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INTERFERENCE OF VOLUNTEER CORN ON SOYBEAN GROWN UNDER CERRADO CONDITIONS

Interferência de Plantas Voluntárias de Milho RR[®] sobre a Soja Cultivada no Cerrado

ABSTRACT - The presence of volunteer corn plants in coexistence with soybean has been increasing since the introduction of glyphosate-resistant corn hybrids. This study aimed to evaluate the effect of interference of volunteer RR[®] corn plants at different densities on two RR[®] soybean cultivars. The experiment was conducted in Rio Verde, GO. The experimental design was a randomized block design in a factorial arrangement (2×5), with four replications. Factor A consisted of two soybean cultivars (BMX Potência RR[®] and M8210 IPRO[®]), while five densities of RR[®] corn plants per m² (0, 4, 8, 12, and 16) were adopted for factor B. The following evaluations were carried out for soybean: plant height, SPAD index, percentage of interrow closure, shoot dry matter, first pod height, number of pods per plant, 100 grain weight, and grain yield of grains. Soybean plant height presented a linear and positive relationship with the increased density of corn plants. Shoot dry matter, 100 grain weight, number of pods per plant, and grain yield were negatively affected by the increased density of volunteer corn infestation. The soybean cultivar M8210 IPRO[®] was more susceptible to corn plant interference when compared to the cultivar BMX Potência RR[®].

Keywords: soybean cultivars, *Glycine max*, glyphosate, weed competition, *Zea mays*.

RESUMO - A presença de plantas voluntárias de milho em convivência com a soja vem se acentuando desde a introdução no mercado de híbridos de milho resistentes ao glyphosate. O objetivo deste trabalho foi avaliar o efeito da interferência de plantas voluntárias de milho RR[®] em diferentes densidades em dois cultivares de soja RR[®]. O experimento foi conduzido no município de Rio Verde (GO). O delineamento experimental utilizado foi de blocos casualizados em arranjo fatorial (2x5), com quatro repetições. O fator A correspondeu a duas cultivares de soja (BMX Potência RR[®] e M8210 IPRO[®]). Para o fator B, foram adotadas cinco densidades de plantas de milho RR[®] por m² (0, 4, 8, 12 e 16). Foram realizadas as seguintes avaliações referentes à soja: altura de plantas, índice SPAD, porcentagem de fechamento das entrelinhas, massa seca da parte aérea, altura de inserção da primeira vagem, número de vagens por planta, massa de 100 grãos e rendimento de grãos. A altura de plantas de soja possui relação linear e positiva com o aumento na densidade de plantas de milho. Massa seca da parte aérea, massa de 100 grãos, número de vagens por planta e rendimento de grãos foram afetados negativamente pelo aumento na densidade de infestação de milho voluntário. O cultivar de soja M8210 IPRO[®] demonstrou ser mais suscetível à interferência das plantas de milho que o cultivar BMX Potência RR[®].

Palavras-chave: cultivares de soja, *Glycine max*, glyphosate, matocompetição, *Zea mays*.

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INTRODUCTION

Among the main exploited crops in the Brazilian agricultural production systems are the soybean under summer season conditions, sown between October and November, and the off-season corn, sown after soybean harvest. Due to the good profitability that the commercialization of both crops brings, soybean and maize have been commonly grown in succession in most agricultural properties in the Midwest of Brazil (Conab, 2018).

In areas cultivated with the soybean-corn succession, the occurrence of volunteer corn plants in the soybean field has been common. It is due to the loss of grains from the corn harvesting process, which may remain viable during the whole off-season, emerging before or during soybean cycle and interfering with the development of the soybean crop. This problem becomes even greater when the same technology that confers resistance to herbicides, such as RR[®] soybean and RR[®] corn, is used in these succession systems, being necessary to use herbicides belonging to other mechanisms of action to control volunteer plants (Petter et al., 2015).

There are several negative impacts on soybean cultivation due to the presence of volunteer corn plants, including grain contamination, difficulties in mechanized harvest, pest and disease hosting, and competition for resources necessary for plant development (Deen et al., 2006). Losses in soybean crop yield may vary according to soil type, climate conditions, phenological stage, infestation density, and interval of coexistence between the undesired species and soybean (López Ovejero et al., 2016; Piasecki et al., 2018).

