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# Residual effect of diclosulam on the early development of maize and sorghum

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## ABSTRACT

Herbicide carryover is one of the challenges in crop succession and rotation systems that can affect the development of sensitive crops such as maize and sorghum. This study aimed to evaluate the early development of maize and sorghum under different residual levels of the herbicide diclosulam. The experiment was conducted in a greenhouse, arranged in a completely randomized design, with six treatments and four replications for each crop. The tested doses were 5.23, 10.43, 20.85, 41.70, and 83.40 g ai ha$^{-1}$ applied pre-emergence to maize and sorghum, plus an untreated control for each crop. Injury symptoms and the number of emerged seedlings were assessed at 7, 14, 21, and 28 days after emergence (DAE), along with plant height and shoot dry mass. Injury symptoms were more severe in sorghum. Doses of 20.85, 41.70, and 83.40 g ai ha$^{-1}$ reduced maize height and shoot dry mass of both maize and sorghum. A reduction in the number of emerged plants was observed at the highest residual dose, that is, 70 g ai ha$^{-1}$. Doses above 20.85 g ai ha$^{-1}$ were detrimental to the early development of maize and sorghum.

**Keywords:** Carryover, Plant-back interval, *Sorghum bicolor*, *Zea mays.*

# Efeito residual de diclosulam sobre o desenvolvimento inicial de milho e sorgo

## RESUMO

Um dos desafios dos sistemas de sucessão e rotação de culturas é o carryover de herbicidas que pode afetar o desenvolvimento de culturas sensíveis, como a cultura do milho e do sorgo. O objetivo desse estudo foi avaliar o desenvolvimento inicial do milho e do sorgo em diferentes residuais do herbicida diclosulam. O experimento foi realizado em casa de vegetação, em delineamento inteiramente casualizado, com seis tratamentos e quatro repetições para cada uma das culturas. As doses testadas foram de 5,23; 10,43; 20,85; 41,70 e 83,40 g i.a. ha$^{-1}$ aplicadas em pré-emergência das culturas do milho e sorgo, e um tratamento controle sem aplicação para cada uma das culturas. Foram avaliados os sintomas de injúrias e número de plântulas emergidas aos 7, 14, 21 e 28 dias após a emergência (DAE), altura e massa seca da parte aérea. Os sintomas de injúrias foram maiores na cultura do sorgo. As doses de 20,85; 41,70 e 83,40 g i.a. ha$^{-1}$ reduziram a altura do milho e a massa seca da parte aérea do milho e do sorgo. Na dose residual mais elevada de 70 g i.a. ha$^{-1}$ houve redução no número de plantas emergidas. Doses acima de 20,85 g i.a. ha$^{-1}$ foram prejudiciais para o desenvolvimento inicial do milho e sorgo.

**Palavras-chave**: Carryover, Intervalo de segurança, *Sorghum bicolor*, *Zea mays*.

## 1. Introduction

In Brazil, the cultivated area of maize (*Zea mays* L.) was 21.3 million ha, with a yield of 5,853 kg $ha^{-1}$, and the cultivated area of sorghum (*Sorghum bicolor* L.) Moench) was 1.5 million ha, with a yield of 3,116 kg $ha^{-1}$ (Companhia Nacional de Abastecimento - CONAB, 2025). These two crops are used as second‑season options after soybean cultivation, especially maize, which can also be grown in the main season in rotation (Nóia Júnior and Sentelhas, 2019; Sodré Filho et al., 2020).

Herbicide residual activity is one of the main challenges in crop succession and rotation, as it can last longer than the crop in the field and cause injury to the following crop (Gonçalves et al., 2018; Silva et al., 2024). Ideally, the herbicide residual effect should persist only until the end of the critical period of weed interference prevention, but the residual effect can last longer in some cases and cause injury to the subsequent crop, a phenomenon known as carryover (Mancuso et al., 2011; Roncatto et al., 2023).

Sorghum shows greater susceptibility to herbicides compared with maize and is commonly used as an indicator plant (Faustino et al., 2015; Souza et al., 2023; Souza et al., 2016). These crops are often grown in succession to soybean, and considering the herbicide half‑life ($t_{1/2}$) to avoid injury problems is important. The $t_{1/2}$ is the time required for 50% of the herbicide molecules to dissipate and can vary from days to years depending on the product (Mendes et al., 2017).

