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Interference and economic damage threshold of smooth pigweed in soybean

Abstract – The objective of this work was to determine the interference and economic damage threshold of smooth pigweed (*Amaranthus hybridus*) in soybean. The experiments were carried out in two agricultural harvests (2020/2021 and 2021/2022) in an area with natural infestation of smooth pigweed. The treatments consisted of different levels of smooth pigweed infestation (0, 1, 3, 6, 9, and 12 plants per square meter) in an area cultivated with soybean. The design was completely randomized with ten replicates. The analyzed variables were: number of pods per plant; grains per pod; and soybean grain yield, converted into loss percentage in relation to the controls without the presence of smooth pigweed. One smooth pigweed plant per square meter can reduce soybean yield, on average, by 4.32 to 5.09%, whereas the presence of 12 plants per square meter reduces soybean yield by 36.03 to 37.93%. The economic damage threshold of smooth pigweed in soybean occurs in the range of 0.35 to 0.93 plants per square meter. When the cost of control is lower, the economic damage threshold is achieved with smaller infestations of 0.36 plants per square meter. However, when the cost of control is high, the economic damage threshold becomes economically viable with larger infestations above 0.63 plants per square meter.

Index terms: *Amaranthus hybridus*, *Glycine max*, weed competition.

Interferência e limiar de dano econômico de caruru-roxo em soja

Resumo – O objetivo deste trabalho foi determinar a interferência e o limiar de dano econômico de caruru-roxo (*Amaranthus hybridus*) em soja. Os experimentos foram realizados em duas safras agrícolas (2020/2021 e 2021/2022), em área com infestação natural de caruru-roxo. Os tratamentos consistiram de diferentes níveis de infestação de caruru-roxo (0, 1, 3, 6, 9 e 12 plantas por metro quadrado) em área cultivada com soja. O delineamento foi inteiramente casualizado com dez repetições. As variáveis analisadas foram: número de vagens por planta; grãos por vagem; e produtividade de grãos de soja, convertida em percentual de perda em relação aos controles sem a presença de caruru-roxo. Uma planta de caruru-roxo por metro quadrado pode reduzir a produtividade de grãos de soja, em média, de 4,32 a 5,09%, enquanto a presença de 12 plantas por metro quadrado reduz a produtividade de soja de 36,03 a 37,93%. O limiar de dano econômico de caruru-roxo em soja ocorre na faixa de 0,35 a 0,93 plantas por metro quadrado. Quando o custo de controle é mais baixo, o limiar de dano econômico é alcançado com infestações menores de 0,36 plantas por metro quadrado. No entanto, quando o custo de controle é mais alto, o limiar de dano econômico torna-se economicamente viável com infestações maiores, acima de 0,63 plantas por metro quadrado.

Termos para indexação: *Amaranthus hybridus*, *Glycine max*, matocompetição.

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Introduction

Soybean [*Glycine max* (L.) Merr.] is one of the main agricultural crops grown worldwide, but its grain yield is reduced due to the competition with weeds for water, light, and nutrients (Agostinetto et al., 2017). The degree of this interference is directly influenced by weed population and period of coexistence with the crop (Piasecki et al., 2018).

In cropping systems, such as that of soybean, the main weed management practice has been chemical control through herbicides (Resende et al., 2022). However, herbicide-resistant crops have started to be widely adopted due to their benefits to farmers, such as flexibility in herbicide application time and reduced costs with weed control (Agostinetto et al., 2017). This simplification in cropping systems, however, has also led to the selection of herbicide-resistant weed biotypes (Perotti et al., 2020).

Among the species with reports of resistance to herbicides, smooth pigweed (*Amaranthus hybridus* L.) stands out as one of the main weeds in agricultural production systems (Resende et al., 2022). This species is highly competitive due to its rapid growth and development, extensive seed viability in the soil, and high rate of viable seed production (Barroso et al., 2012), as well as to its C4 photosynthetic metabolism (Martins et al., 2020). Furthermore, the gene responsible for herbicide resistance in the genus *Amaranthus* can be transferred to other species through interspecific hybridization (Gaines et al., 2012). Therefore, the difficulty in the control of and the ecophysiological characteristics of this species increase the risk of the emergence of populations resistant to multiple mechanisms of action.