Corn interference level on soybean development depends on several factors, such as infestation density (number of plants), location (row or interrow), and time when volunteer plants settle in the field. Besides these aspects related to the weed species, it is essential to observe factors related to the crop, for example, the possibility of verifying a different response of the interference imposed by corn plants as a function of the sowing of soybean cultivars with different growth habits and distinct development cycle (Nordby et al., 2007).

The impacts that the interference of volunteer corn plants can cause on soybean development were evaluated by Beckett and Stoller (1988), who verified a yield reduction of up to 25% in the presence of 5 to 6 corn plants per m². Marquardt et al. (2012a) found a soybean yield loss from 10 to 41% with the presence of 0.5 to 16 corn plants per m², respectively.

In this context, this study aimed to evaluate the effect of interference of volunteer RR[®] corn plants at different densities on the development of two RR[®] soybean cultivars sown under Cerrado conditions.

MATERIAL AND METHODS

The experiment was conducted in a field located in Rio Verde, GO, Brazil, at the geographical coordinates 17°46'01.10" S and 51°02'18.40" W and altitude of 828 m. The experiment was conducted from November 20, 2015, to March 28, 2016.

According to Köppen classification, the local climate is Aw type, i.e., a tropical climate with a dry season and characterized by more intense precipitations in the summer when compared to the winter. The mean precipitation and temperatures observed during the experimental period are shown in Figure 1.

The soil of the experimental area is classified as a dystrophic Red Latosol (Oxisol) (Embrapa, 2013). Before the experiment set up, soil samples (0–20 cm layer) were collected for the physicochemical characterization, with the following results: pH in CaCl₂ of 5.5, Ca²⁺ of 3.7 cmol_c dm⁻³, Mg²⁺ of 1.25 cmol_c dm⁻³, K⁺ of 0.15 cmol_c dm⁻³, Al³⁺ of 0.04 cmol_c dm⁻³, H⁺ + Al³⁺ of 1.6 cmol_c dm⁻³, P of 33 mg dm⁻³, S of 5.3 mg dm⁻³, OM of 25.5 g kg⁻¹, clay of 531 g kg⁻¹, silt of 54 g kg⁻¹, and sand of 415 g kg⁻¹ (clay loam texture).

The area where the experiment was set up was at fallow, with no plant species grown in the second season of 2015. Desiccation of emerged weeds in the experimental area was performed mechanically by a sequential herbicide application at a rate of 100 L per hectare. The first application was carried out at 20 days before sowing with glyphosate + 2,4-D amine

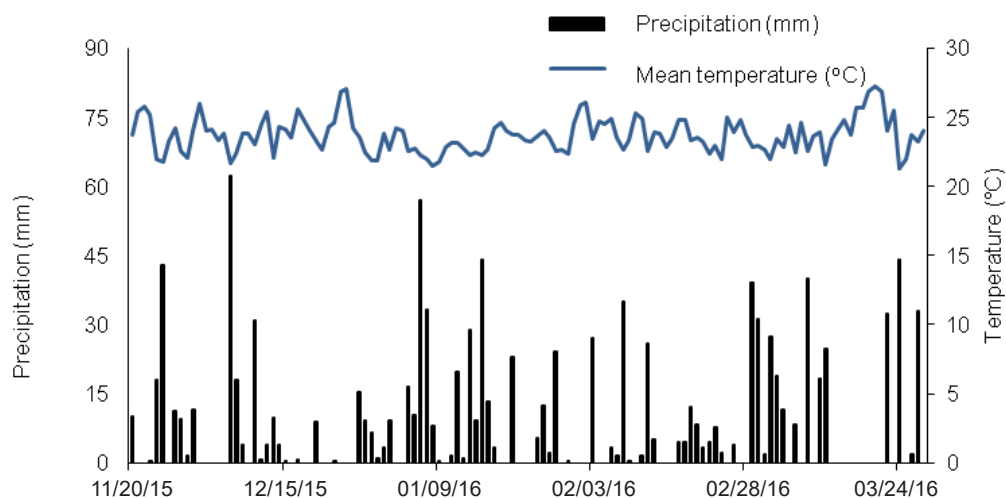


Figure 1 - Data of precipitation (mm) and mean temperature (°C) in the experimental period. Rio Verde, GO, Brazil, 2015/2016.

