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Article

INTERFERENCE PERIODS OF *Raphanus raphanistrum* L. IN SUNFLOWER CROP

Períodos de Interferência de ***Raphanus raphanistrum*** *L. na Cultura do Girassol*

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ABSTRACT - *Raphanus raphanistrum* L. (wild radish) stands out among the weeds that cause greatest damage to the sunflower crop, due to the development cycle and adaptability. The objective of this research was to determine interference periods of sunflower interacting with wild radish, and the effects of competition on yield and its components. The experiment was conducted in the field in a randomized block design with four replications. The treatments were arranged in a factorial design with factor A composed of wild radish coexistence or control in sunflower, and factor B, for eight periods (0, 7, 14, 21, 28, 35, 42 and 135 days after crop emergence). It was evaluated height, diameter of chapters, achene yield and dry matter of weeds and crop. The presence of wild radish adversely affects the accumulation of dry mass, head diameter, thousand grain weight and reduces sunflower productivity when the wild radish interacts during the whole crop cycle, but does not affect on plant height. Chemical control of wild radish may be adopted at the end of period prior to interference, which for sunflower crop is 13 DAE, and the application is sufficient to avoid weed interference until the end of the total period of interference prevention which occurs until 17 days after crop emergence.

Keywords: *Helianthus annuus,* competition, weeds.

RESUMO - ***Raphanus raphanistrum*** *L. (nabo) se destaca entre as plantas daninhas que causam os maiores prejuízos à cultura do girassol, em função do ciclo de desenvolvimento e adaptabilidade. Objetivou-se com esta pesquisa determinar os períodos de interferência da cultura do girassol convivendo com nabo, os efeitos da competição na produtividade e seus componentes. O experimento foi conduzido a campo, em delineamento experimental de blocos casualizados com quatro repetições. Os tratamentos foram arranjados em esquema fatorial, sendo o fator A composto pela convivência ou controle de nabo na cultura do girassol e o fator B, por sete períodos (0, 7, 14, 21, 28, 35 e 90 dias após a emergência da cultura). Avaliou-se a estatura, o diâmetro de capítulos, a produtividade de aquênios e a massa seca das plantas daninhas e da cultura. A presença de nabo afeta negativamente o acúmulo de massa seca, o diâmetro de capítulo, o peso de mil aquênios e reduz a produtividade de girassol, quando o nabo convive durante todo o ciclo da cultura, porém não influencia a estatura das plantas. O controle químico de nabo deve ser realizado ao final do período anterior à interferência, o qual, para a cultura do girassol, é de 13 dias após a emergência, sendo suficiente para evitar a interferência de plantas daninhas até o final do período total de prevenção à interferência, que ocorre até os 17 dias após a emergência da cultura.*

Palavras-chave: *Helianthus annuus*, competição, plantas daninhas.

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INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the four most important annual crops in the world grown for the production of edible oil or biodiesel. In Brazil, approximately 120.4 thousand tons are produced in an area of 76.4 thousand hectares (Conab, 2018). This species cultivation can be carried out in practically the entire national territory, due to the adaptability to different climatic conditions (Silva et al., 2012). However, several factors can interfere with crop's productivity.

Among the factors that cause losses in productivity are the occurrence of weeds in the cultivated areas, the scarcity of post-emergent herbicides registered for the crop (Silva et al., 2012; Pannacci et al., 2007) and the difficulty of weed control due to the wide spacing between rows and low population of plants per hectare, which makes the sunflower more vulnerable to weed competition during the first weeks of growth (Bruniard and Miller, 2001; Elezovic et al., 2012). Thus, in the presence of weeds, sunflower productivity is reduced by up to 81% (Fried et al., 2006; Jursík et al., 2015). Crop damage is influenced by the weed species and population in the area (Rizzardi et al., 2003), period of emergence and phenological stage of crop development (Agostinetto et al., 2014), which provide different degrees of competition.