Acetolactate synthase (ALS)−inhibiting herbicides, such as diclosulam, are commonly used in soybean cultivation for weed management (Silva et al., 2023). Diclosulam was the third most marketed product in this group, with 210.3 t of active ingredient sold (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis – IBAMA, 2025; Ministério da Agricultura, Pecuária e Abastecimento – MAPA, 2025).

The herbicide diclosulam has the following physicochemical characteristics: low water solubility (6.32 mg $L^{-1}$), being moderately lipophilic (octanol–water partition coefficient of 0.85), classified as a weak acid herbicide (electrolytic dissociation constant of 4.0), non‑volatile, and with a low organic carbon–normalized sorption coefficient (Koc: 90 L $kg^{-1}$) (Lewis et al., 2016). Its degradation occurs mainly through microbial activity (Bedmar and Gianelli, 2014; Rodrigues and Almeida, 2018), with a $t_{1/2}$ ranging from 60 to 90 days in a dystroferric Red Latosol (Oxisol) (Lavorenti et al., 2003). The dry period after herbicide application (Barros et al., 2021) and the organic matter content, such as the presence of crop residues (Agostinetto et al., 2024), are the main factors affecting its adsorption.

In this context, the working hypothesis of this study is that diclosulam affects the initial development of maize and sorghum depending on the herbicide dose available in the soil. Thus, this study aimed to evaluate the residual effect of diclosulam on the initial maize and sorghum development.

## 2. Material and Methods

The experiment was carried out between May and June 2023 in a greenhouse located at the Department of Agronomy of the State University of Londrina (UEL), Londrina, Paraná, Brazil (23°32′89″ S, 51°20′37″ W). The regional climate is classified as Cfa, a humid subtropical climate characterized by hot summers and mild winters, with well‑distributed precipitation throughout the year, according to the Köppen classification. The soil chemical properties, according to soil analysis, were as follows: pH ($CaCl_2$) = 5.9, P = 2.71 mg $dm^{-3}$, K = 0.42 $cmol_c$ $dm^{-3}$, Ca = 4.19 $cmol_c$ $dm^{-3}$, Mg = 1.03 $cmol_c$ $dm^{-3}$, H+Al = 2.19 $cmol_c$ $dm^{-3}$, organic matter = 15.1 g $kg^{-1}$, and base saturation = 72%, classifying it as a clay‑textured soil.

The experimental design was completely randomized, with six treatments and four replications for each crop. The experimental unit consisted of one-liter plastic pots filled with soil, in which six seeds were sown at a depth of three centimeters. The pots were irrigated daily. The treatments consisted of diclosulam (Spider® 840 WG) doses of 5.23, 10.43, 20.85, 41.70, and 83.40 g ai $ha^{-1}$ applied pre‑emergence to maize (cultivar KWS 7510 VIP3) and sorghum (cultivar AL Precioso), and one untreated control for each crop.

The application was performed with a $CO_2$ pressurized backpack sprayer equipped with a boom containing four flat‑fan spray nozzles (XR 110.02), at a constant pressure of 2 bar, a spray volume of 150 L $ha^{-1}$, operating at a height of 50 cm from the target, and at a speed of 1 m $s^{-1}$, resulting in an applied swath of 50 cm per nozzle. The application was performed on the same day as sowing.

The assessments of injury symptoms and the number of emerged plants were carried out at 7, 14, 21, and 28 days after emergence (DAE) in the untreated control for maize, and at 28 DAE for sorghum. Scores from 0 to 100% were assigned for injury symptoms, where zero corresponds to the absence of symptoms and 100% to plant death (European Weed Research Council – EWRC, 1964). Plant height was also measured for maize at 28 DAE using a graduated ruler, recording the total length of the emerged seedling, with data expressed in centimeters (cm).

The shoot dry mass (SDM) of maize and sorghum was determined at 28 DAE. Plants were cut with scissors at the soil surface, placed in paper bags, and dried in a forced‑air circulation oven at 65 °C until reaching constant weight, with data expressed in grams (g).

Before analysis of variance (ANOVA), homogeneity of variances (Levene and Bartlett) was tested, as well as residual normality using the Shapiro‑Wilk and Box Cox tests. After meeting these assumptions, the data were transformed and subjected to ANOVA using the F test ($p < 0.05$), and means were compared by Tukey's test at 5% probability when significant. Statistical analyses were performed using R software v. 4.4.2 (R Core Team, 2024).