(1,440 + 670 g a.i. ha⁻¹) (Roundup Original®, 480 g a.i. L⁻¹, SL, Monsanto + DMA 806 BR, 806 g a.i. L⁻¹, SL, Corteva Agriscience). The second application was carried out on the sowing day with 1,440 g a.i. ha⁻¹ of glyphosate (Roundup Original®, 480 g a.i. L⁻¹, SL, Monsanto).

The experimental design was a randomized block design in a factorial scheme (2×5), with four replications. Factor A consisted of two soybean cultivars (BMX Potência RR® and M8210 IPRO®), which has distinct characteristics. The cultivar BMX Potência RR® has an indeterminate growth habit and early cycle (relative maturity group of 7.0), while M8210 IPRO® presents a determinate growth habit and medium cycle (relative maturity group of 8.2). Factor B consisted of five infestation densities of RR® corn plants (AS 1633 PRO2 hybrid, F1 generation) per m² (0, 4, 8, 12, and 16). Each experimental unit had 20 m² of total area, with plots composed by ten rows of 4 m in length and spaced 0.5 m from each other. The useful area consisted of the six central rows with 2 m in length (6 m²).

Soybean sowing was performed mechanically on November 20, 2015. The sowing furrow was fertilized with 250 kg ha⁻¹ of MAP Turbo (10–50–0 kg of N, P₂O, and K₂O, respectively) + 120 kg ha⁻¹ potassium chloride (60% K₂O). Both cultivars were sown at a depth of 3 cm. A total of 20 seeds of the soybean cultivar BMX Potência RR® were distributed per meter, reaching an initial number of plants of 18 plants m⁻¹ (360,000 plants ha⁻¹), while 12 seeds of M8210 IPRO® were sown per meter, with an initial number of plants of 11 plants m⁻¹ (220,000 plants ha⁻¹), according to the recommendations of the companies holding the cultivars. Seed treatment was carried out for both cultivars with fipronil + pyraclostrobin + thiophanate-methyl at a dose of 3+30+27 g 100 kg⁻¹ of seeds (Standak Top®, 25+725+213 g a.i. L⁻¹, SC, Basf). A liquid inoculant composed of strains of *Bradyrhizobium elkanii* and *Bradyrhizobium japonicum* was applied in the sowing furrow (2 doses ha⁻¹). The emergence of both cultivars occurred six days after sowing (November 26, 2015).

Manual sowing was carried out to simulate the different corn densities per m² at each treatment, as follows: 50% of the population in the soybean interrow and 50% in the soybean row. Corn sowing was performed 3 cm deep in the soil and immediately after soybean sowing to avoid that soil disturbance during soybean sowing altered the spatial distribution of corn seeds. At eight days after sowing, corn plants were thinned to ensure the desired stand.

Weeds that emerged after soybean sowing were controlled with an application of glyphosate at a dose of 1,920 g a.i. ha⁻¹ (Roundup Original®, 480 g a.i. L⁻¹, SL, Monsanto) at 20 days after soybean emergence (DAE). Weeds tolerant and/or resistant to this herbicide were eliminated by manual weeding. Pest and disease management was carried out according to the technical recommendations for soybean cultivation.

The following evaluations were performed to assess the effect of the different treatments on soybean development: plant height at 7, 28, and 105 DAE; and SPAD index at 28, 35, and 42 DAE, by sampling five plants per experimental unit. Plant height was measured using a graduated

ruler from the soil surface (plant base) to the apical meristem. The SPAD index was evaluated with Minolta SPAD-502 chlorophyll meter by measuring the central leaflet of the third fully expanded leaf, located in the direction from the apex to the plant base.

The percentage of soybean interrow closure was also evaluated at 35 DAE, and the shoot dry matter of soybean plants was measured at 42 DAE. A scale (%) of how much the soybean interrows were shaded by plant canopy was assigned for the evaluation of the percentage of interrow closure, being considered 100% the condition in which the rows were completely covered by leaves and stem of soybean plants (Heiffig et al., 2006). Dry matter was evaluated by collecting the shoot of five soybean plants per experimental unit and placing them in a forced air circulation oven at a constant temperature of 65 °C for 72 hours.

