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The population density of *Digitaria insularis* influences *Phaseolus vulgaris* agronomic traits

A densidade da população de *Digitaria insularis* influencia características agronômicas de *Phaseolus vulgaris*

La densidad de población de *Digitaria insularis* influye en las características agronómicas de *Phaseolus vulgaris*

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Abstract

The common bean (*Phaseolus vulgaris* L.) is an important species for human nutrition in Brazil and its cultivation has been hampered in recent years by the interference of sourgrass [*Digitaria insularis* (L.) Mez ex Ekman] populations. However, just a few studies evaluated sourgrass interaction with common beans. Therefore, we aimed to evaluate the influence of sourgrass density on common bean agronomic characteristics. Seven sourgrass densities, equivalent to populations from 0 to 12 plants m^{-2}, were established in a common bean crop field with a randomized block design and four replicates. The increase in sourgrass density boosted weed dry matter and the common bean plant's height and leaf area index. Contrarily, the same increase in weed density reduced the crop chlorophyll content, stem diameter, shoot, root and total dry mass, and grain yield. The variables' behavior testifies to the high sensitivity of the common bean to sourgrass interference reported by farmers. Variables such as common bean chlorophyll, stem diameter, and the shoot and root dry mass presented a strong negative correlation to the reduction in crop grain yield. The decrease in yield reached 69% with 12 sourgrass plants m^{-2} when compared to control. The density of 3.7 weed plants m^{-2} reduced the maximum common bean grain yield by half. Such significant results suggest the need for developing efficient sourgrass management methods and strategies to avoid common bean yield loss.

Keywords: Weed ecology; Weed interference; Crop interference.

Resumo

O feijão (*Phaseolus vulgaris* L.) é uma espécie importante para a alimentação no Brasil e seu cultivo tem sido dificultado nos últimos anos pela interferência de populações de capim-amargoso [*Digitaria insularis* (L.) Mez ex Ekman]. Entretanto, os estudos avaliando a interação entre capim-amargoso e feijão são escassos. Portanto, nosso trabalho teve por objetivo avaliar a influência da densidade de capim-amargoso nas características agronômicas do feijão. Sete densidades de capim-amargoso, equivalentes a populações entre 0 e 12 plantas m^{-2}, foram estabelecidas em cultivo de feijão com delineamento de blocos casualizados e quatro repetições. O aumento na densidade de capim-amargoso impulsionou a massa seca do inço e a altura e índice de área foliar do feijão. Contrariamente, o mesmo aumento de densidade do inço reduziu o teor de clorofila, diâmetro de caule, massa seca de parte aérea, de raiz e total e o rendimento de grãos da cultura. O comportamento das variáveis comprova a alta sensibilidade do feijão a interferência do capim-amargoso reportada por agricultores. Variáveis como a clorofila, diâmetro de caule e massa seca de parte aérea e de raiz do feijão apresentaram forte correlação negativa com a redução no rendimento de grãos da cultura. A redução no rendimento atingiu 69% com 12 plantas de capim-amargoso m^{-2} em comparação a testemunha. A densidade de 3,7 plantas de inço m^{-2} reduziu o máximo rendimento de grãos de feijão pela metade. Resultados tão significativos sugerem a necessidade de desenvolvimento de estratégias e métodos de manejo de capim-amargoso eficientes para evitar perdas no rendimento de feijão.

Palavras-chave: Ecologia de plantas daninhas; Interferência de plantas daninhas; Interferência em culturas agrícolas.