In the literature, species of the *Amaranthus* genus have been shown to cause significant losses in several agricultural crops. Palmer's pigweed (*Amaranthus palmeri* S.Watson), for example, can cause losses from 6.0 to 65% in cotton (*Gossypium hirsutum* L.) yield (Berger et al., 2015) and from 56 to 78% in soybean grain yield, depending on population density and emergence period. Redroot pigweed (*Amaranthus retroflexus* L.), at a density of up to 32 plants per square meter, can reduce bean (*Phaseolus vulgaris* L.) yield by 81% due to competition (Amini et al., 2014). Zandoná et al. (2022) concluded that the presence of just one smooth pigweed plant per square meter can reduce soybean grain yield by 6.4%.

The reduction in crop grain yield due to competition with weeds can be evaluated and quantified using mathematical models, where equations predict the ecophysiological behavior of the crop in the presence of a given weed (Ulguim et al., 2020). The rectangular hyperbola model is one of the most used, simulating the effects of interference and determining the loss of unit yield in relation to plant populations through mathematical parameters (Fleck et al., 2007), in addition to allowing to estimate the economic damage threshold of weeds to crops (Zandoná et al., 2022).

The economic damage threshold is the pest level in which more control measures should be applied to prevent economic losses, i.e., when the damage caused to crop grain yield is higher than the control costs (Agostinetto et al., 2017). The equation used to determine this threshold takes into account crop yield losses caused by competition with weeds, the expected final yield, the price paid for the produced grain, and the costs and efficiency of weed control (Hussain et al., 2015). This tool is an integrated weed management strategy that can assist in the sustainable use of chemical control, contributing to maintain the economic viability of agricultural production, also bringing socioeconomic benefits to the farmers (Zandoná et al., 2022). Therefore, economic damage threshold models can help determine the ideal population for the adoption of control measures, consequently rationalizing the use of herbicides, which, together with integrated management techniques, increases sustainability in agriculture.

The objective of this work was to determine the interference and economic damage threshold of smooth pigweed in soybean.

Materials and Methods

To determine the economic damage threshold of smooth pigweed in soybean, two experiments were carried out in different harvests (2020/2021 and 2021/2022), in an agricultural area naturally infested with smooth pigweed, located in Bugre Morto, in the municipality of Pontão, in the state of Rio Grande do Sul, Brazil (28°2'31"S, 52°34'49"W, at 695 m altitude). According to Köppen-Geiger's classification, the local climate is humid subtropical (Cfa), with no defined dry season (Alvares et al., 2013). The soil in the experimental area is classified as a Latossolo Vermelho Distrófico típico (Santos et al., 2018), i.e., an Oxisol.

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The treatments consisted of different levels of smooth pigweed infestation (0, 1, 3, 6, 9, and 12 plants per square meter) in soybean. To this end, 1.0 m^2 micro plots were randomly demarcated in a 20,000 m^2 area cultivated with the crop and with a natural infestation of smooth pigweed; the emerged weeds were manually controlled to reach the populations determined for each treatment. The experimental design was completely randomized with ten replicates in both experiments.

Different cultivars were sown in 2020/2021 and 2021/2022 after a black oat (*Avena strigosa* Schreb.) and wheat (*Triticum aestivum* L.) crop, respectively: SYN1059 RR, considered early, of maturity group 5.9, and with a good productive stability; and BRS 5804RR, which is early, of maturity group 5.8, and has a high productive potential. In both cases, the spacing between lines was 0.45 m, and the density of soybean plants was 300,000 plants per hectare. In each experiment, fertilization was performed using the N-P-K formula (8-30-15), at a rate of 250 kg ha^{-1}. Phytosanitary management was carried out based on the infestation of pests and diseases, according to the technical recommendations for the soybean crop (Reunião, 2019). The other weeds that appeared in the plots were controlled through manual weeding.