Also, the following evaluations were carried out during soybean harvest: first pod height, number of pods per plant, and 100 grain weight (five soybean plants per plot). Soybean grains were harvested at the end of the crop cycle, and grain moisture was corrected to 13% (wet basis). The cultivar BMX Potência RR[®] was harvested on March 10, 2016, closing the production cycle at 105 days, while the cultivar M8210 IPRO[®] was harvested on March 28, 2016, with a total cycle of 123 days.

The statistical analyses were performed with the software SISVAR (Ferreira, 2011). After the end of the experiment, the data were tabulated and submitted to analysis of variance. When significant effects were observed between the tested factors or between the levels of each factor, the data were submitted to regression analysis at 5% probability. When significant differences were verified between cultivars by analysis of variance, they were analyzed separately by regression analysis.

RESULTS AND DISCUSSION

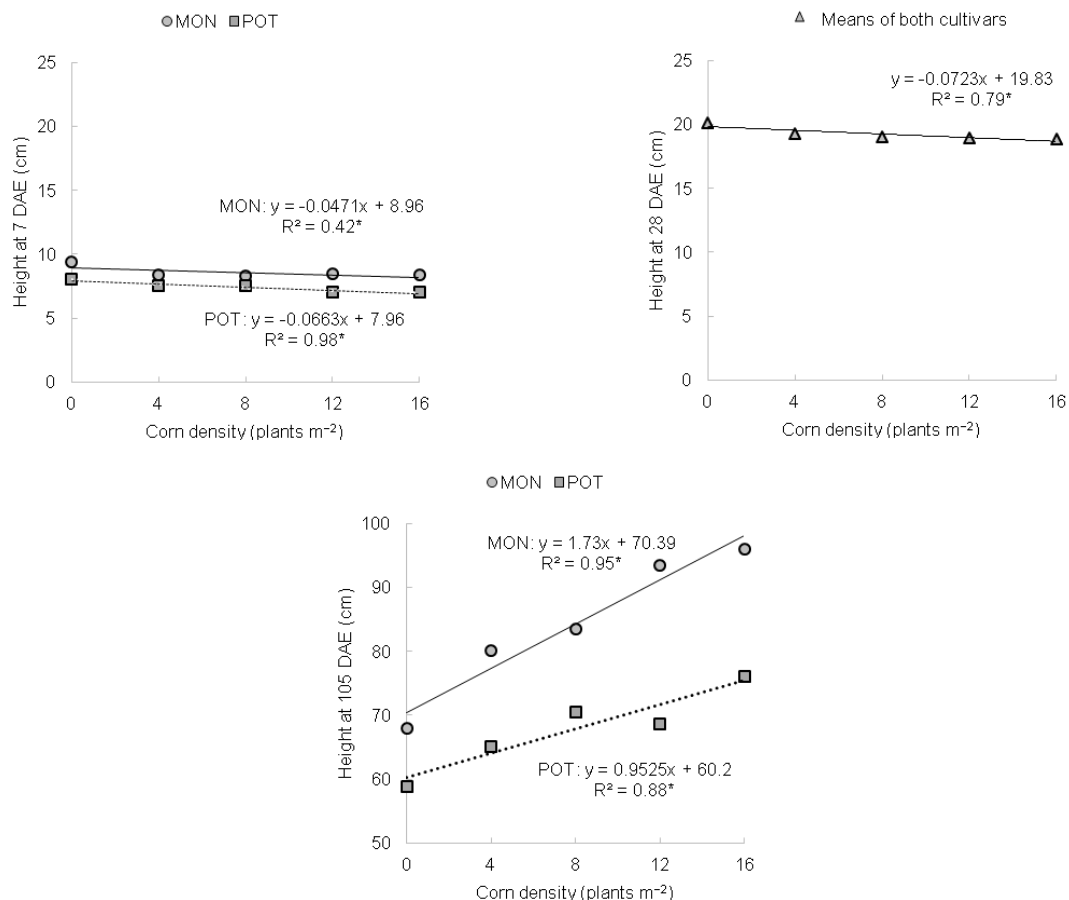
Corn plant density influenced soybean plant height at 7 DAE, and this behavior was observed in the cultivars M8210 IPRO[®] and BMX Potência RR[®] (Figure 2). The treatments in which soybean was not submitted to the coexistence with corn showed the highest values of plant height in both cultivars. Regardless of the presence of corn plants, the cultivar M8210 IPRO[®] had the highest values of plant height when compared to BMX Potência RR[®].