Resumen

El frijol (*Phaseolus vulgaris* L.) es una especie importante para la alimentación en Brasil y su cultivo se ha visto obstaculizado en los últimos años por la interferencia de las poblaciones de pasto amargo [*Digitaria insularis* (L.) Mez ex Ekman]. Sin embargo, los estudios que evalúan la interacción entre el pasto amargo y el frijol común son escasos. Por lo tanto, nuestro estudio tuvo como objetivo evaluar la influencia de la densidad del pasto amargo en las características agronómicas del frijol común. Se establecieron siete densidades de pasto amargo, equivalentes a poblaciones entre 0 y 12 plantas m^{-2}, en cultivo de frijol común con un diseño de bloques al azar y cuatro repeticiones. El aumento en la densidad del pasto amargo impulsó la masa seca de la mala hierba y la altura y el índice de área foliar del frijol común. Por el contrario, el mismo incremento en la densidad de la maleza redujo el contenido de clorofila, el diámetro del tallo, la parte aérea, la raíz y la masa seca total y el rendimiento de grano del cultivo. El comportamiento de las variables demuestra la alta sensibilidad del frijol a la interferencia del pasto amargo reportada por los agricultores. Variables como clorofila, diámetro de tallo y masa seca de parte aerea y raíz del frijol común mostraron una fuerte correlación negativa con la reducción en el rendimiento de grano. La reducción del rendimiento alcanzó el 69% con 12 plantas de pasto amargo m^{-2} en comparación con el control. La densidad de 3,7 gramíneas m^{-2} redujo a la mitad el rendimiento máximo de grano de frijol. Resultados tan significativos sugieren la necesidad de desarrollar estrategias y métodos eficientes de manejo del pasto amargo para evitar pérdidas en el rendimiento del frijol.

Palabras clave: Ecología de malezas; Interferencia de malezas; Interferencia en cultivos agrícolas.

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is a major Brazilian summer crop. The species was domesticated in the Andes and Mesoamerica around 8.000 years ago (Gaut, 2014). As human food, it is relevant since its grains constitute an abundant and cheap source of protein, carbohydrates, and minerals (Lovato et al., 2017).

Many Brazilian farmers consider common bean as one of the riskiest summer crops. The species sensitivity to environmental interactions is evidenced by the variability of the crop yield in space and over time (Melo et al., 2018). Ecological limitations to the common bean development and yield might include abiotic (rainfall, temperature, frost, hail, wind, etc.) and biotic factors (the action of natural enemies such as pests and pathogens and weed interference) (Clemente et al., 2017).

Weed interference is one of the main biotic factors lowering common bean yield and grain quality (Karavidas et al., 2022). The result of weed communities and common beans interaction depends on the weed population density in crop field (Silva et al., 2019). For this reason, the weed population density is usually used to make decisions about its management in common bean fields (Vidal et al., 2010).

Due to huge losses caused to crops and its difficulty of control, sourgrass [*Digitaria insularis* (L.) Mez ex Ekman] has drawn attention from Brazilian farmers in the last years (Braz et al., 2021; Silveira et al., 2018). Its high persistence in the environment because of rhizome formation and easy dispersion due to its high number of seeds with high germination percentage (Zambão et al., 2020) is aggravated by the glyphosate resistant biotypes (Takano et al., 2018). However, despite its importance, there are few studies evaluating sourgrass influence in agronomic characteristics of major summer crops in Brazil, including in common bean.

Moreover, we believe that knowing sourgrass ecological behavior among agricultural crops is essential to understand its interference and optimize its management. Our hypothesis is that higher sourgrass densities will lead to a decrease in common bean agronomic variables. In such context, this study aimed to evaluate the interference caused by different sourgrass densities in common bean development and grain yield.

2. Methodology

The experiment was carried out in 2018 in Laranjeiras do Sul, Paraná, Brazil (-25.418336, -52.342465). The experimental design was randomized blocks with seven treatments and four replicates. Each experimental unit consisted of a plot formed by a 2 m side square plot.

The natural weed community was desiccated using glyphosate (532.8 g e.a. ha^{-1}) twice with 30-day intervals, with the last just before common bean sowing. The experiment was kept free of other weeds by hand weeding. The soil (Dystroferric Red Latosol) fertilization followed the recommendations of the state of Paraná Fertilization and Liming Manual for common bean based on the soil analysis results (Table 1) (Pavinato et al., 2017).

