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Article

Interference of GR® Volunteer Corn Population and Origin on Soybean Grain Yield Losses

Interferência da População e da Origem do Milho Voluntário RR® nas Perdas de Rendimento de Grãos da Soja

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ABSTRACT - The cultivation of GR® maize prior to soybean, mainly in the no-tillage system favors the higher occurrence of GR® volunteer corn interfering in soybean crops. Volunteer corn originate from seeds that were lost during harvest or from non-harvested seeds from the field; these are individual seeds, originating individual plants, or several seeds adhered to segments of the rachis, which originate clumps. Volunteer corn in the form of clumps predominates in soybean crops, but little information about its effect on soybean is available in the literature. During two years, three experiments were carried out with the objective of evaluate the impact of the interference of GR® F_2 generation volunteer corn populations coming from individual and clump seeds (seven corn plants emerged at the same point) over soybean yield components and grain yield. The results show that losses in soybean yield components and grain yield are influenced by the population and origin of volunteer corn. Clumps cause losses over 90% for populations above four clumps m^{-2}, while the mean maximum loss observed for individual plants was 83% in the largest studied populations. Soybean yield decreased significantly when competing with populations below one plant or clump m^{-2}, being 16% and 46% in the population of 0.5 individual plant and clump m^{-2}, respectively.

Keywords: *Glycine max*, *Zea mays*, competition, individual plants, clumps, harvest losses.

RESUMO **-** *O cultivo de milho RR® precedendo a soja, principalmente no sistema de semeadura direta, favorece a maior ocorrência de plantas voluntárias de milho RR®, interferindo em lavouras de soja. Plantas voluntárias de milho são originadas a partir de sementes perdidas na colheita ou não colhidas do campo, sendo estas, sementes individuais, que originam plantas individuais, ou várias sementes aderidas a segmentos da ráquis, que dão origem às touceiras. Milho voluntário na forma de touceiras predomina em lavouras de soja, porém poucas informações sobre seu efeito sobre a soja estão disponíveis na literatura. Durante dois anos foram realizados três experimentos em campo com o objetivo de avaliar o efeito das interferências de populações de milho voluntário RR® F_2 oriundas de sementes individuais e de touceiras (sete plantas de milho emergidas no mesmo ponto) sobre os componentes do rendimento e o rendimento de grãos da soja. Os resultados demonstram que as perdas nos componentes do rendimento e no rendimento de grãos da soja são influenciadas pela população e origem do milho voluntário. Touceiras de milho causaram perdas superiores a 90% para populações acima de quatro touceiras m^{-2}, enquanto a perda máxima média observada para plantas individuais foi de 83% nas maiores populações estudadas. O rendimento*

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de grãos da soja reduziu de forma expressiva quando em competição com populações inferiores a uma planta ou touceira m^{-2}, sendo de 16% e 46% na população de 0,5 planta individual e touceira m^{-2}, respectivamente.

Palavras-chave: *Glycine max*, *Zea mays*, competição, plantas individuais, touceiras, perdas na colheita.

INTRODUCTION

Each plant occurring where it is not desired and where it causes damages (economic, social and/or environmental) is considered as weed (Shaw, 1982). In this definition, it is possible to include volunteer plants of corn or "*tigueras*". Volunteer corn (VC) is originated by seeds that are lost during the harvest or that were not harvested and it occurs in the form of individual seeds, whole cobs or rachis segments containing various seeds in a same point, which originate individual plants and clumps, respectively (Newcomer, 1971; Beckett and Stoller, 1988). VC plants originated by clumps predominate in soybean cultivations (Deen et al., 2006), and their management is difficult due to the fact that the germination of the seeds that compose them is nonuniform, resulting in emergence flushes (López-Ovejero et al., 2016).

The occurrence of VC in soybean cultivations is favored in three main situations: a) in production systems where corn cultivation precedes soybean, within the same crop year ("second harvest") or in the following harvest (Deen et al., 2006); b) the no-tillage systems (kernels are not buried), since it allows the permanence of viable corn propagules over the soil surface until the environmental conditions help germination and emergence (Beckett and Stoller, 1988); and c) in the cultivation of glyphosate resistant (GR®) corn (Davis et al., 2008). Although VC in soybean crops had been reported before the introduction of herbicide-tolerant transgenic crops (Andersen, 1976), the introduction of GR® corn in production systems has been associated with a higher occurrence (Davis et al., 2008).