Also for the evaluation carried out at 7 DAE, corn plant density that provided the lowest values of plant height was not estimated for both cultivars because this variable continued to be reduced by densities higher than the evaluated range in this study. Despite this, in the evaluated density range, a height 13.5 and 8.5% lower was observed in soybean plants developed in coexistence with 16 corn plants m⁻² when compared to those not submitted to coexistence with corn, for the cultivars BMX Potência RR[®] and M8210 IPRO[®], respectively.

At 28 DAE, an increase in corn plant density similarly influenced plant height in both soybean cultivars (Figure 2). At that time, an increase of one corn plant per m² provided a reduction in soybean plant height of approximately 0.07 cm. The highest reduction in this variable was observed with the presence of 16 corn plants per m², with soybean plant height 5.6% lower in these plots when compared to those developed free from coexistence with corn.

In the evaluation of height of the earliest cultivar carried out at harvest time (105 DAE), a different behavior was observed when compared to that of previous evaluations since the increased density of corn plants in coexistence with soybean led to the presence of soybean plants with higher heights (Figure 2). This behavior can be justified by light competition between soybean and corn since the faster growth of corn favored crop shading when compared to soybean plants. Soybean under intense shading conditions shows an increase in internode length, which leads to soybean etiolation (Castro and Garcia, 1996).

Analyzing the data of soybean plant height, the cultivar BMX Potência RR[®] was initially (7 DAE) more sensitive to the coexistence with corn plants, considering that the maximum reduction in height values within the density range was higher when compared to that of M8210 IPRO[®]. It is more evident when the maximum reduction percentages of plant height are observed since this value was 11.4% at a density of 10.46 corn plants m⁻² for M8210 IPRO[®] and 13.5% at a density of 16 corn plants m⁻² for BMX Potência RR[®].



* Significant at 5% ($p < 0.05$).

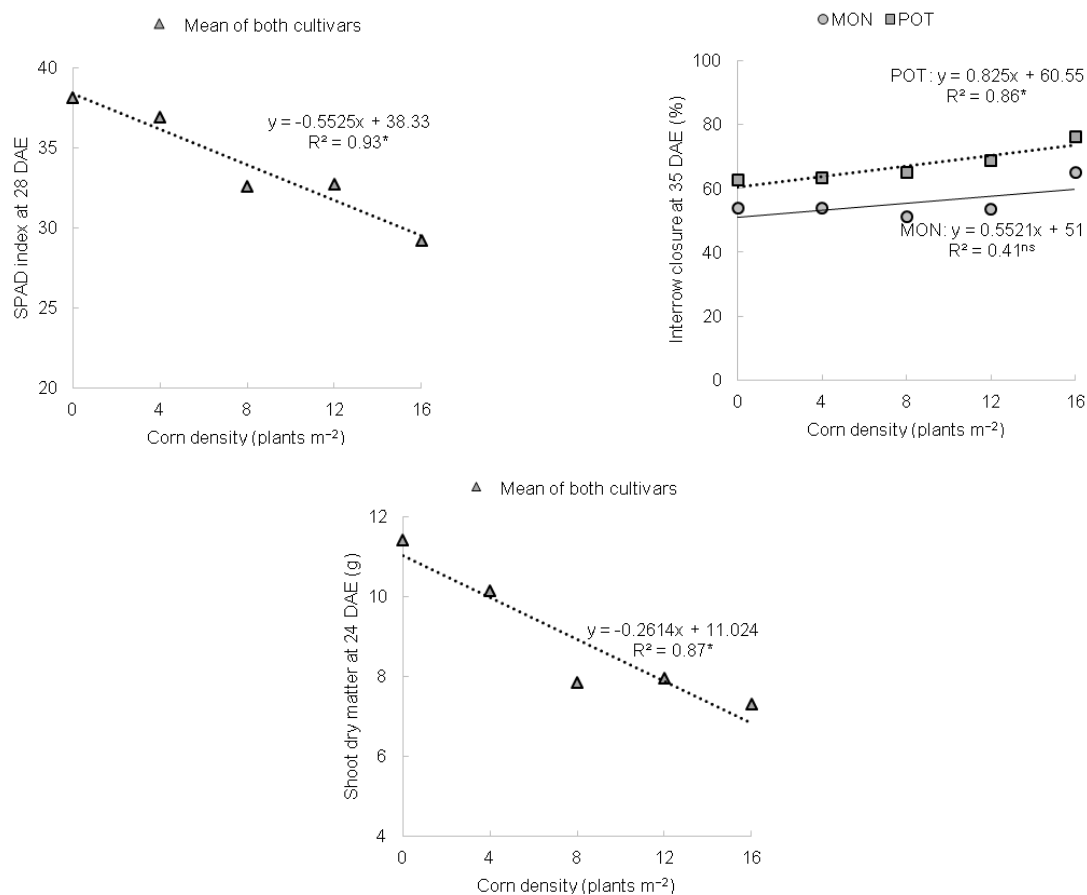
Figure 2 - Height of soybean plants at 7, 28, and 105 DAE as a function of different infestation levels of volunteer corn. Rio Verde, GO, Brazil, 2015/2016. MON: M8210 IPRO®; POT: BMX Potência RR®.

