Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.14, n.2, e5636, 2019
Recife, PE, UFRPE. www.agraria.pro.br
DOI:10.5039/agraria.v14i2a5636
Protocolo 5636 - 08/08/2018 • Aprovado em 02/01/2019

Bean yield loss in response to volunteer corn

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ABSTRACT: Volunteer corn can become a weed where beans are grown in succession to corn and there is little information on yield losses and economic threshold for volunteer corn on bean. The objective was to evaluate the effect of volunteer corn density and emergence timing on bean yield and economic threshold. The volunteer corn was planting at 0, 0.5, 1, 2, 4, 8 and 12 plants m^{-2} in two relatives emergence timing on bean crop (at bean emergence and seven days after bean emergence). The competitive effects on bean yield was high when volunteer corn emerge at bean emergence than late emergence. When volunteer corn emerges at early timing, the yield bean was reduced between 19.6 and 35.5% at one volunteer corn m^{-2}, while for late emergence of volunteer corn, the yield losses ranged from 11.1 and 19.7%. The bean yield had highest impact on economic threshold, indicating low corn densities to justify the control. The increase of grain yield, bean price, herbicide efficiency and reduction in control costs decreased the economic threshold of volunteer corn on bean. The volunteer corn shows high interference potential on bean. The early timing emergence and increase of density of volunteer corn growing with bean causes highest yield losses.

Key words: economic threshold; emergence timing; interference; *Phaseolus vulgaris*; *Zea mays*

Perda de rendimento de feijão em resposta ao milho voluntário

RESUMO: O milho voluntário se tornou uma planta daninha no feijão em sucessão ao milho e há poucas informações sobre a perda de rendimento e os níveis de danos econômicos desta planta sobre o feijão. O objetivo foi avaliar os efeitos da densidade e época de emergência do milho voluntário sobre o rendimento e nível de dano econômico no feijão. O milho voluntário foi semeado em 0, 0.5, 1, 2, 4, 8 e 12 plantas m^{-2} em duas épocas de emergência relativas ao feijão (na emergência do feijão e sete dias após emergência do feijão). A emergência precoce do milho voluntário causa maiores efeitos negativos sobre o feijão comparado com emergência tardia. A emergência precoce de uma planta de milho voluntário reduz entre 19,6 a 35,5% do rendimento do feijão, enquanto que a emergência tardia reduz entre 11,1 a 19,7%. A produtividade do feijão teve alto impacto sobre o nível de dano econômico, indicando que o controle se justifica em baixas densidades. Incrementos em rendimento de grãos, preço do feijão, eficiência do herbicida e redução nos custos de controle, diminuíram os níveis de dano do milho voluntário sobre o feijão. O milho voluntário apresenta alto potencial de interferência sobre o feijão. A emergência precoce do milho voluntário e o aumento da densidade causam altas perdas no rendimento da cultura.

Palavras-chave: nível de dano; época de emergência; interferência; *Phaseolus vulgaris*; *Zea mays*

Introduction

The weed interference affects bean growth and yield by competition for soil nutrients and water, and promote shading, showing several yield reductions that varies from weed species and densities (Salgado et al., 2006; Silva et al., 2008). In Brazil, average bean losses yield are estimated around 25% by weeds, which is equivalent to R$ 1 billion (Vidal et al., 2010).

Common bean is an option for off-season cropping succession following corn, and this comprising a cultivated area of 284,000 hectares in southern Brazil (Conab, 2017). As a result of this succession, kernels or seeds corn are dropped in the field for mechanized harvesting can germinate following bean crop, becoming a volunteer plant problematic (Sbatella et al., 2016; Marquardt et al., 2012b; Alms et al., 2016).