Table 1 - Soil chemical attributes (0-20 cm).

pH	OM	P	K	Al	Ca	Ca+Mg	H+Al	CEC	BS	SB
	g dm^{-3}	mg dm^{-3}	ppm	cmolc dm^{-3}	cmol(+) dm^{-3}				%	
5.2	44.23	24.57	70.38	0	6.6	9.44	4.96	9.62	65.98	9.62

pH: potential of hydrogen; OM: organic matter; P: phosphorus; K: potassium; Al: aluminum; Ca: calcium; Mg: magnesium; H+Al: soil potential acidity; CEC: cation-exchange capacity; BS: base saturation; SB: sum-of-bases. Source: Authors.

A type II, undetermined growth habits common bean (*Phaseolus vulgaris* L. cv. IPR Tuiuiú) was used. The seeds were inoculated with the bacteria *Rhizobium tropici* just before sowing. We sowed with a 0.45 m space between rows and used a 288.000 seeds ha^{-1} density.

Sourgrass seedlings with approximately two leaves and up to 5 cm of height were transplanted in the densities of 0, 1, 2, 3, 5, 8 and 12 plants m^{-2} immediately after common bean emergence. The seedlings were got from seeds sampled from plants in a nearby infested crop field in the previous year from 100 sourgrass individuals.

The sourgrass shoot dry matter variable was evaluated, while common beans had the following variables evaluated: leaf chlorophyll content (Teixeira et al., 2004), stem diameter (Marana et al., 2008), shoot, root, and total dry mass (Andrade et al., 2009), leaf area, plant height, thousand grain mass, and grain yield (Brasil, 2009).

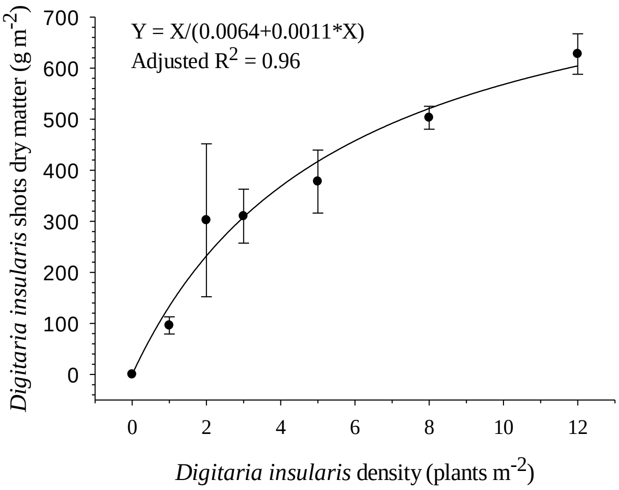
The data were submitted to normality and variance analyses, and whenever applicable, a regression analysis was carried out, adopting the models that best adjusted to the biological response and presented the highest determination coefficients (Storck et al., 2011). Time was considered a cause of variation for the variables sampled more than three times during the common bean cycle. In those cases, a bi-factorial analysis of variance was employed with the sourgrass densities as the first factor and time in days after common bean emergence as the second factor. The association between variables was verified by applying the Pearson correlation analysis. Statistical analyses were performed using the Genes computing application (Cruz, 2013).

3. Results and Discussion

Sourgrass density influenced the weed shoot dry mass ($p < 0.05$). The weed density influenced common bean chlorophyll content, leaf area, stem diameter, plant height, shoot, root and total dry mass, and grain yield ($p < 0.05$).

Sourgrass shoot dry mass raised with the increase in weed density (Figure 1). The highest weed shoot dry mass value was obtained with 12 plants m^{-2}, resulting in 612 g m^{-2}, which is equivalent to 6.18 t ha^{-1}. In a study evaluating sourgrass interference in soybean, the 320 g m^{-2} shoot dry mass treatment reduced crop grain yield up to 250 kg ha^{-1} (Gazziero et al., 2019).

Figure 1 - *Digitaria insularis* shoot dry mass as a function of density. Dots are the averages and bars represent the standard error.