On the other hand, in the evaluation carried out during soybean harvest, a higher etiolation was observed for the cultivar M8210 IPRO® due to the increased density of corn plants in coexistence with soybean, which can be verified by the angular coefficient of both linear equations since that of this cultivar (1.73) was higher than the that of BMX Potência RR® (0.95) (Figure 2). Etiolation observed in soybean plants under the interference of volunteer corn may make them more susceptible to lodging. Lodging occurs when a plant has not enough support of the stem and/or root system, leading to its toppling, thus affecting soybean yield (Sangoi et al., 2001). In general, etiolated plants tend to have a smaller stem diameter, which leaves them more exposed to lodging.

At 28 DAE, an evaluation was carried out for the SPAD index of soybean plants, showing that the increased density of corn plants in coexistence with the crop similarly affected both soybean cultivars (M8210 IPRO® and BMX Potência RR®) (Figure 3). An increase of one corn plant per m² provided a decrease equivalent to 0.55 in the value of the SPAD index measured in the soybean crop. The maximum reduction of this variable was observed with the presence of 16 corn plants per m², being this value 23.1% lower than that registered in soybean plants developed freely from corn interference.

Despite the differences verified for the SPAD index at 28 DAE, results found in the literature correlating this response variable with weed interference are, in general, not clear. In a study with tomato, Silva et al. (2010) did not find a significant effect of weed interference on the SPAD index.

The evaluation of SPAD indexes in soybean plants at 35 and 42 DAE at different corn densities showed no significant results, i.e., the presence of corn plants did not alter the green color level of soybean leaves and probably their chlorophyll contents. Although it did not show significant



* Significant at 5% ($p < 0.05$); ^{ns} Non-significant ($p > 0.05$).

Figure 3 - SPAD index, crop interrow closure, and shoot dry matter as a function of different infestation levels of volunteer corn. Rio Verde, GO, Brazil, 2015/2016. MON: M8210 IPRO®; POT: BMX Potência RR®.

differences in subsequent evaluations, the response presented by soybean for the SPAD index at 28 DAE indicates that this equipment can be used as an indication of whether or not there is interference of weeds on soybean, being necessary additional studies to confirm this hypothesis.

The percentage of soybean interrow closure was significantly influenced by corn density only for the cultivar BMX Potência RR® at 35 DAE (Figure 3). For this cultivar, soybean plants submitted to the coexistence with higher corn densities presented higher values of interrow closure when compared to those free of interference (zero corn plants per m^2). This behavior can be justified by higher etiolation in soybean plants that coexisted with higher densities of corn plants, contributing to the faster interrow closure. Despite this, the effect of the increasing corn plant density on soybean interrow closure was of small magnitude when compared to other response variables.

The cultivar BMX Potência RR® presented higher percentages of interrow closure when compared to M8210 IPRO®. It can be justified by the lower development cycle of this cultivar when compared to M8210 IPRO®, leading the cultivar BMX Potência RR® to reach its growth apex faster. In addition, BMX Potência RR® has an indeterminate growth habit, which indicates that even after reaching the reproductive stage, this cultivar continues to show intense growth in height and mass (Stülp et al., 2009). Another factor that contributed to the higher interrow closure of this cultivar was the sowing density, which was higher than that used for the cultivar M8210 IPRO®.