Volunteer corn causes yields losses and contaminate seed in several crops, such as soybeans, corn, beet, dry edible bean, and cotton. The soybean grain contamination was 46% at 16 plants of corn m^{-2} (Marquardt et al., 2012b; Alms et al., 2016; Sbatella et al., 2016). Infestations can occur at high densities due to excessive losses of grains and kernels during harvest, which may reach 9% (Souza et al., 2006), thus kernels and grain of corn in contact with the soil will outcome volunteer corn on the following crop.

The weed management in bean crop occur basically with the use of herbicides, due to the high efficiency and lower cost compared to other control methods (Galon et al., 2016). The use of most sustainable production systems that reduce the risk of residues in food and the environmental impact on agroecosystems can become an important management tool. Thus, weed management based on the economic threshold (ET) becomes an important economic and environmental tool that helps farmers to make decisions on weed control (Kalsing & Vidal 2013; Westendorff et al., 2014).

Previous studies have shown different threshold level of *Euphorbia heterophylla* and *Bidens pilosa* in bean crop (Machado et al., 2015; Galon et al., 2016), which can reduce crop grain yield in 60%. However, there is little information on yield losses and ET for volunteer corn on bean. As hypothesis of this study is that yield losses of beans are higher when volunteer corn emerges early and at low densities already justifies control in the crop. Therefore, the objective of this study was to evaluate the effect of volunteer corn density, emergence timing on bean yield and economic threshold.

Material and Methods

Field trials were conducted during 2015, 2016 and 2017 growing seasons at Dois Irmãos da Missões, RS, Brazil, and Frederico Westphalen, RS, Brazil. The data of bean cultivars, planting and emergence date, plant population, thermic sum, and rainfall are presented in Table 1. Soil at these locations was a typical dystrophic red latosol. The climate in the locations where the experiments were conducted, according to Köppen's Climate classification, is humid subtropical (CFA).

Table 1. Bean cultivars, planting and emergence date, plant population, crop cycle, thermal sum and rainfall.

Operations	Dois Irmãos das Missões, RS		Frederico Westphalen, RS
	2015	2016	2017
Cultivar	IPR Gralha	IPR Gralha	IPR Uirapuru
Planting date	Fev 03	Fev 29	Set 21
Emergence date	Fev 10	Mar 05	Set 28
Plant population	288.000	288.000	288.000
Crop cycle (DAE)[1]	88	83	90
Thermal sum[2]	987	772	1010
Rainfall (mm)	316	501	718

[1] Days after emergence. [2] Growing degree days (ºC day). Growing degree days were calculated using 10°C and 30°C as critical minimum and maximum temperatures, respectively.

The soil characteristics at Dois Irmãos das Missões were 60% clay, 2.6% organic matter, pH 5.6, phosphorus and potassium of the 3.8 and 176 mg dm^{-3}, respectively. At Frederico Westphalen were 60% clay, 3.2% organic matter, pH 6.2, phosphorus and potassium of the 4.5 and 120.5 mg dm^{-3}, respectively.

The experiments designs were randomized blocks design with four replicates. Two volunteer corn emergence timing were used: early emergence (bean and volunteer corn plants emerged at the same time) and late emergence (seven days after bean emergence) and seven volunteer corn densities (0, 0.5, 1, 2, 4, 8, 12 plants m^{-2}). The grains of volunteer corn F2 (DK 240 VT PRO2 hybrid) was planted hand randomly between the *bean*s rows of each plot at approximately 2 cm deep and adjusted according to the respective volunteer corn densities. In the 2015 and 2016 crop season, each experimental plot contained six rows and row spacing was 0.45 and 6.0 m long, and in 2017 crop season, the plots were five rows and row spacing was 0.45 and 4.5 long.