Whenever soybean cultivation is preceded by corn, VC plants could be a potential problem (Deen et al., 2006). Due to the fact that it presents C4 photosynthetic pathway, corn has advantages in relation to soybean, which presents C3 photosynthetic pathway, mainly under extreme conditions (Sage, 2004). Moreover, corn competes with soybean for resources from the environment and it grows quicker, mainly at the initial development stage; this determined the damage level in the culture (Chahal et al., 2014).

In soybean, the interference degree of weeds is directly influenced by the coexistence period and by the population (Pitelli, 1985). The competition of VC populations lower than a plant m^{-2} in soybean results in direct losses in the yield components and in grain yield - these losses may be higher if VC comes from clumps (Marquardt et al., 2012; Chahal et al., 2014; López-Ovejero et al., 2016). In the population of four clumps m^{-2}, the grain yield of soybean reduced by 69.9% (López-Ovejero et al., 2016) and by 25% in competition with 6 individual plants m^{-2} (Beckett and Stoller, 1988). The occurrence of VC plants also causes indirect losses in soybean, such as harvest difficulties, post-harvest grain contamination (Deen et al., 2006), as well as being hosts for pest-insects and pathogens (Nepomuceno et al., 2007).

Weed management in soybean must be performed respecting the period before interferences (PBI) (Radosevich et al., 1997). Thus, the control of GR® VC may be carried out during the pre-emergence of soybean, with the application of the herbicides diclosulam, chlorimuron + sulfometuron and imazapic + imazapyr (Piasecki and Rizzardi, 2016), and during post-emergence, with Acetyl-CoA Carboxylase (ACCase) enzyme inhibitor herbicides (Marca et al., 2015).

Glyphosate controls non-tolerant VC in GR® soybean, but it does not control GR® corn (López-Ovejero et al., 2016). Thus, is necessary to adopt specific herbicides to control it, and this contributes to the increase in production costs (Deen et al., 2006). The occurrence of an infesting population of VC GR® in soybean is minimized avoiding the cultivation of GR® corn before soybean (Davis et al., 2008) and with an increase in the effectiveness of the processes involving the cultivation of corn, in order to increase the effectiveness of the harvest (hybrid choice, seeding period and density, spacing, management, machine regulation, harvest time and operation speed, etc), in order to minimize losses.

Keeping in mind the negative interferences caused by VC on soybean, the objective of this work was to evaluate the impact of GR® F_2 VC populations coming from individual seeds and clumps over the yield components and grain yield of soybean.

MATERIAL AND METHODS

Three experiments were carried out during the 2011/2012 and 2013/2014 season. The experiments were developed in the randomized block design with four replications. All the experiments were established at Centro de Pesquisa e Extensão Agropecuária (CEPAGRO) of the Universidade de Passo Fundo (UPF), Passo Fundo, Rio Grande do Sul state, Brazil.

In the first year, an experiment (experiment 1) where individual seeds originated individual corn plants was conducted with the 0; 0.5; 1; 2; 4; 8; 10; and 16 m^{-2} populations. In order to establish the respective populations, seeds were aleatory distributed on the soil surface of the 4.4 m^2 (2.0 x 2.2 m) experimental units and, after that, they were manually buried at approximately 3.5 cm depth. Immediately after corn seeding, the soybean cultivar BMX Impacto GR® was sowed mechanically in a density that provided the establishment of 30-soybean plants m^{-2}, spaced 50 cm apart.

In the second year, two experiments were conducted, where individual seeds (experiment 2) and clumps (experiment 3) originated populations of 0; 0.5; 1; 2; 4; 8; 10; and 12 individual plants or clumps m^{-2}, respectively. Each clump was constituted of rachis segments containing seven corn plants on an average. The VC populations, coming from seeds and clumps, were distributed randomly and, after that, they were buried manually at approximately 3.5 cm depth in plots of 17.5 m^2 (3.5 x 5 m). Immediately after corn seeding, the soybean cultivar BMX Turbo GR® was sowed mechanically in a density that provided the establishment of 30-soybean plants m^{-2}, spaced 50 cm apart.