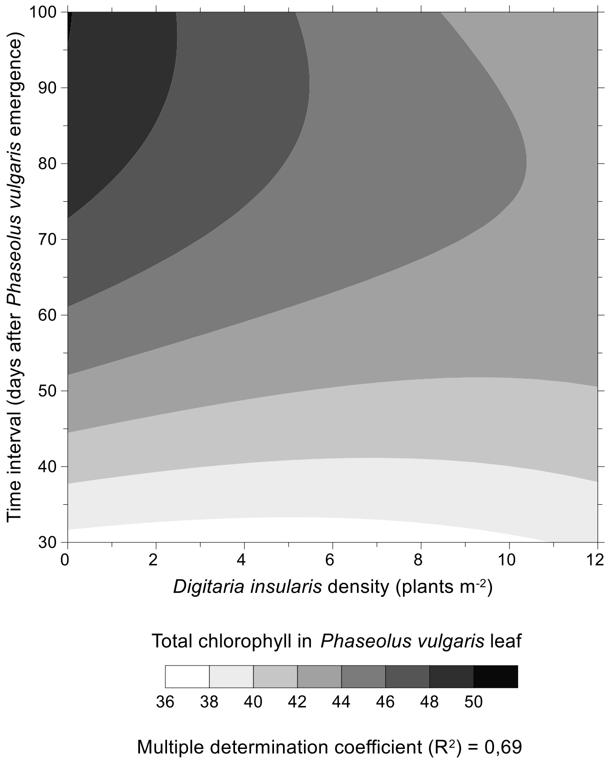
Source: Authors.

The sourgrass shoot dry mass presented a strong positive correlation (r = 0.80) (correlation analysis data not shown) with the reduction in the common bean grain yield. This confirms the relation observed in previous works between weeds and bean (Carvalho et al., 2004). That is, a growing reduction in bean grain yield was expected with the increase in the sourgrass shoot dry mass production.

In a study to evaluate different levels of weed infestation of weed species in bean, Silva et al. (2008) obtained a maximum of 437 g of shoot dry mass per m^{-2} with a density of over 600 individuals m^{-2}. When compared to this study, the total corresponding dry mass would be obtained with only five sourgrass plants m^{-2}. Even taking into consideration the differences in methodology and the environment between these two studies, the discrepancy shows the sourgrass high capability of development and shoot dry mass production.

The interaction between the factors time after bean emergence and sourgrass density was significant ($p < 0.05$) for the variable bean chlorophyll content. The chlorophyll content in bean leaves tended to increase over time and reached a peak 73 days after emergence (Figure 2). However, from 2.4 plants m^{-2} onwards, a gradual reduction was seen in the bean chlorophyll content. In the last evaluation, 100 days after emergence, the chlorophyll content in the beans kept weed free was around 23% higher than that of the treatment with 12 plants m^{-2}.

Figure 2 - *Phaseolus vulgaris* chlorophyll content in leaves as a function of the interaction between time elapsed from crop emergence and *Digitaria insularis* density.



Source: Authors.

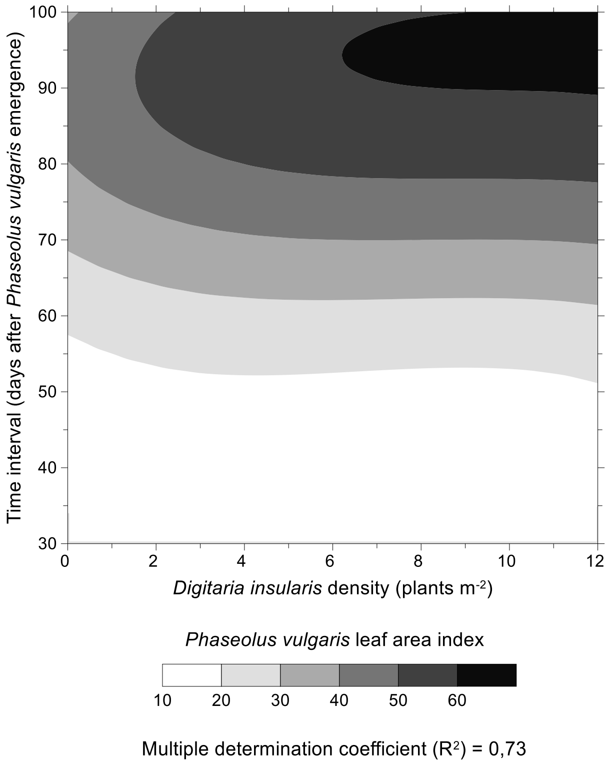
Close to the 65th day after common bean emergence (the period before flowering) the N demand have a tendency to be above average (Soratto et al., 2005). During this period, the increase in total chlorophyll content was delayed by the increase in the sourgrass density. This result suggests that the assumed increase in the soil N mobilization by the higher weed density might have reduced its availability for common bean. Plants of the genus *Digitaria* are known for their ability to mobilize N from soil (Oliveira et al., 2015).