Competition between weeds and crops can cause irreversible losses due to morphological and physiological changes in plants, which compromise the development of reproductive organs, leading to a reduction in grain production even after the removal of stress (Breccia et al., 2011). The coexistence period between the crop and the weeds defines the level of damage caused to productivity (Silva et al., 2012). Thus, the longer the coexistence period of the weed with the crop, the greater the losses in grain yield (Furtado et al., 2012). However, the degree of competition between weeds and crops can be changed due to periods when the community is competing for a given resource. It is known that the competition established in the initial phases of the crop cycle causes irreversible losses in productivity (Agostinetto et al., 2014), and the establishment of the crop should be provided without the presence of weeds in order to avoid such losses.

The crop can interact with weeds for a certain period, but there are other periods in which interference must be avoided, and control is essential to maintain productivity (Radosevich et al., 2007). According to researches, at the beginning of the crop development cycle, weeds can coexist, this phase being known as the period before interference (PBI), that is, the period when the environment is able to provide the necessary resources for the growth of the weed community and the crop.

The stage in which the crop must develop in the absence of weeds so that productivity is not affected is known as the total period of interference prevention (TPIP). From that period, new weeds may emerge, but they will not result in a reduction in crop productivity. This characteristic stems from the fact that, in this condition, the crop has the capacity to suppress competing plants (Radosevich et al., 2007).

The third period, known as the critical period of interference prevention (CPIP), corresponds to the difference between TPIP and PBI, being the phase in which management practices must be effectively carried out in order to avoid irreversible losses in productivity (Radosevich et al., 2007). In general, the ideal time to adopt the control strategy is as close as possible to PBI, since in the CPIP there are already losses in productivity.

Studies of competition between weeds and crops that define the critical period of interference tend to conclude which is the best time to control the weed community (Furtado et al., 2012) and what may be the management alternatives. In the Southern region of Brazil, *Raphanus raphanistrum* L. stands out among the weeds that cause the greatest damage to sunflower crop, due to the development cycle and adaptability to different climatic conditions, so there is a need to study the behavior of the crop in the presence of this weed. Therefore, the aim of this research was to determine the interference periods of sunflower crop interacting with wild radish and the effects of competition on grain yield and its components.

MATERIAL AND METHODS

The experiment was conducted in field during the agricultural year 2012/13, in the experimental area of Centro Agropecuário da Palma (CAP/UFPel), in the municipality of Capão do Leão – RS (31º48’30"S, 52º30’14,5"W) , using a randomized block design with four replications. The experimental units were composed of plots of 18 m² (5 x 3.6 m).

Sunflower hybrid M734 was used, cultivated in no-tillage system with spacing between rows of 0.9 m and population of 45 thousand plants ha^{-1}. Sowing took place on October 16th, 2012, and 300 kg ha^{-1} of fertilizer was used in the base, from the formula 05-30-15, distributed in the sowing line, with a complement of 72 kg of nitrogen ha^{-1} in coverage at 30 days after crop emergence. The area was desiccated three days before the sunflower sowing with the herbicide glyphosate at a dose of 1.260 g a.e. ha^{-1}.

The treatments were arranged in a 2 x 7 factorial scheme, with factor A composed by the presence and absence of weeds in the sunflower crop and factor B, for seven periods of coexistence. During these periods, the sunflower was kept in the presence of weeds for increasing periods of 0, 7, 14, 21, 28, 35 and 90 DAE, from which they were controlled until the end of the cycle. During the control periods, the crop was kept free of wild radish during the same periods previously described, and the weeds emerged after these intervals were not controlled. The control was performed through manual weeding; the other species that emerged during the crop cycle were manually controlled in all experimental units, and the weed population came from the seed bank present in the soil.

At the end of each competition period, the dry mass of the aerial part (DMAP) of the crop and of the wild radish was evaluated, with the exception of the harvest evaluation, as the weeds were senescent. For DMAP determination, the wild radish plants were collected in an area of 0.25 m², and the sunflower plants, in 1 m of row (0.90 m²). Subsequently, the samples were dried in an oven with forced air circulation at 60 °C for 72 hours, when they were quantified on analytical scale. At the end of the sunflower cycle (90 DAE), the height of the crop was measured, which was determined randomly in ten plants in each plot, taking the height from the soil level to the apex of them.