The experiments in 2015 and 2016 were established in no-tillage system following corn crop and the burndown was performed with glyphosate (1,080 g ae ha^{-1}). The fields were fertilized with 252 kg ha^{-1} of N, 184 kg ha^{-1} of P_2O_5 and 60 kg ha^{-1} of K_2O on the corn crop. The bean crop was fertilized with 67.5 kg ha^{-1} of N on V_3 stage. The experiment in 2017, bean crop was implemented in no-tillage in winter fallow area with burndown operation with paraquat (400 g ai ha^{-1}). The fertilization was performed with 57.5 kg ha^{-1} of N, 62.5 kg ha^{-1} of P_2O_5 and 37.5 kg ha^{-1} of K_2O. No herbicide was applied in post-emergence of bean during these experiments, and the plots were kept weed free other than volunteer corn by hand hoeing, removed at weekly intervals.

At the end of the growing season, bean grain yield was determined by manual harvesting of three central rows of each plot, and bean grain were adjusted to 13% moisture and expressed in kg ha^{-1}. The bean yield data was transformed into a yield loss (YL %) to the volunteer corn free.

The yield losses data were submitted to analysis of variance by the F test ($p < 0.05$), and the interaction between emergence timing and densities of volunteer corn presented for years since there was significant volunteer corn density by year interactions.

The data were adjusted to the nonlinear regression model of the rectangular hyperbola, that describes the behavior of the yield losses as a function of the volunteer corn density:

$$YL = \frac{(i \cdot D)}{\left[1 + \left(\frac{i}{a}\right) \cdot D\right]} \quad (1)$$

where:

YL - yield loss relative in volunteer corn free plots;

D - volunteer corn density;

i - the yield loss per unit of volunteer corn when the density approached zero; and,

a - maximum yield loss with the increase of volunteer corn density tends to infinity.

The adjustment of the data to the model was performed by the "*PROC NLIN*" procedure of the Statistical Analysis System (SAS) computer program, and the graphs were constructed by SigmaPlot 10.0. Furthermore, was calculated the D_{50} that indicate the volunteer corn density at which occurs 50% reduction in grain yield.

To calculate the economic thresholds (ET), we used the estimates of parameter *i* obtained from the equation cited before and the equation:

$$ET\left(\text{plants ha}^{-2}\right) = \frac{WC}{\left[Y \cdot P \cdot \left(\frac{i}{100}\right) \cdot \left(\frac{E}{100}\right)\right]} \quad (2)$$

where:

WC - weed control cost (herbicide and application, in US\$ ha^{-1});

Y - bean yield grains (kg ha^{-1});

P - bean prices (US\$ kg^{-1});

i - bean loss yield (%) per volunteer corn unit when the density level approaches zero; and,

E - herbicide efficiency (%).

The variable WC was estimated to be US\$ 36, 54 e 72 ha^{-1}; the for Y the values extrapolated from the average yield of the beans in the last five years in Southern Brazil, ranging between 500, 1,500 and 2,500 kg ha^{-1} (Conab 2017). The P was estimated in US\$ 0.5, 0.75 and 1 kg^{-1} (minimum, average and maximum values offered in the last five years in the average of Rio Grande do Sul) (Conab 2017); and for the herbicide efficiency (E) in the control of volunteer corn, the range of values consisted of 80, 90 and 100%.

Results and Discussion

A significant year by emergence timing, year by volunteer corn density and emergence timing by volunteer corn density were observed, suggesting that the yield bean effect of volunteer corn density and emergence timing was driven by growing conditions for each year (Table 2).

The bean yield in the volunteer corn free was estimated in 2,702, 503 e 1,220 kg ha^{-1} in 2015, 2016 e 2017, respectively. The low bean yield observed in 2016 crop season may partially explain by late planting date, low temperature during crop development, and frost in the reproductive stage bean (Table 1). The occurrence of frosts in early autumn is a factor limiting to bean production, and the high corn straw volume can be favored the increase negative effects on bean growth by low temperature and frost (Farinelli et al., 2010).

The bean yield loss results show that the rectangular hyperbola model had a good fit adjustment, showing coefficients of determination above 0.86 (Figure 1; Table 3). Volunteer corn can be highly competitive in bean, because corn is taller than bean, and can grow above canopy bean establishing light competition. The competitive effects on bean yield are high when volunteer corn emerge at bean emergence than late emergence (Figure 1).