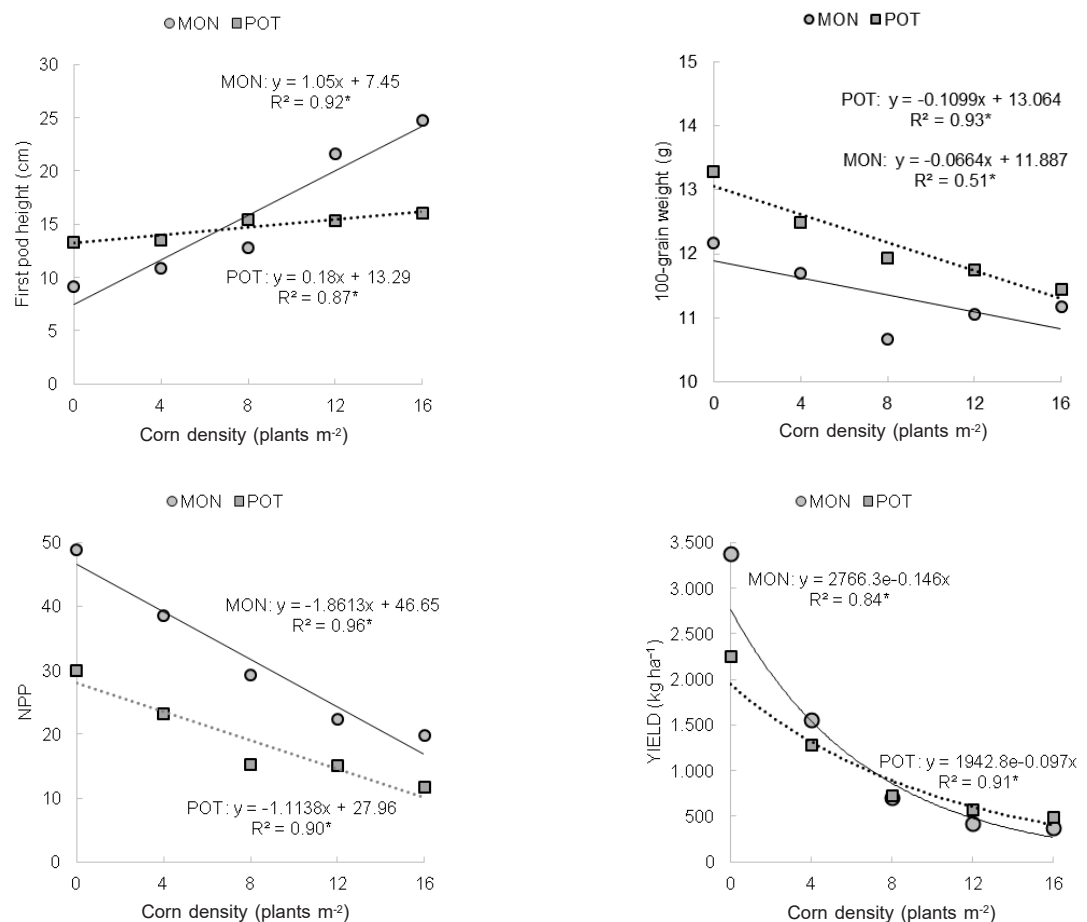
The shoot dry matter per soybean plant was similarly influenced in both cultivars (M8210 IPRO® and BMX Potência RR®) due to the increased corn density in coexistence with the crop (Figure 3). Under a condition of higher corn plant density in coexistence with soybean ($16 \text{ plants } m^{-2}$), a maximum reduction of 37.9% was observed for dry matter in relation to soybean

plants free of interference. The reduction in soybean dry matter accumulation is due to a higher competitive ability of corn, which is a C4 species that responds better to the climate stimuli found under tropical conditions (Marquardt et al., 2012b; Mendes et al., 2013).

The evaluation of the first pod height is important since although it is not classified as one of the components of soybean yield, it has a direct influence on grain yield of the soybean crop (Nepomuceno et al., 2007). In general, the lower the pod insertion height is, the higher the grain loss potentials at harvest time because the harvester header works at a minimum soil height (Braz et al., 2010).