During the harvest, carried out at 90 DAE, productivity components [chapter diameter (CD) and weight of a thousand achenes (WTA)] and crop productivity (PROD) were also evaluated, in a usable area of 4.2 m². The CD was measured with the support of a digital caliper, and the WTA was determined using a precision analytical scale. Plants were manually harvested from the two central lines of the plots to obtain the PROD of the crop. After harvesting, the chapters were dried in the sun and then threshed manually, cleaning and correcting the humidity to 11%.

The data obtained were evaluated for normality (Shapiro-Wilk test) and homoscedasticity (Hartley test) and, subsequently, subjected to analysis of variance ($p \le 0.05$). When significance was found, the averages were compared using the t test ($p \le 0.05$) for the control and coexistence factor and the Duncan test ($p \le 0.05$) to compare the periods within each factor.

To determine the period of coexistence (PBI), a regression equation with three parameters was used, according to Velini (1992):

$$y = a/[1 + (x/x_0)^b]$$

where: y = grain productivity; a = maximum productivity obtained in the control, in clean soil; x = number of days after crop emergence; x_0 = number of days in which occurred 50% of the decrease in maximum productivity; and b = curve slope. The period before interference (PBI) was determined by subtracting 5% from the maximum productivity estimated by the model, which is the value assumed as the cost of chemical weed control.

As for the data referring to the total period of interference prevention (TPIP), the following four parameters equation was used:

$$y = y_0 + a/[1 + (x/x_0)^b]$$

where: y_0 = minimum productivity obtained in the infested treatment; and a = estimated difference by the model between the maximum productivity in the control treatment (without weeds) and the minimum productivity in the infested treatment. The other parameters are similar to those described for the PBI determination equation. To estimate the weeds critical period of interference prevention (CPIP), the PBI value was subtracted of the TPIP.

RESULTS AND DISCUSSION

The results of the homoscedasticity and normality tests revealed that it was not necessary to transform the data. There was interaction among the factors for DMAP, height, CD, WTA and PROD of achenes of sunflower crop.

The increase in the coexistence periods provided greater accumulation of wild radish DMAP, a fact that stems from the growth and development of the plants, causing greater interference on the crop (Table 1). The dry matter accumulated by the plant is a consequence of the amount of resources it can absorb from the environment; therefore, plants that produce more dry matter cause greater depletion of niche resources, resulting in suppression of growth and development of neighboring plants (Fleck et al., 2006). In the control periods, from 14 to 28 DAE, the largest accumulations of wild radish DMAP were observed, while in the subsequent period of 35 DAE the wild radish DMAP showed a reduction of 60%. Other studies have shown a 9% to 10% reduction in weed DMAP in sunflower crop in the summer and winter season, respectively (Silva et al., 2013a). This decrease is related to cultural control (Silva et al., 2012) and the fact that some plants finished the cycle before the evaluation. In addition, the control carried out over a period of more than 28 DAE of the sunflower crop causes marked losses in the population and in the weeds dry mass (Brighenti et al., 2004).

Comparing the coexistence periods with the control periods, it was observed that at 21, 28 and 35 DAE there was a difference in the accumulation of DMAP, and the greatest accumulations occurred in the coexistence periods of the weed with the crop (Table 1). The difference verified among the periods was expected, since the weeds present in the control period had a maximum of seven days since their emergence, while in the coexistence periods they were in the area since the emergence of the crop. It was observed that DMAP remained at low levels for the initial period and, after 14 DAE, it showed a great increase. In other crops, weed DMAP accumulation also remained at low levels until 20 DAE (Freitas et al., 2004; Silva et al., 2009), which can provide a competitive advantage to the crop.

In the coexistence, there was an increase in the accumulation of sunflower DMAP from 21 DAE (Table 1). During the control periods, there was an increase in the sunflower DMAP accumulation after 7 DAE, due to the growth and development of the crop free from weed interference. Comparing the coexistence periods with the control periods, it was observed that the sunflower DMAP accumulation was not altered by interacting with wild radish until 14 DAE, with a decrease of 11% at 35 DAE of the crop compared to the same control period. The greater DMAP accumulation in the control periods guarantees better establishment and competitive ability with weeds for the environment resources (Radosevich et al., 2007).