In the 2015 and 2017 seasons, the values of the parameter *i*, estimated by the yield loss model were 35.5 and 27.1, respectively, when volunteer corn emerges simultaneously with bean (early) (Table 3 and Figure 1). However, in late

Table 2. Analysis of variance – F values and significance levels – for bean yield.

Source of variation	Pr < F
Year	<0.001
Emergence timing	<0.001
Density	<0.001
Year x Emergence timing	<0.001
Year x Density	<0.001
Emergence timing x Density	0.0338
Year x Emergence timing x Density	0.4028

Table 3. Hyperbole parameters model of the bean yield loss as a function of emergence timing and density of volunteer corn in 2015, 2016 and 2017.

Crop season	Volunteer corn emergence[1]	Equation parameters[2]			
		i	D_{50}	*a*	R^2
2015	Early	35.5 (3.1)	4.59	72.1(2.7)	0.99
	Late	11.7 (4.6)	>12	57.5 (16.0)	0.86
2016	Early	19.6 (3.8)	9.39	68.6 (7.8)	0.97
	Late	19.7 (4.3)	>12	43.7 (4.3)	0.96
2017	Early	27.1 (7.4)	6.16	70.2 (9.5)	0.97
	Late	11.1 (1.8)	>12	77.4 (11.8)	0.98

[1] Early emergence (bean and volunteer corn plants emerged at the same time) and late emergence (volunteer corn emerges seven days after bean emergence). [2] $Pr = [i.D]/[1+(i/a) . D]$, *i* = percentage of yield loss for addition one volunteer corn; *a*= yield loss maximum; D_{50} = volunteer corn density at which occurs 50% reduction in yield. R^2 = determination coefficient. Values in parentheses indicate the standard error.