Chlorophylls are closely related to plant photosynthesis efficacy. The content of these pigments usually shows a direct relation to the amount of nitrogen in the environment (Song et al., 2019). Such relation can be confirmed by the fact that 75% total of N in leaves is associated with the chloroplasts (Poorter & Evans, 1998), and for being mostly used in the biosynthesis process and the chlorophyll constitution.

In addition, crop shading might also explain the inversely proportional relationship between the bean chlorophyll content and the sourgrass density. Since chlorophyll biosynthesis depends on light radiation, the increase in the weed density might have contributed to the reduction in the common bean’s total chlorophyll (Taiz et al., 2017).

An interaction between the factors time after bean emergence and sourgrass density was noted for the variable bean leaf area ($p < 0.05$). At the beginning of the crop life cycle, no density influence was noticed, however, from around day 80 onwards, a strong influence of the weed density was observed on the common bean leaf area index (Figure 3).

Figure 3 - *Phaseolus vulgaris* leaf area as a function of the interaction between time elapsed from crop emergence and *Digitaria insularis* density.

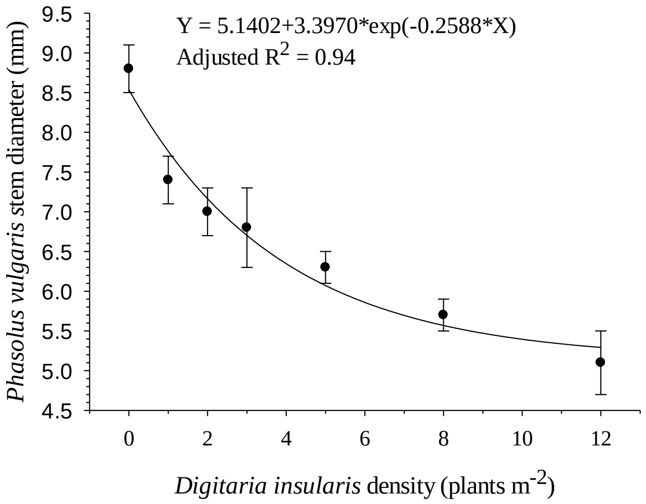


Source: Authors.

A directly proportional relation was seen between the common bean leaf area index and the sourgrass density, resulting in a higher leaf area index with weed density growth. Our hypothesis is that this reaction is associated with the decrease in common bean radiation availability. In this perspective, the adjustment of the photosynthesis apparatus to the environmental conditions is a plant response to improve the use of the available radiation. In addition to the leaf area index increase, shading might also be associated with a negative effect on the allocation of biomass in the root system (Semchenko et al., 2012), which should be investigated in further studies.

The variable stem diameter was also influenced by sourgrass density ($p < 0.05$). An exponential reduction occurred in the common bean stem diameter with the increment in sourgrass density (Figure 4). The bean stem diameter with 12 plants m^{-2} was 38% lower than the control.

Figure 4 - *Phaseolus vulgaris* stem diameter as a function of the *Digitaria insularis* density. Dots are the averages and bars represent the standard error.