In the three experiments, corn and soybean seeding was performed on the same day every year, and corn emergence occurred one day before, in relation to soybean. Soybean was fertilized with 5.6 ha^{-1} N, 78.4 kg ha^{-1} P_2O_5 and 50.4 kg ha^{-1} K_2O. Soybean seeds were inoculated with *Bradyrhizobium japonicum*, and treated with insecticides and fungicides recommended for the culture (Embrapa, 2012).

Corn F_2 generation used to form the populations in the three experiments was originated from ears of the AG 8088 PRO_2® hybrid, collected manually the year before each experiment. After corn emergence, the populations were manually adjusted according to each treatment. In order to avoid the interference of other weeds, the herbicide glyphosate was sprayed at the rate of 720 g a.e. ha^{-1}, as needed, during the culture cycle. Pests and diseases were controlled according to the recommendation (Embrapa, 2012).

In experiment n. 1, the height of soybean plants was evaluated in ten aleatory plants from the ground to the tip of the last fully expanded trifoliate leaves, at the physiological ripeness stage. The mean number of nodes (MNN) and grains (MGN) per plant was obtained through the count of ten soybean plants per plot, at the physiological ripeness stage. Grains were harvested in a two-meter long sample area in the two central lines of the plots, totalizing a 2.2 m^2 area. Following the harvest, the material was threshed and weighed, and the grain moisture content was determined. The soybean grain moisture content was corrected to 13%, and the grain yield per hectare (kg ha^{-1}) was estimated. The thousand grain weight (TGW) was calculated from weighing 250 grains collected randomly from the total harvested.

In the experiments n. 2 and 3 the same evaluations were performed on the same dates. After 60 days from the emergence (DAE), the evaluation of soybean and corn height was performed on 10 aleatory plants or clumps per experimental unit. Soybean height was determined as described for experiment 1. Corn height was measured from the ground to the tip of the last fully expanded leaf in corn, i.e., the last leaf with the leaf sheath base not touching the corn stalk at the base of its blade. For the VC clumps, the average height of all the plants in each clump was considered. The shoot dry weight (SDW) of soybean was quantified at the R5.3 stage (grains with 26 to 50% of development) trough collecting ten aleatory plants close to the soil per plot, following drying in an oven at 60 °C to constant weight. The weight of the 10 plants was used to calculate the soybean SDW m^{-2} (g) by the rule of three, considering that the collected sample corresponded to 0.33 m^2.

The soybean grain yield were obtained through harvesting from a sampling area of 7.5 m^2 in each plot. Grain yield, TGW and MGN per plant were determined according to the methodology described for experiment 1.

With the data about grain yield in the three experiments, it was possible to calculate the percentage losses in relation to the treatments that were kept free from corn plants, according to the equation: Loss (%) = [(Ra-Rb)/Ra]*100, where: Ra = yield without corn and Rb = yield with the presence of corn. The non-linear regression model of the rectangular hyperbole proposed by Cousens (1985) was adjusted to the percentage data about losses: Yl = (i*P)/[1+((i/a)*x)], where: Yl = yield losses (%); P = VC populations; i = yield loss percentage per VC unit when its population is close to zero; a = yield loss percentage when population tends to infinite.

Data were analyzed as for normality by the Shapiro-Wilk test and homoscedasticity by the Hartley's test and, subsequently, they were submitted to analysis of variance of the regression (ANOVA) ($p<0.05$). The effect of the populations was calculated by regression, testing the linear, quadratic polynomial, exponential and hyperbolic adjustment models, at 5% significance.