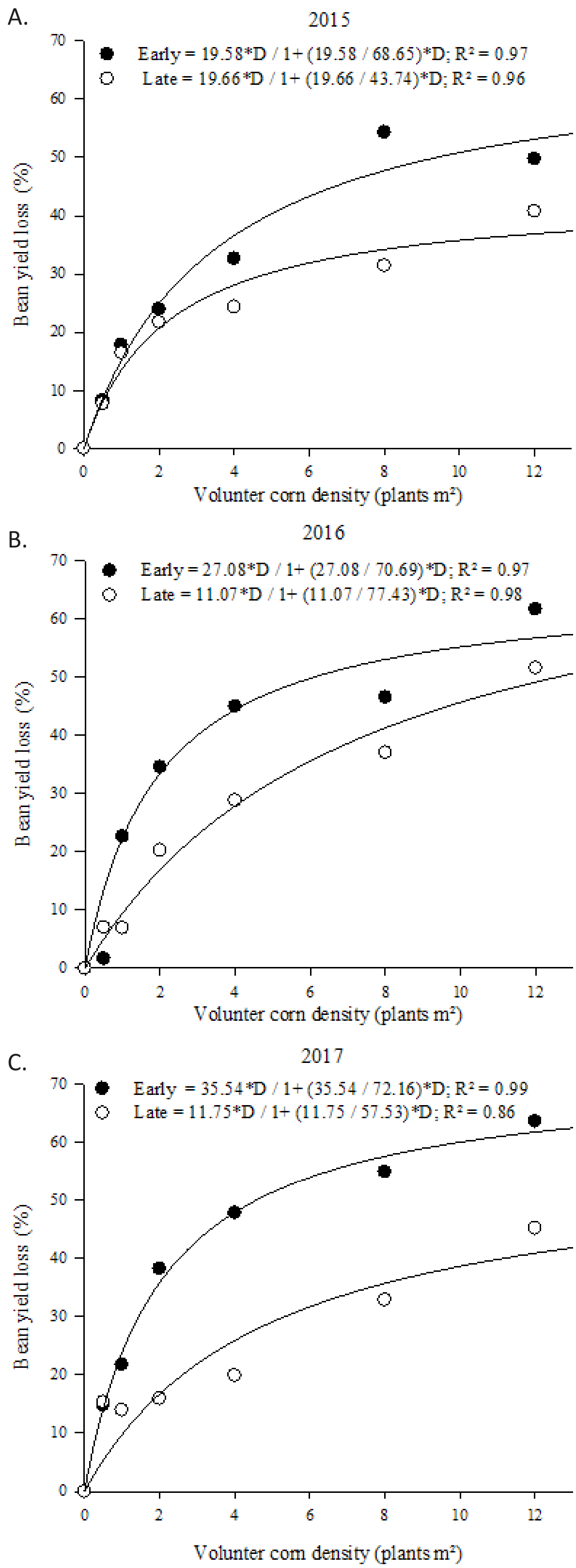

Figure 1. Bean yield loss as a function of emergence timing and volunteer corn density. Early (bean and volunteer corn plants emerged at the same time) and late (volunteer corn emerges seven days after bean emergence).

volunteer corn emergence the values for *i* were 11 for both years. Already in 2016 season, the estimated *i* parameter was different than the other two season, has been shown very close between the emergence timing for volunteer corn. Early emergence plants show greater growth because has an advantage by accessing the resources of the environment, increasing the competitive ability, affecting substantially the crop (Agostinetto et al., 2004). The late planting date and low temperature during crops development and frost in the reproductive stage may explain the very close *i* values for different emergent timing of volunteer corn on bean.

Previous research also showed that volunteer corn growing in bean can be a highly competitive weed. Our results are consistent with those found by Alms et al. (2016) that found *i* = 39.7, and Marquardt et al. (2012b) observed *i* = 25, being these values obtained for the simultaneous emergence between volunteer corn and soybean. For dry bean, at each volunteer corn plant per square meter, the reduction on dry bean yield ranged from 6.5 at 19.3% (Sbatella et al., 2016). The yield loss from volunteer corn in this study is substantially higher than level of yield loss from weeds such as *Euphorbia heterophylla* (Machado et al., 2015) and *Bidens pilosa* (Galon et al., 2016). According to these authors, the values of *i* were 5.5 and 2.4% for *E. heterophylla* when the weed emerged seven days before and simultaneously with the bean, respectively, and while to *B. pilosa* the values of *i* ranged from 3.4 to 12.8%.

Volunteer corn has competitive advantages growing on bean, because it has a different canopy architecture, which allows intense shading under crop. In addition, corn is a C4 plant, and has a highly developed root system causing high depletion on water and soil nutrients, and these traits confer a high competitive ability compared to weeds (Marquardt et al., 2012 a, b; Caratti et al., 2016). It is likely that the impact of volunteer corn on crops as bean or soybean are related to direct competition for light due to its higher height, which to grow above the crop canopy, causing a shading (Caratti et al., 2016). Since the bean is a crop with lower competitive capacity with weeds, because it presents slow initial growth and because it is enclosed in the group of crops that less shade the soil (Manabe et al., 2015).

Our results are consistent with previous reporters for cotton, soybean, beet and dry bean in competition with volunteer corn. Bean yield reduction around 13% for each volunteer corn weed (Sbatella et al., 2016). The interference of volunteer corn reduced 41% of soybean yield when the weed emerges at the same time as soybean; however, when the volunteer corn emerged 21 days after soybeans, not there was a loss of income (Marquardt et al., 2012b). Volunteer corn also caused a reduction in the yield of sucrose in beet, reaching a reduction of 19% for each volunteer corn weed per square meter (Kniss et al., 2012). Similarly, volunteer corn reduced 34% of cotton yield for a population of 5.25 plants m^{-2} (Thomas et al., 2007).