For the height variable, interacting with wild radish in different periods did not interfere in the crop, as well as in the control performed from the 7 DAE (Table 2). However, when the control

***Table 1* -** Dry matter of aerial part accumulation (DMAP) (g m^{-2}) of sunflower plants, hybrid M734, and of wild radish plants due to the effect of control or coexistence periods

Period	DMAP wild radish (g)		DMAP sunflower (g)	
	Coexistence	Control	Coexistence	Control
0 DAE[1]	0.03 b[2]ns[3]	0.01 e	0.06 d^{ns}	0.03 d^{ns}
7 DAE	0.04 b^{ns}	0.04 d	0.16 d^{ns}	0.15 c^{ns}
14 DAE	0.28 b^{ns}	0.12 bc	0.63 d^{ns}	1.17 c^{ns}
21 DAE	0.92 b*	0.12 b	4.14 c*	7.37 b*
28 DAE	2.68 a*	0.20 a	18.11 b*	30.41 a*
35 DAE	3.48 a*	0.08 cd	24.02 a*	27.01 a*
90 DAE	---	---	---	---
CV (%)	52.91	31.14	33.72	21.04

(1) Days after emergency. (2) Means followed by different letters, compared in the column, differ by Duncan's test (p≤0.05). (3) * or ns significant difference or not, respectively, by t test (p≤0.05), comparing periods within each variable.

***Table 2* -** Effect of wild radish control and coexistence periods on height (m) and chapter diameter (cm) of sunflower, hybrid M734

Period	Plants height (m)		Chapter diameter (cm)	
	Coexistence	Control	Coexistence	Control
0 DAE[1]	1.80 a [2]*[3]	1.65 b	18.64 a*	14.78 b
7 DAE	1.81 a^{ns}	1.78 a	18.58 a^{ns}	18.26 a
14 DAE	1.80 a^{ns}	1.82 a	21.16 a^{ns}	18.93 a
21 DAE	1.77 a^{ns}	1.80 a	19.53 a^{ns}	20.66 a
28 DAE	1.70 a^{ns}	1.80 a	19.24 a^{ns}	19.51 a
35 DAE	1.70 a^{ns}	1.79 a	18.54 a*	20.71 a
90 DAE	1.71 a^{ns}	1.71 a	15.14 b*	19.06 a
CV (%)	4.34	3.77	10.23	9.35

(1) Days after emergency. (2) Means followed by different letters, compared in the column, differ by Duncan's test (p≤0.05). (3) * or ns significant difference or not, respectively, by t test (p≤0.05), comparing periods within each variable.

was done only on the date of the emergency (0 DAE), the weeds caused a reduction of approximately 7% in the sunflower plants height, comparing the average height obtained in the control periods above 7 DAE. Other studies showed a 14% reduction in height when the crop remained in contact with wild radish for 60 DAE (Silva et al., 2012).

Comparing the coexistence periods with the weed control, there was only difference in plants H at 0 DAE. Although in the early development stages the sunflower crop does not develop quickly enough to promote soil cover and prevent the establishment of weeds, it has high stature and leaf area rate in the more advanced development stages, which allows greater competitive ability with weeds.

The smallest chapter diameter (CD) was observed when the wild radish remained competing throughout the crop cycle or when the control was performed only on the day of emergence (Table 2). The coexistence with weeds after 28 DAE of the sunflower negatively influenced the size of the chapter (Silva et al., 2013), reaching a reduction of 58.5% (Alves et al., 2013). However, when the sunflower plants remained free from competition with wild radish for 35 DAE, there was an increase of 11.7%, compared to the same period of coexistence. This result corroborates with Silva et al. (2012), who observed that sunflower plants, hybrid M734, that remained in clean soil until 49 DAE had a chapter diameter 11.8% higher when compared to plants that remained in competition for the same period with a weed complex.