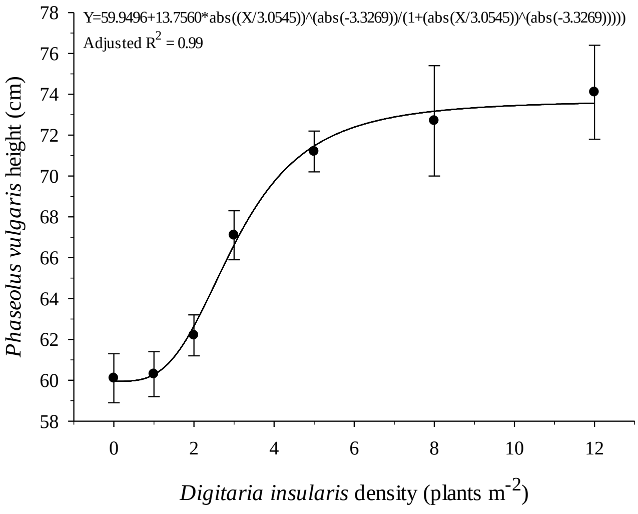


Source: Authors.

A strong negative correlation was observed (r = -0.81) between common bean stem diameter and the sourgrass shoot dry mass. This means that higher weed dry mass is associated with smaller common bean stem diameter. The fact that the vegetable community competition for radiation results in both stem diameter reduction and promotion of other plant shoot tissues is well known (Villalobos et al., 2016).

The bean plant height was also influenced by sourgrass density, whose effect was mainly seen between one to five plants m^{-2} ($p < 0.05$) (Figure 5). The common bean plant height in the 12 plants m^{-2} plot was 22.7% higher than the control. However, the crop height increment as a function of density slowed down from the curve inflexion point onwards, which is equivalent to approximately three plants m^{-2}. Therefore, weed density had little influence on the common bean plant height (< ~1 cm) in treatments with six to 12 plants m^{-2}.

Figure 5 - *Phaseolus vulgaris* height as a function of the *Digitaria insularis* density. Dots are the averages and bars represent the standard error.



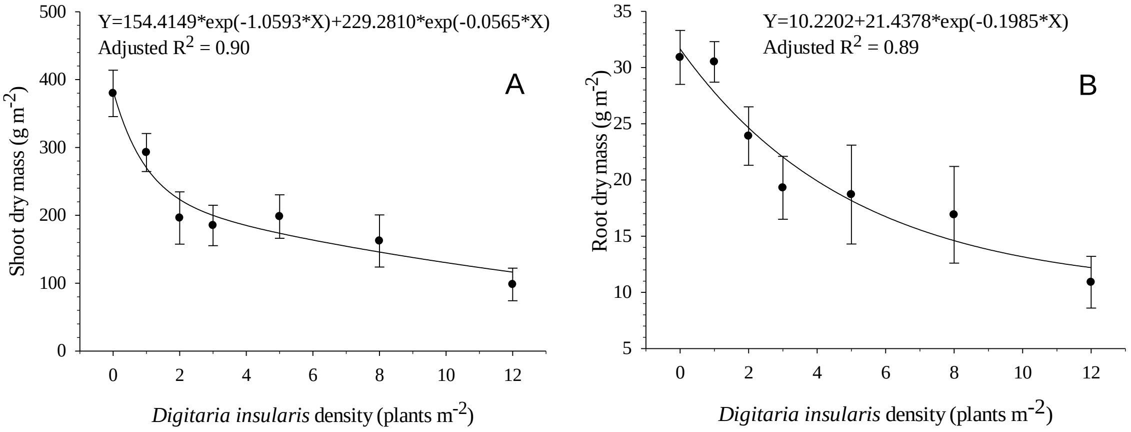
Source: Authors.

The influence of weed density on the common bean plant height was more pronounced from 2 plants m^{-2} onwards. This was similar to results of another experiment with sourgrass and soybean, where control did not differ from the treatment with one weed m^{-2} (Gazziero et al., 2019). This morphological response to the threat of competition for light might represent a competitive advantage, mainly to plants that require direct radiation and open environments (Schmitt & Wulff, 1993), as common bean cultivars usually do. However, although higher densities increased crop plant height, its association with a reduction in the stem diameter makes common bean more susceptible to lodging (Oliveira et al., 2014).