The D_{50} that represent the volunteer corn density needed to reduce 50% of bean yield, thus, volunteer corn that emerged after seven days to bean was much less competitive than volunteer corn that emerged simultaneously with bean. The time of volunteer corn emergence comparative to the crop was critical in determining the outcome of bean yield loss, being that the D_{50} ranged from 4.59 to 9.4 plants per square meter when early emergence and higher densities (>12 plants m^{-2}) were required for similar yield loss on bean at late emergence (Table 3). The similar results were observed by Marquardt et al. (2012 a, b), which found low interference when volunteer corn emerge after the crop.

The values of *a* (maximum asymptote) of the rectangular hyperbola represent an estimated yield loss when the volunteer corn density tends to infinity. This parameter allows the comparison of maximum yield losses between the relative emergences timing of volunteer corn. The maximum yield loss ranged from 68.6 to 72.1% for early emergence, however, in late emergence, yield loss ranged from 77.4 to 43.7% (Table 2).

The high losses of bean yield due to the increase of volunteer corn density, agree with found by Alms et al. (2016), which verified a maximum yield loss in soybean of 71% for three plants m^{-2} of volunteer corn. The interference effects on bean yield from weeds is lower than volunteer corn, where the impact of high density of *E. heterophylla* (23 plants m²) reduce 54% of bean yield (Machado et al., 2015) and maximum losses for different bean cultivars ranging from 15.4 to 43.6% (density ranging from 0 to 50 plants m²) in competition with *Bidens pilosa* (Galon et al., 2016).

The bean yield potential is the parameters that had higher impact on ET compared with the other approaches in this study, regardless of the volunteer corn emergence timing and crop seasons (Figure 2). The time weed emergence or