The diameter obtained in the control in the clean soil (coexistence at 0 DAE) was approximately 18.8% greater than the CD evaluated in plants that lived with weeds throughout the cycle (Table 2). For the same hybrid, Silva (2012) recorded a decrease of 9.6% in plants CD that lived with the weed community throughout the crop cycle. When the emergence of *Kochia scoparia* plants occurred at the beginning of the sunflower cycle, there was a reduction of 24% in the CD and of about 7% in the size of achenes (Lewis and Gulden 2014).

For coexistence conditions, the WTA did not change until 28 DAE, with a reduction of 15.4% when the weed interacted until 90 DAE, when compared to the coexistence at 0 DAE (Table 3). In the control periods, the crop must be kept free of weeds until 35 DAE in order to reach the achenes maximum weight. In percentage terms, the WTA increased by 17.2% when the crop was maintained in the absence of weeds until 35 DAE, compared to the treatment with weed control at 0 DAE. This is explained by the degree of competition exerted by weeds on the crop, which is greater when the interference period and duration are prolonged (Furtado et al., 2012). Thus, at the beginning of the cycle, weeds can interact with the crop without causing damage, however, with the progress of the cycle, competition is established (Brighenti et al., 2004). Comparing the two periods, at 28 DAE the WTA in the coexistence was 4.0% higher than the control period. However, in the control periods, at 35 and 90 DAE, the WTA was 11.7% and 18.9% higher, respectively, than the same periods in the coexistence.

Table 3 - Effect of wild radish control and coexistence periods on productivity (kg ha^{-1}) and weight of a thousand achenes (g) of sunflower, hybrid M734

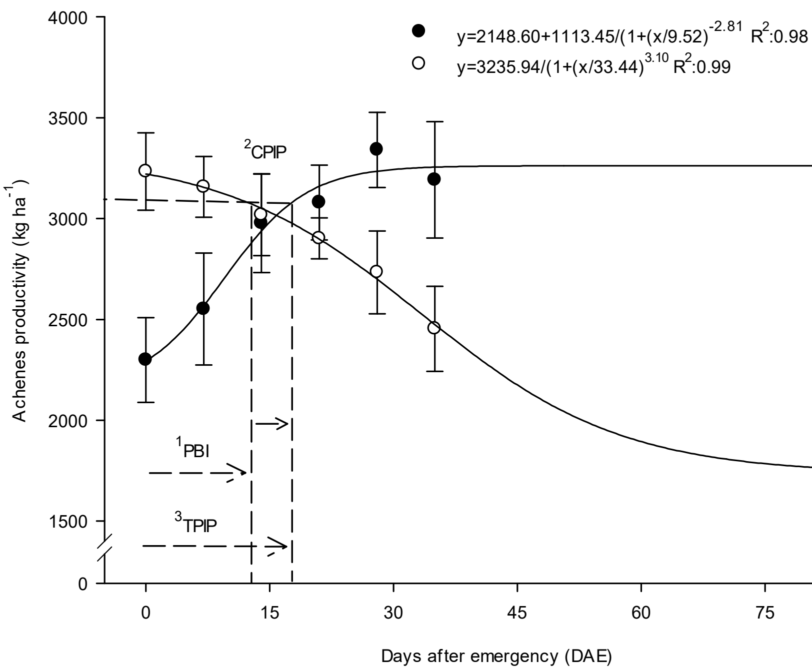
Period	Weight of a thousand achenes (g)		Productivity (kg ha^{-1})	
	Coexistence	Control	Coexistence	Control
0 DAE[(1)]	81.82 a[(1)*(3)]	72.04 c	3233.4 a*	2298.7 c
7 DAE	79.32 ab[ns]	73.19 c	3157.2 a*	2551.3 bc
14 DAE	84.37 a[ns]	74.87 c	3018.2 a[ns]	2977.7 ab
21 DAE	78.87 ab[ns]	74.88 c	2902.1 ab[ns]	3079.8 ab
28 DAE	82.78 a*	79.46 b	2733.4 ab*	3340.9 a
35 DAE	76.80 b*	86.96 a	2453.6 b*	3192.1 a
90 DAE	69.26 c*	85.48 a	1750.5 c*	3272.7 a
CV (%)	7.06	5.84	10.58	9.86

[(1)] Days after emergency. [(2)] Means followed by different letters, compared in the column, differ by Duncan's test ($p \leq 0.05$). [(3)] * or [ns] significant difference or not, respectively, by t test ($p \leq 0.05$), comparing periods within each variable.