RESULTS AND DISCUSSION

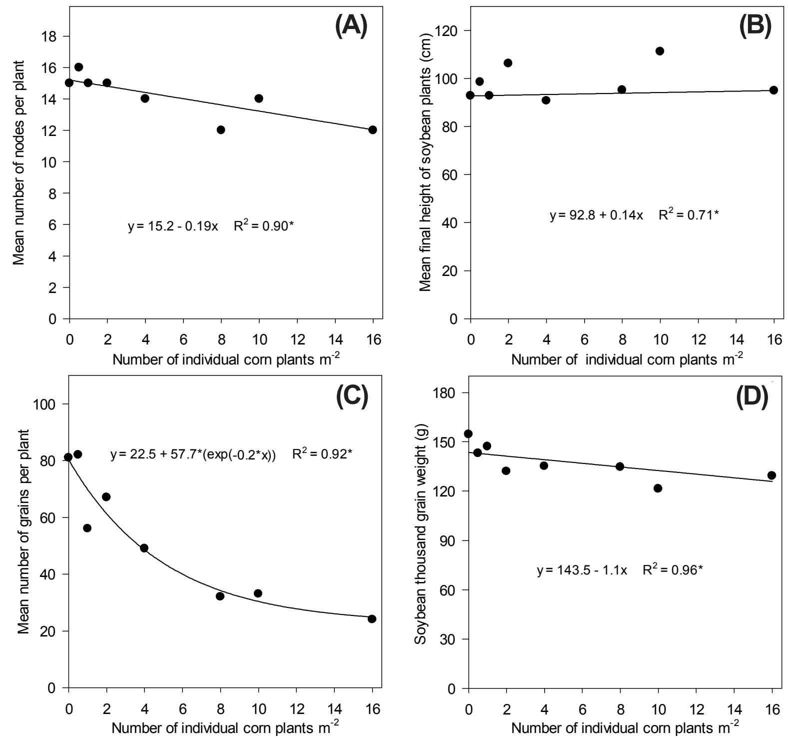
In experiment 1 (first year), according to the interference executed by populations of individual corn plants, there was linear reduction for the mean number of nodes per plant and for the thousand grain weight (TGW) of soybean. The average number of grains per plant decreased exponentially; accentuated effects were observed up to the population of eight individual plants m^{-2}. Starting from it, it tended to stabilize. Soybean height increased linearly with the increase in the interferences on day 60 after emergence (DAE) (Figure 1).

For the experiments 2 and 3 (second year), due to the interferences of VC populations and origins, there was an exponential reduction for the shoot dry weight (SDW) , for the mean number of grains (MGN) and for the TGW of soybean, whereas the increase in soybean height was linear (Figures 2 and 3). The greatest interferences impacts on soybean were observed up to the population of eight plants or clumps m^{-2}, tending to stabilize. For soybean in competition with populations starting from eight clumps m^{-2} there was no grain yield and, consequently, the grain number and TGW could not be calculated (Figure 3).

The average loss variation (experiments 1 and 2) between the studied lowest and biggest populations of individual VC plants in relation to the competition-free treatment was from 11.6% to 66.4% for MGN, from 5.9% to 65.8% for SDW and from 0.95% to 16.1% for TGW (Figures 1 and 2); on the other hand, the loss variation between the smallest and biggest VC clump population under study (experiment 3) was from 15.3% to 100% for MGN, from 31.7% to 79.3% for SDW and from 5.9% to 100% for TGW (Figure 3). As for these variables, the results allow deducing that the competition caused by corn clumps leads to greater losses on soybean yield components.

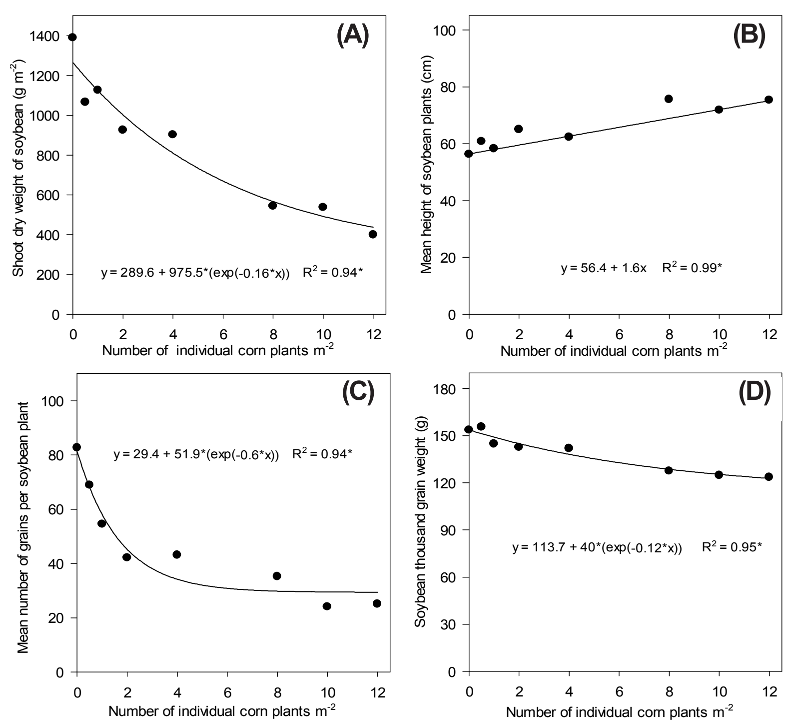
The reduction in the soybean yield components in the three experiments indicates that the intense competition executed by VC over soybean interfered negatively on the number of produced pods per plant and/or caused a decrease in the grain number per pods. It is far more likely that it has reduced the number of vegetables per soybean plant, since this variable is more responsive to competition stress among competing species, whereas the number of grains per pods and the grain weight have more individual genetic control, having less competition influence (Board et al., 1995).