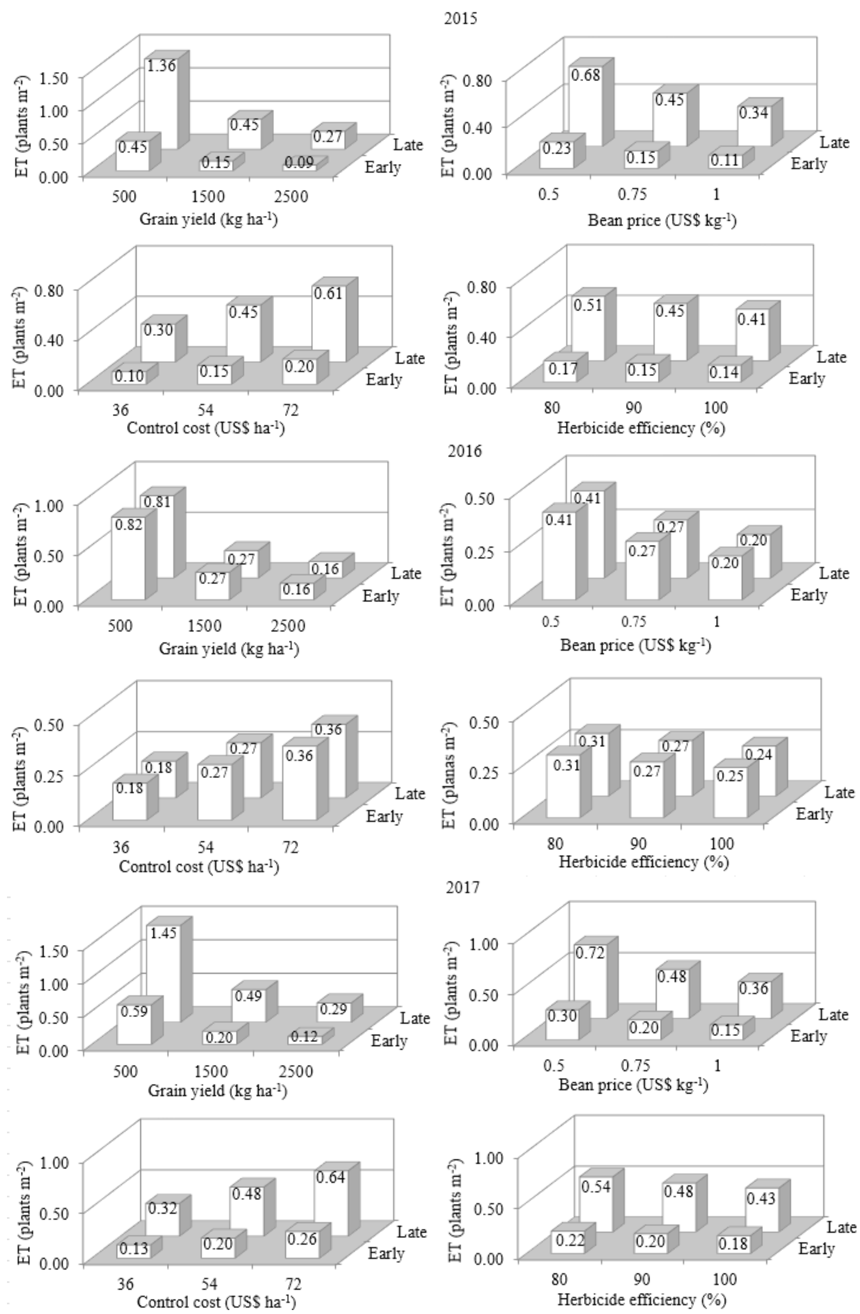

Figure 2. Economic threshold (ET) of volunteer corn emerged at different time on bean as a function of estimates of grain yield, bean prices, weed control cost, herbicide efficiency. Early: volunteer corn emerging at the same time as bean emergence; and Late: volunteer corn emerging seven days after bean emergence.

early competition have critical effects on crop yield (Page et al., 2009). The crop tolerance to interference of volunteer corn is increased by high expected yield and delay on time of volunteer corn emergence. Considering raise bean yield potential from 500 to 2,500 kg ha^{-1}, the ET was reduced by 80%. Similarly, the reduction on bean yield caused by delay in volunteer corn emergence was 67%.

In 2015 and 2017 seasons, the ET values were very similar and the ET reduction can be observed when volunteer corn emerge simultaneously with the crop comparing to later emergence (Figure 2). Considering the crop yield expectation from 500 to 2,500 kg ha^{-1}, the ET reduced, on average, from 1.40 to 0.28 corn m^{-2} for late emergence of volunteer corn, notwithstanding when the emergence was synchronized the ET values were even lower, on average, from 0.52 to only 0.10 corn m^{-2}. In contrast, in 2016 season, the ET was similar between the emergence times of volunteer corn, explained by the similar *i* values found in the rectangular hyperbole model (Table 3). The results supported that in situations with high yield potential, the weed control under even very low densities of volunteer corn becomes more profitable. Alternatively, in situations with low yield expectation, the higher densities of volunteer corn may be tolerated in order to be economically viable.

The increase in the price of bean also outcomes in a reduction in ET values by up to 50% (Figure 2). In 2015 and 2017 season, there was a more substantial reduction on ET when volunteer corn emerged simultaneously with bean crop, about 67% reduction in ET values comparing to late emergence of volunteer corn. In the scenario of the increase in the expectation of beans price from US$ 0.5 to 1.0 kg^{-1}, the ET values were reduced from 0.68 to 0.34 plant m^{-2} and 0.72 to 0.36 plant m^{-2} in the 2015 and 2017 season, respectively, when the corn emerged seven days later. Yet, when the volunteer corn emerged along with the beans, the ET reduction was lower, ranging from 0.22 to 0.11 plant m^{-2} in 2015 season and from 0.29 to 15 plants m^{-2} in 2017 season.

On the other hand, in the 2016 season, as highlighted above for the values of expected yield of the crop, the values of emergence season of the volunteer corn did not, however, differ the reduction of ET values due to the increase in price expectation behaved in a similar way to other years of cultivation (Figure 2).