A strong positive correlation (r = 0.67) was also observed between crop height and grain yield loss. Thus, we assumed that the increment in common bean plant height observed in higher weed densities is associated with a reduction in crop yield. This association might be credited to the energy cost for the plant vegetative development as a response to the competition for light, which limits the crop reproduction investments (Schmitt & Wulff, 1993).

Common bean shoot dry mass was influenced by sourgrass density ($p < 0.05$). Control treatment produced nearly three times more crop shoot dry mass than the treatment with 12 plants m^{-2} (Figure 6A).

Figure 6 - *Phaseolus vulgaris* shoot (A) and root (B) dry mass as a function of the *Digitaria insularis* density. Dots are the averages and bars represent the standard error.



Source: Authors.

The bean shoots dry mass decreased in higher weed densities, even with an increase in the leaf area index and plant height (Figures 3 and 5), might be explained because of the smaller stem diameter and leaf thickness. These are characteristics observed in plants subjected to shading. Leaves grown in the shade, when compared to those grown in full sun, show an increase in area but a reduction in blade thickness (Araújo et al., 2019). This is due to the reduction in the thickness of the palisade and spongy parenchyma (Schulze et al., 2019) which optimizes the capture of radiation in the shading condition, as it facilitates the absorption of radiation by the leaf mesophyll tissues (Ptushenko et al., 2016).

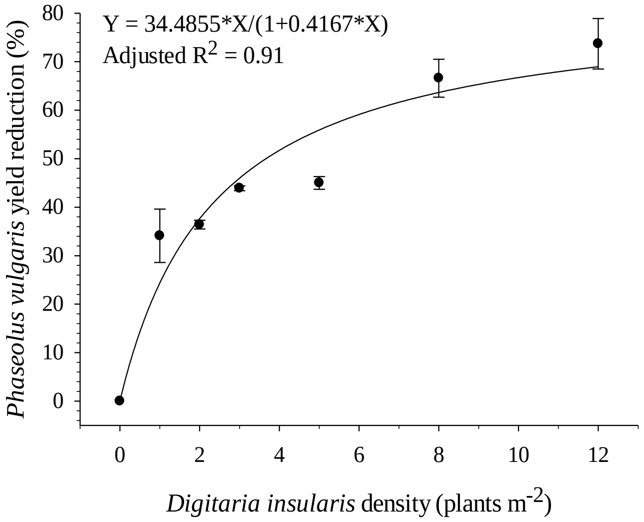
Through interpolation of the model, it was possible to observe that the highest common bean shoots dry matter value (control) was reduced by half with only 3.5 sourgrass plants m^{-2}. We also associated with the reduction in the grain yield, evidencing the association between these variables. The accumulation of plant dry mass is one of the main variables used to evaluate plant growth, which directly results from the capability of production and transfer of photoassimilates.

Sourgrass density also influenced the common bean root system dry mass ($p < 0.05$), with a decrease in this variable being observed when the weed density increased (Figure 6B). The common bean root system dry mass in control was more than double than in the highest weed density (12 plant m^{-2}). In a hypothetical situation of hydric shortage, the crop would have an additional difficulty extracting water from the soil due the reduced root system.

In a study that evaluated the effect of common bean interaction with aggressive weeds, an increase in the shoot dry mass was observed to the detriment of the root system when the common bean shared space with *Urochloa plantaginea* (Manabe et al., 2015). Conversely, in this study, a reduction in the relation between shoot and root dry mass was observed in the interaction between the crop and sourgrass. The quotient between the common bean shoot and root dry mass was 12 for control and ranged from 10 to 8 in plots with different sourgrass densities (shoot/root dry mass quotient data not shown).

The common bean grain yield of plants interacting with sourgrass densities was lower than the 3,522 kg ha^{-1} of control. The percentage of common bean grain yield reduction presented a directly proportional relation with sourgrass density. For this reason, the greatest reduction in common bean grain yield was observed in 12 plants m^{-2}, which was 69% lower than the control (Figure 7).

Figure 7 - *Phaseolus vulgaris* grain yield reduction in relation to control as a function of the *Digitaria insularis* density. Dots are the averages and bars represent the standard error.