The average height of individual plants and clumps of VC on day 60 DAE was 2.6 and 2.2 times higher than soybean, respectively (Figures 2, 3 and 4). Thus, corn had a preferential access to light and it shaded soybean, which may have contributed to the lower production of photo-assimilated compounds by the culture and, probably, it increased the photorespiration of soybean (plant C3). Among the main consequences of the photosynthesis reduction and higher respiration, there is a lower energy accumulation by the plant, which influences directly the yield and shoot dry weight accumulation by the affected plants (Taiz and Zeiger 2004). In this case, the probable



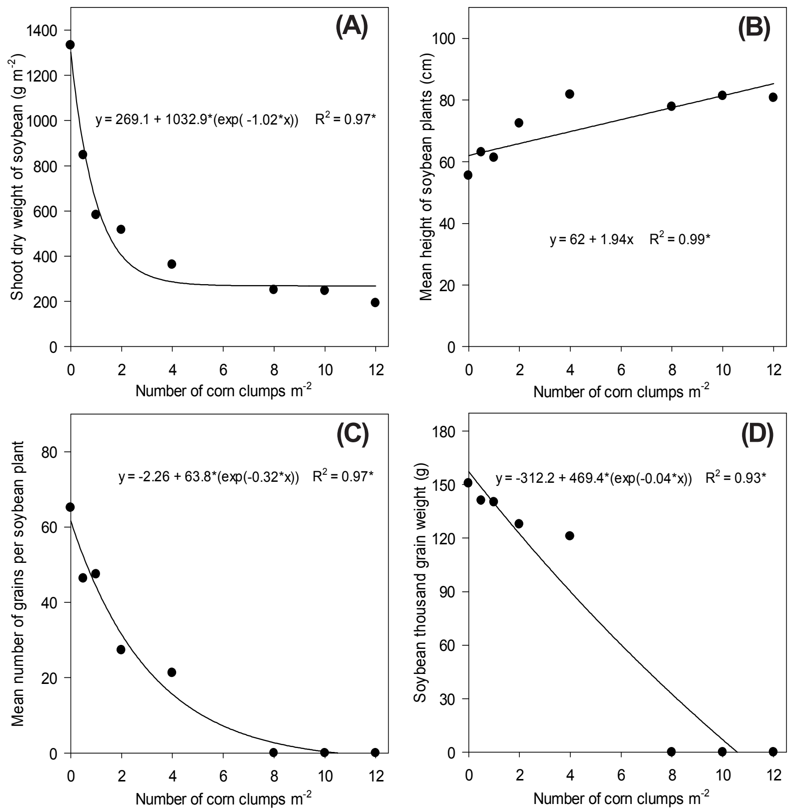
* Significant at p<0.05.

Figure 1 - Effect of populations of GR® F_2 volunteer corn individual plants over the development of soybean (experiment 1). (A) mean number of nodes per soybean plant; (B) average height of soybean plants (cm) on day 60 after emergence (DAE); (C) average number of grains per plant; (D) soybean thousand grain weight (g) (TGW). Passo Fundo, RS.