The average air temperature and rainfall during the experimental period are shown in Figure 1. The values recorded in the 2020/2021 harvest were: 729.6 mm rainfall, 20ºC average temperature, and 74% average relative humidity. In the 2021/2022 harvest, the values were: 550.4 mm rainfall, 21ºC average temperature, and 71% average relative humidity. A low soil moisture due to a reduced precipitation, especially in the 2021/2022 harvest, was the factor that most interfered with the establishment of the weeds and the crop.

The variables analyzed in soybean were: number of pods per plant, determined by counting the pods on ten random plants, at the R6 stage, in each micro plot; number of grains per pod, determined using the same plants; and grain yield, obtained by harvesting the micro plot and adjusting for a moisture content of 13%. For the variables number of pods per plant and grains per pod, the data were collected and evaluated only in the 2021/2022 harvest. Yield data were converted into percentages in relation to the controls without the presence of smooth pigweed, in order to define the loss of each variable due to competition through the following equation:

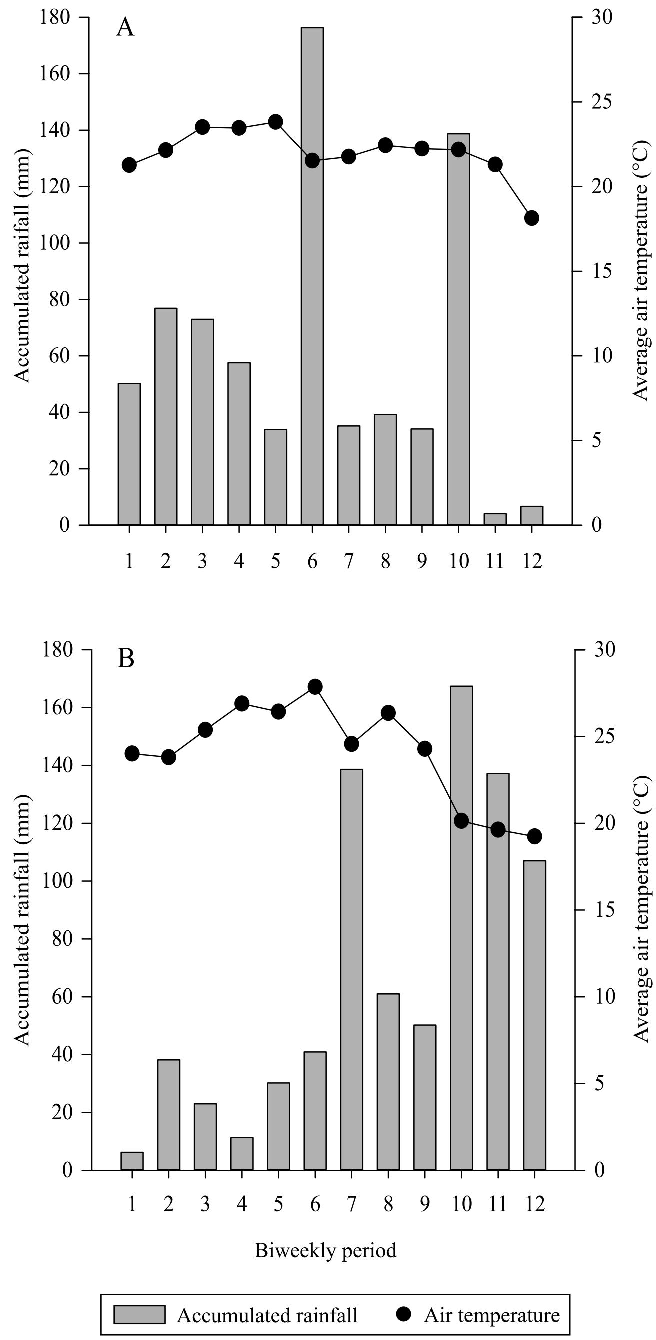

Figure 1. Accumulated rainfall and average daily air temperature in the 2020/2021 (A) and 2021/2022 (B) soybean (*Glycine max*) harvests in the municipality of Passo Fundo, in the state of Rio Grande do Sul, Brazil. The data on accumulated rainfall and average air temperature were grouped by fortnight, which ranged from 11/01/2020 to 04/30/2021 in 2020/2021 and from 11/01/2021 to 04/30/2022 in 2021/2022. Therefore, numbers 1 to 12 represent the fortnight periods, as follows: 1, 11/01/2020 to 11/15/2020; 2, 11/16/2020 to 30/11/2020; and so on. Source: Adapted from Instituto Nacional de Meteorologia (Inmet, 2022).