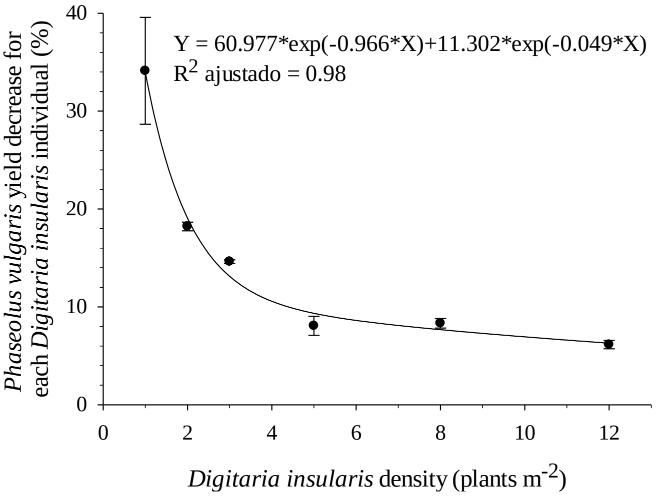
Source: Authors.

Treatments with the highest sourgrass density resulted in higher weed plant dry mass and consequent reduction in crop yield, confirming results obtained by Salgado et al. (2007) in common bean and Gazziero et al. (2019) in soybean. By interpolating the adjusted data to the hyperbolic model, it was possible to determine that the 50% decrease in the maximum bean yield occurred with approximately 3.7 plants m^{-2}, which is the equivalent to 36,629 plants ha^{-1}.

However, sourgrass density did not seem to influence the bean thousand-grain mass ($p = 0.44$). Despite being influenced by the environment, the thousand-grain mass is strongly genetically determined, and for this reason it is one parameter evaluated in programs aiming at the genetic improvement of the species (Coimbra et al., 1999).

The contribution of each sourgrass individual to the reduction of the common bean grain yield decreased with the increase in the weed density (Figure 8). This pattern had already been observed in the interaction between *Euphorbia heterophylla* and common bean (Machado et al., 2015). This suggests that the population increase also increased the weed intraspecific interference, diminishing the relative interference of each sourgrass plant in the common bean population.

Figure 8 - Reduction in *Phaseolus vulgaris* grain yield in comparison to control as a function of each individual plant in the *Digitaria insularis* population. Dots are the averages and bars represent the standard error.



Source: Authors.

The reduction of 34% in the common bean grain yield with only one weed m^{-2} highlights sourgrass's high interference capability when interacting with crops, a feature that had already been recorded in soybean (Gazziero et al., 2019). The relevance of these results confirms sourgrass as one of the most significant weed species in the State of Paraná (Kranz et al., 2009).

The potential of high negative impact from sourgrass on common bean yield also shows the importance of monitoring this weed in crop fields to prevent crop losses. For this reason, sourgrass presence in common bean field, independent of its density, might justify the adoption of management measures, as already performed for *E. heterophylla* (Machado et al., 2015).

The results highlight sourgrass population interference potential in common bean development and yield when the weed is stablished from seeds. The perennation of the weed with clump formation, associated to the occurrence of pesticide-resistant biotypes, might result in a higher level of interference. However, despite the expressive results obtained, we must highlight that the crop and the weed interaction may depend on many other environmental factors that vary in space and time, making the product of this relation hard to predict in distinct conditions.

4. Conclusion

The sourgrass dry matter increases with its density but accompanied by a decrease in the contribution of each plant to the total.

The density and the time elapsed in the interaction with sourgrass influenced the common bean chlorophyll content.

The highest common bean chlorophyll contents were obtained closer to the 75th DAE and decreases with the increase in weed density.

The sourgrass density increase causes morphophysiological alterations in common bean plants such as an increase in leaf area and plant height and a decrease in stem diameter.

The common bean root system, shoot and total dry matter decrease exponentially in response to sourgrass density increase.

The common bean grain yield decreases with the increase in sourgrass density, reaching a 69% reduction with 12 plants m^{-2}.

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