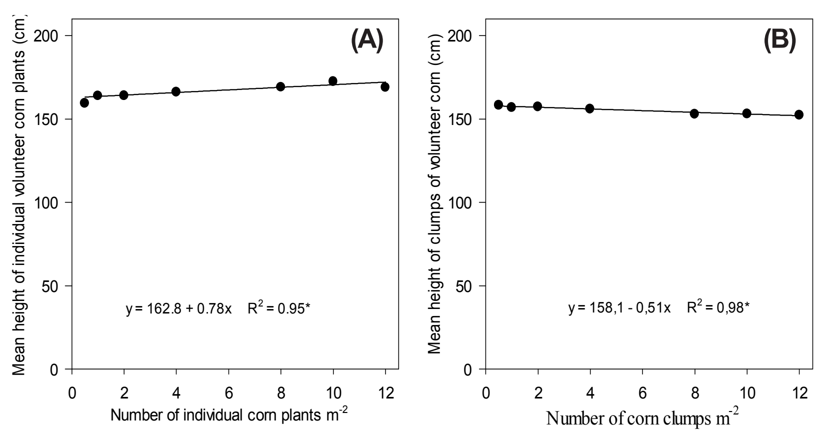
* Significant at p<0.05.

Figure 2 - Effect of populations of GR® F_2 volunteer corn individual plants over the development of soybean (experiment 2). (A) shoot dry weight of soybean (g m^{-2}) at the R 5.3 stage; (B) average height of soybean plants (cm) on day 60 after emergence (DAE); (C) average number of grains per plant; (D) soybean thousand grain weight (g) (TGW). Passo Fundo, RS.



* Significant at $p<0.05$.

Figure 3 - Effect of populations of GR® F_2 volunteer corn clumps over the development of soybean (experiment 3). (A) shoot dry weight of soybean (g m^{-2}) at the R 5.3 stage; (B) average height of soybean plants (cm) on day 60 after emergence (DAE); (C) average number of grains per plant; (D) soybean thousand grain weight (g) (TGW). Passo Fundo, RS.



* Significant at $p<0.05$.

Figure 4 - GR® F_2 volunteer corn height (cm) on day 60 after emergence (DAE) according to populations of corn individual plants and clumps in competition with soybean (experiments 2 and 3). (A) average height of individual corn plants (cm); (B) average height of corn clumps (cm). Passo Fundo, RS.

resource of environment that limited the growth of soybean and caused expressive losses in the yield components and grain yield was light, especially for corn originated from clumps (Figures 1 to 5).

Alterations in light quality and intensity incising on soybean plants had a negative impact on development. Plants from the infesting community reflect light at a certain wave length and they stimulate height growth even before the establishing of competition, as a way to capture the most of available radiations and to shadow weeds (Radosevich et al., 1997). This effect depends on the quality of received light, culture and composition of the infesting community (Silva et al., 2009).