Both soybean cultivars showed higher values of first pod height when the density of corn plants in coexistence with the crop was increased (Figure 4). This behavior is related to the etiolation observed in soybean plants under intense light competition with corn plants. Although both cultivars responded to increased corn density, this response variable was most strongly influenced by M8210 IPRO®, with an increase in the first pod height of 1.05 cm for each corn plant added in coexistence with soybean. Sedyama et al. (1985) observed that soybean cultivars must have a minimum first pod height equal to or higher than 12 cm to minimize losses in the mechanized harvest.

Moreover, both soybean cultivars showed a reduction in the values of 100 grain weight when in coexistence with corn plants (Figure 4). Regardless of the coexistence with corn, the soybean cultivar BMX Potência RR® presented a higher 100 grain weight when compared to that of M8210 IPRO®. The highest corn plant density evaluated in this study (16 plants per m²) showed a reduction of 8.9 and 13.4% in the 100 grain weight for M8210 IPRO® and BMX Potência RR®, respectively, in relation to treatments free from the coexistence with corn plants.



* Significant at 5% ($p < 0.05$).

Figure 4 - First pod height, 100 grain weight, number of pods per plant (NPP), and soybean yield (YIELD) as a function of different infestation levels of volunteer corn. Rio Verde, GO, Brazil, 2015/2016. MON: M8210 IPRO®; POT: BMX Potência RR®.

Differently from the evaluation of 100 grain weight, for the total number of pods per plant, the cultivar M8210 IPRO® presented higher values when compared to BMX Potência RR® (Figure 4). Despite the difference in the total number of pods among both cultivars, when the maximum percentage of reduction in relation to its respective control (without coexistence with corn) is compared, the obtained value is the same, with a 36.2% decrease in the total number of pods when these cultivars were grown in the presence of 16 corn plants per m².

Soybean grain yield had higher values for the cultivar M8210 IPRO®, reaching 3,374 kg ha⁻¹ in the absence of corn plants when compared to BMX Potência RR®, which reached 2,246 kg ha⁻¹ in the absence of competition (Figure 4). Although the cultivar M8210 IPRO® showed higher yield, when comparing the effect of the coexistence of corn plants for this cultivar with that observed for BMX Potência RR®, there was a more pronounced decrease in grain yield for the cultivar M8210 IPRO® due to the interference of volunteer corn. This behavior can be exemplified by observing the effect of coexistence with only one corn plant per m² with soybean plants, which provided a 13.5% reduction in yield for the cultivar M8210 IPRO® when compared to soybean yield in the treatment without corn interference (Figure 4). For the cultivar BMX Potência RR®, this reduction was close to 9.3%.

From the density of eight corn plants per m², yield reductions of both soybean cultivars presented a similar behavior, with a decrease of approximately 69 and 54% for M8210 IPRO® and BMX Potência RR®, respectively. Alms et al. (2016) observed a 71% reduction in soybean yield due to the presence of six corn plants per m² in experiments repeated in two agricultural seasons.

Reductions in soybean yield due to the presence of corn plants are related not only from a specific action but from a set of actions that determine the interference process. Among these actions is the competition for light, which can be verified by the etiolation in the evaluation of height at harvest time, a mechanism in which soybean presents greater metabolic expenditure to compensate the shading environment in which it was developed.

There is also a problem related to the competition for nutrients. The contents of these elements in the experimental area are adequate for soybean cultivation. However, the extraction per unit area in the presence of corn plants is higher, limiting the availability of these nutrients to the crop with less competitive ability, i.e., the soybean in this case (Cury et al., 2012).

Volunteer corn plants have a high capacity to interfere with soybean development cycle, causing reductions in its yield. As there is an increase in the density of corn plants in coexistence with soybean, the negative effects on the crop are more pronounced.

Each soybean cultivar responds differently to interference with corn plants. This differential behavior may be the result of several factors related to soybean cultivars such as growth habit (determinate or indeterminate), development cycle (the period in which the crop is exposed to interference), leaf area, branching, and root system. Phytotechnical adjustments, such as interrow spacing and plant density, are also important as strategies to mitigate interference.

It is possible to conclude that the height of soybean plants at harvest is higher when they are submitted to coexistence with corn plants. Yield components are adversely affected under any density of volunteer corn infestation. Also, the presence of corn plants promoted an increase in the first pod height of soybean plants, being positively correlated with an increase in corn plant density. The soybean cultivar M8210 IPRO® is more susceptible to interference of volunteer corn plants when compared to the cultivar BMX Potência RR®.

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