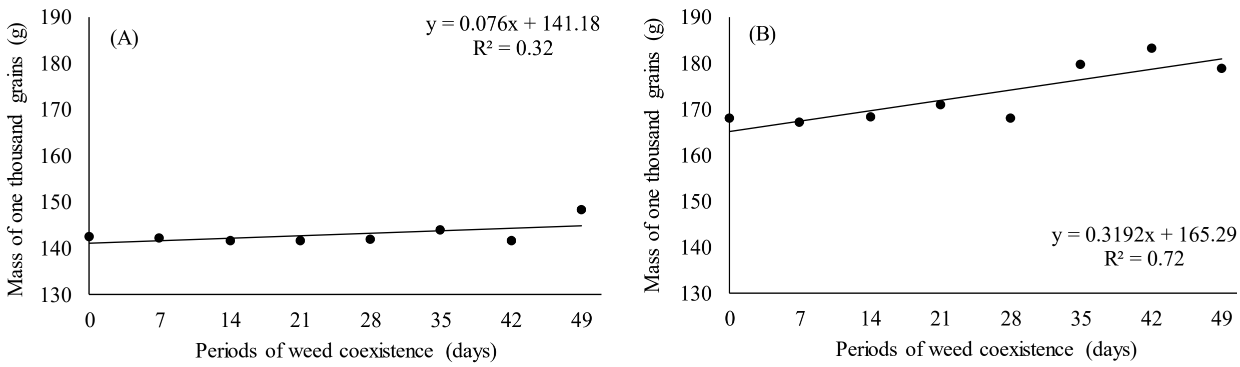


Figure 5 - Mass of one thousand grains of soybean cultivars 'NA 5909 RG' (A) and 'P95R51' (B) as a function of periods of weed coexistence in the average herbicide treatments.

4 Conclusions

The use of herbicides with residual activity diclosulam and flumioxazin, increased the PPI of 'NA 5909 RG' and 'P95R51' soybean cultivars in areas mainly infested with horseweed and radish.

5 Contributions

APR and TS carried out the experiment. APR wrote the manuscript with support from MAR. MAR conceived the original idea. MAR supervised the project.

6 Acknowledgments

We acknowledge the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq-Brazil) and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES-Brazil) for their financial support. This manuscript is based on the thesis presented by Ana Paula Rockenbach.

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