The productivity of the sunflower crop was altered by the period of weed control, and increasing the period when the crop remains free from interference reduces losses. When the culture remained clean during the whole cycle, PROD was 29.8% higher than the control performed only on the day of the culture's emergence (Table 3). Correlated to this, weeds living with the crop reached dry matter accumulation of 3.48 g m^{-2} at 35 DAE (Table 1), indicating a direct relationship with the reduction in productivity observed in the period. These results are in agreement with those of other authors, who observed that competition with weeds always causes damage to sunflower productivity, which depends on the species present, the population of weeds and of the sunflower cultivar (Silva et al., 2012; Alves et al., 2013).

Comparing the coexistence and control periods, it was observed that there was no difference in PROD only at 14 and 21 DAE (Table 3). Thus, in the initial periods (up to 7 DAE) PROD is greater in the coexistence, while from 28 DAE it is greater in the control periods. So, the control carried out until the end of the crop cycle prevented 46.5% of PROD losses, compared to the same period of coexistence. It should be noted that the damage caused by weed interference is irreversible, and the damage is not recovered after its control (Agostinetto et al., 2014).

The treatments in which the sunflower was kept in the absence of weeds during the initial growing periods allowed us to estimate the period in which the wild radish can emerge and interact with the crop, without causing damage to PROD (Figure 1). Thus, considering 5% of the maximum productivity estimated by the model (3,235.94 kg ha^{-1}) as the cost of chemical control, it was determined that the PBI occurred from the emergency until 13 DAE of the crop, while the TPIP was 17 DAE and the CPIP consist of the period from 13 to 17 DAE of the crop, in which the control practices must be effectively applied (Figure 1). However, the appropriate time for weed control would be at the end of the PBI, close to 13 DAE, as weeds are at the beginning of development and have low dry mass accumulation, when the control techniques adopted are generally more efficient (Cabral et al., 2013).



[1] Period before interference. [2] Critical period of interference prevention. [3] Total period of interference prevention. Vertical bars represent the confidence intervals (p≤0.05).

Figure 1 - Effect of wild radish control and presence on the productivity of sunflower crop, hybrid M734, and determination of the weed interference periods in the crop.

These results corroborate with those observed by Silva et al. (2012), that, for the same hybrid, found PBI at 15 DAE. For the AGROBEL 960 hybrid, the PBI was 21 DAE when the crop was in the presence of *Bidens subalternans* L. and wheat voluntary plants (Brighenti et al., 2004). Other studies evaluating competition periods, determined with different hybrids and sunflower cultivars, showed different results to the present study, with CPIP between 31 and 69 DAE (Furtado et al., 2012) and 10 to 49 or 21 to 56 DAE (Alves et al., 2013), however, in these studies the weeds remained competing until the end of the cycle, a fact that did not occur in the present study, due to the competitor's senescence.

The observed value for TPIP can be considered reduced compared to the values observed in the literature (Furtado et al., 2012; Silva et al., 2012; Alves et al., 2013); thus, the control carried out with herbicide without residual effect close to the PBI would be enough to release the culture from wild radish interference. However, as the weed community in the field is made up of a weed complex (Guglielmini et al., 2016) and in these situations the TPIP is higher, it is recommended to use herbicides with a residual compatible with the CPIP.

Wild radish competition for environment resources negatively affects the accumulation of dry mass, chapter diameter, weight of a thousand achenes and the productivity of the sunflower, hybrid M734, however it does not influence the plants height. The wild radish chemical control must be carried out at the end of the period before interference (PBI), that is, at 13 DAE of the sunflower, hybrid M734, and it is sufficient to keep the soil clean until the end of the total period of interference prevention (TPIP), which occurs until the 17 DAE of the culture.

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