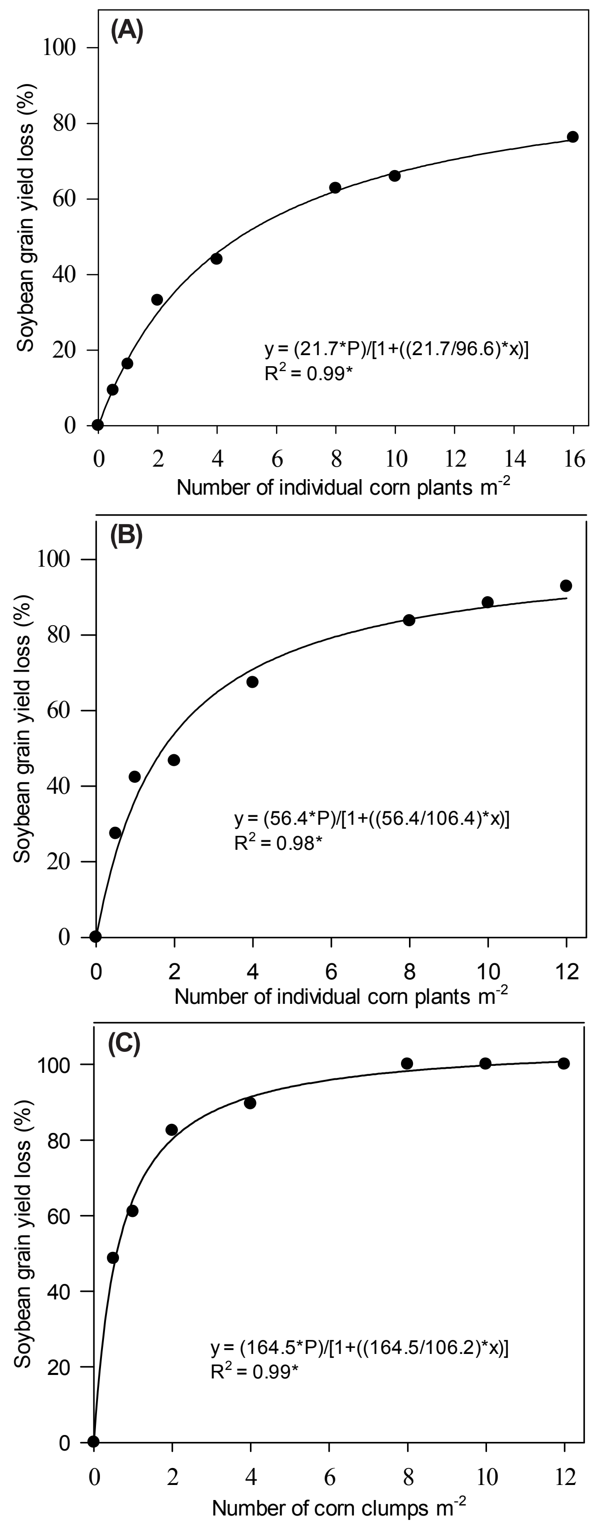


Figure 5 - Percentage losses in soybean grain yield according to the interference of populations of GR® F_2 volunteer corn individual plants (A and B) and clumps (C). (A) experiment 1; (B) experiment 2; (C) experiment 3. Passo Fundo, RS.

Before shadowing, the quality of light is perceived by phytochromes, cytochromes and phototropin and, thus, it adjusts the plant growth according to the presence of other plants (Taiz and Zeiger 2004). The relation of the red/far-red radiation (R/FR), perceived by phytochromes, plays an important role in the induction of many morphological alterations in the architecture of plants (Balaré and Casal, 2000). The plant shadowing detected by the incidence of far-red light make them allocate a higher quantity of resources for the growth of the shoot, affecting the development of the root system, and possibly compromising the dispute for soil resources (Rajcan and Swanton, 2001).

Due to the competition with populations and origins of VC, the grain yield of soybean was expressively negative impacted. In experiment 1, losses varied from 9.8% to 75.6% in the populations of 0.5 and 16 individual VC plants m^{-2}, respectively (Figure 5A). In experiments 2 and 3, soybean in competition with populations of 0.5 and 12 corn individual plants and clumps m^{-2}, there were losses in the grain yield of soybean from 22.2% to 91.9% and from 46.4% to 100%, respectively (Figures 5B, C).

The high competition executed by corn clumps suppressed the growth of soybean starting from the population of eight clumps m^{-2}, where the culture did not have enough resources from the environment to produce grains (Figure 5C). In spite of the fact that no statistical comparisons were made between the effects of corn individual plants and clumps on soybean, the results obtained in the experiments 2 and 3 (performed under the same conditions) allow deducing that clumps have a greater negative impact over soybean in relation to individual plants. This effect is attributed to the higher number of plants per area contained in clumps.

Losses observed in the grain yield for soybean in competition with individual plants were consistent during the two study years and presented the same tendency. The high competitive capacity of corn in relation to soybean is highlighted in the results about grain yield, since, even in populations of 0.5, 1 and 2 individual plants m^{-2}, there was an average yield reduction of 16%, 27% and 42.3% (Figure 5A, B) respectively, whereas, in the same respective clump populations, losses were 46.4%, 64.5% and 80.3%. As for soybean in competition with population starting from four clumps m^{-2} there was a reduction above 90% in the grain yield of soybean (Figure 5C).

Starting from eight individual plants and four clumps m^{-2}, losses in the grain yield of soybean were less intense, with a tendency to stabilization (K) (Figure 5). Stabilization is probably due to the limitation in providing resources from the environment, due to the elevated interspecies and intraspecies competition of corn. As the plant population increased, the potential of providing resources by the environment becomes limiting, that is, the yield starts to become independent from the plant density starting from a certain infestation level (Radosevich et al., 1997).

It is possible to conclude that losses in the yield components and grain yield of soybean in competition with GR® F_2 volunteer corn are influenced by the population and the origin of corn. More accentuated losses in soybean occurred in the biggest populations and in corn originated from clumps; however, even with small populations, there are expressive losses. Volunteer corn presents a high competitive capacity with soybean, even in populations that are smaller than one plant or clump m^{-2}.

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