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$$R = \left[\frac{(Ta - Tb)}{Ta}\right] \times 100$$

where R is the percentage reduction in yield in relation to the control, Ta is the yield of the treatment without the presence of smooth pigweed (control), and Tb is the observed treatment value.

The obtained data were subjected to the analysis of variance using the F-test, at 5% probability. The normality of residues and the homogeneity of variances were verified by Shapiro-Wilk's and Bartlett's tests, respectively. The relationships between the percentage losses of soybean yield as a function of the plant population were calculated using the nonlinear regression model derived from the rectangular hyperbola, as proposed by Cousens (1985):

$$Y = \frac{(i \times x)}{(1 + a \times x)}$$

where Y is yield loss (%), x is the population of smooth pigweed plants, i is the percentage of yield loss per unit of weed when the population approaches zero, and a is the percentage of yield loss when the weed population tends to infinity.

To calculate the economic damage threshold, estimates of parameter i were used, obtained from the equation proposed by Cousens (1985) and from the following equation adapted from Lindquist & Kropff (1996):

$$ET = \frac{(CC)}{\left(R \times P \times \left(\frac{i}{100}\right) \times \left(\frac{E}{100}\right)\right)}$$

where ET is the economic damage threshold (plants per square meter); CC is the cost of control (cost of herbicide and application in R$ ha^{-1}); R is soybean yield (kg ha^{-1}); P is soybean price (R$ kg^{-1} grains); i is the percentage of soybean yield loss per unit of weed, when its density approaches zero according to the equation of Cousens (1985); and E is the level of herbicide efficiency (%).

For the calculation of the economic damage threshold, three values were estimated for crop yield, soybean price, control cost, and herbicide efficiency. Yield range was estimated at 2,400, 4,200 and 5,400 kg ha^{-1}, representing low, medium, and high technological-level scenarios, respectively. For the price of soybean, the values R$ 2.50, 2.92, and 3.33 kg^{-1} grains were considered, representing the minimum, average, and maximum prices per kilogram of soybean in 2020, 2021, and 2022 according to the average for the state of Rio Grande do Sul (Conab, 2023). The average values paid per bag of soybean in the 2020/2021 and 2021/2022 harvests were used as a basis. The range of the cost of control was estimated at R$ 200.00, 250.00, and 300.00 per hectare, based on the commercial values of the used herbicides in the three experimental years. The considered levels of herbicide efficiency were 80, 90, and 100% control, with 80% being the minimum control considered effective on the weed. The average values of herbicides necessary to control smooth pigweed at crop pre- and post-emergence were used as a basis. In the simulations of the economic damage threshold, average values were used for each parameter that was not subjected to calculations (soybean yield = 4,200 kg ha^{-1}; soybean price = R$ 2.92 kg^{-1}; herbicide efficiency = 90%; and cost of control = R$ 250.00 ha^{-1}).

Results and Discussion

The variables number of pods per plant and grains per pod were only evaluated in the 2021/2022 harvest (Table 1). Both variables were not significantly affected by the different populations of smooth pigweed. This result differs from that of Zandoná et al. (2022), who observed significant differences in all soybean yield

Table 1. Number of pods per plant and grains per pod of soybean (*Glycine max*) as a function of smooth pigweed (*Amaranthus hybridus*) populations in the 2021/2022 harvest in the municipality of Passo Fundo, in the state of Rio Grande do Sul, Brazil.

Plants per meter	Pods per plant	Grains per pod
0	28^{ns}	2.3^{ns}
1	26	2.4
3	25	2.2
6	24	2.0
9	22	2.2
12	19	1.8
Average	24	2.15
CV (%)	28.48	13.66

^{ns}Nonsignificant by Tukey's test, at 5% probability.

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