The bean yield potential can vary according to the edaphoclimatic conditions and management crop practices, thus, due to the excess of rainfall in the planting timing of bean there was a delay in sowing the crop, which resulted in low temperature during crop growth reducing the thermal sum and consequently the bean yield. Other factors that reflect on bean yield are soil fertility and the crop management adopted, while the prices practiced in the region vary according to the domestic market, quantity in grain stock, grain demand and quality of the final product (Machado et al., 2015).

The ET decrease with the increase of the herbicide efficiency in the control of weeds, while maintaining the other fixed factors (Figure 2). The ET was lower in early corn emergence compared to the later emergence. The increase of the control efficiency from 80 to 100% when corn emerged seven days after bean, caused the ET reduced from 0.51 to 0.41 plant m^{-2} and 0.54 to 0.43 plant m^{-2} in the 2015 and 2017 season, respectively. Already in early corn emergence, the reductions ranging from 0.17 to 1.34 plants m^{-2} in 2015 season and from 0.22 to 0.18 plant m^{-2} in 2017 season. However, the emergence timing of the volunteer corn did not differ in 2016 season.

With different behavior of the other parameters, with the increase of the cost of the control raised the volunteer corn density to reach ET. Regarding the corn emergency season, in 2015, with an average control cost of US$ 54 ha^{-1}, ET reduced from 0.45 to 0.15 plant m^{-2} when volunteer maize emerged seven days later and together with beans, respectively. In 2016 season, the emergency timing did not alter the ET, a fact explained by the occurrence of frost at the end of the crop cycle. In 2017 season, the results were similar to 2015 season, where considering an average control cost in the southern region of US$ 54 ha^{-1}, the ET reduced from 0.48 to 0.20 plant m^{-2} when volunteer corn emerged seven days after bean and at the same time with beans, respectively.

Among the simulations performed, only 3.3% of the simulated scenarios had ET greater than one volunteer corn per square meter, and in only 15% of the simulated scenarios the ET values were higher than the lowest density used in the study (0.5 plant m^{-2}) allowing control even at low densities. Similar results were found by Sbatella et al. (2016), where the estimates for control of volunteer corn are justified at 0.1 to 0.6 plant m^{-2}. According to these authors, the volunteer corn control measures should not be delayed 15 days after planting, when volunteer corn densities are near one plant m^{-2}. Alms et al. (2016) point out that the cost of herbicide control would be economically feasible even at volunteer corn density of less than one plant m^{-2}. The ET of volunteer corn in beans is extremely low when compared to other weeds, such as *Bidens pilosa* and *E. heterophylla* in beans (Machado et al., 2015; Galon et al., 2016).

The results indicate the need to adopt effective weed management to avoid the establishment of volunteer corn along the bean crop. The use of burndown and pre-emergent herbicides are capable of providing adequate conditions for crop implantation on weed-free plots. Due to the high loss of yield caused by the competition imposed by the volunteer corn, it is worth mentioning the need of researchers that investigate the herbicide options labeled for bean with adequate efficacy. The option for controlling volunteer corn in bean enclose ACCase inhibiting herbicides, however, there no reports in the literature about volunteer corn control in bean. In soybean, the yield is saved through the effective control of volunteer corn, with a single application of clethodim (108 g ha^{-1}) at the V6 stage of soybean; or by means of two sequential applications with the soybean with V3 and V6 stage (López-Ovejero et al., 2016). However, results from Marquardt & Johnson (2013) found that there was no difference between the early or late applications of clethodim at any of the volunteer corn densities.

Conclusions

The volunteer corn shows high interference potential in bean. The early timing emergence and increase of density of volunteer corn growing with bean causes highest yield losses. Regardless of the simulations, ET of the volunteer corn did not exceed 1.45 plants m^{-2}, reaching the minimum population that needs control of 0.09 plants m^{-2}. These values indicate the need for management of this volunteer species even at low densities or even before sowing, under risk of economic losses. Further studies are required to determine control of volunteer corn in bean with selected post-emergence herbicides.

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