## 3. Results and Discussion

Visual injury symptoms for the different diclosulam doses in maize were observed in seedlings at 21 and 28 DAE. An increase in injury scores was observed with the increase in diclosulam residual dose. A difference was observed at 21 DAE, starting from the dose of 5.23 g ai ha$^{-1}$, compared to the control, with injury symptoms ranging from 33.75% (5.23 g ai ha$^{-1}$) to 61.25% (83.40 g ai ha$^{-1}$). Greater injury symptoms were observed in the last evaluation, at 28 DAE, from the dose of 20.85 g ai ha$^{-1}$ (Table 1).

Injury symptoms in sorghum were observed at 28 DAE. No injury symptoms attributable to diclosulam were recorded at 7, 14, and 21 DAE. However, an impairment in the initial development of the crop was observed starting from the dose of 20.85 g ai ha$^{-1}$, at 28 DAE, with the highest symptoms recorded at doses of 20.85 g ai ha$^{-1}$ (68.75%), 35 g ai ha$^{-1}$ (85%), and 70 g ai ha$^{-1}$ (90%) (Table 2).

Symptoms caused by ALS‑inhibiting herbicides reach their peak approximately 7 to 10 days after application (DAA) (Braz et al., 2024). This explains the increasing injury symptoms observed from 14 DAE in maize and only at 28 DAE in sorghum. Diclosulam is absorbed by the radicle and hypocotyl of germinating and emerging plants and is rapidly metabolized in tolerant plants (Rodrigues and Almeida, 2018). In this study, symptoms took longer to appear in sorghum, but they were more prominent than in maize.

Sorghum is more sensitive to the residual remaining in the soil of the active ingredient diclosulam when compared to maize (Tables 1 and 2), which can be seen in the injury symptoms, for example, at the dose of 20.85 g ai ha$^{-1}$ for maize and sorghum of 38.75% and 68.75%, respectively.

This highlights the importance of choosing herbicides used in soybean cultivation, considering the period between application and sowing of sorghum, as well as the applied dose.

The symptoms caused by ALS‑inhibiting herbicides include growth arrest, leaf chlorosis, chlorosis followed by necrosis of the apical meristem, reduced root volume, and shorter secondary roots (Braz et al., 2024). Figure 1 shows the symptoms of growth arrest and chlorosis in sorghum.

**Table 1.** Injury symptoms in maize at 7, 14, 21, and 28 days after emergence (DAE) in response to pre‑emergence diclosulam doses.

| Doses (g ai ha$^{-1}$) | Injury symptoms (%) | | | |
|---|---|---|---|---|
| | 7 DAE $^{ns}$ | 14 DAE $^{ns}$ | 21 DAE * | 28 DAE * |
| 0.00 | 0.00 | 0.00 | 0.00 a | 0.00 a |
| 5.23 | 0.00 | 5.00 | 33.75 b | 20.00 ab |
| 10.43 | 0.00 | 3.75 | 36.25 b | 22.50 abc |
| 20.85 | 0.00 | 15.00 | 42.50 bc | 38.75 bcd |
| 41.70 | 0.00 | 17.50 | 56.25 cd | 47.50 cd |
| 83.40 | 0.00 | 21.25 | 61.25 d | 62.50 d |
| Mean | 0.00 | 10.41 | 38.33 | 31.87 |
| CV (%) | 0.00 | 46.58 | 20.11 | 16.65 |

*Means followed by the same letters in the column do not differ from each other according to Tukey's test at 5% probability; ns: not significant; CV: coefficient of variation.

**Table 2.** Injury symptoms (%) in sorghum at 28 days after emergence (DAE) in response to pre‑emergence diclosulam doses.

| Doses (g ai ha$^{-1}$) | Injury symptoms (%) | |
|---|---|---|
| 0.00 | 0.00 | a |
| 5.23 | 4.50 | a |
| 10.43 | 10.00 | a |
| 20.85 | 68.75 | b |
| 35.00 | 85.00 | b |
| 70.00 | 90.00 | b |
| Mean | 43.04 | |
| CV | 28.31 | |

Means followed by the same letters in the column do not differ from each other according to Tukey's test at 5% probability; CV: coefficient of variation. Doses in g ai ha$^{-1}$.

**Figure 1.** Injury symptoms in sorghum at 28 days after emergence (DAE) in soil with diclosulam residual. Doses decreasing from left to right: 70.0, 35.0, 20.85, 10.43, 5.23, and 0 g ai $ha^{-1}$. Londrina, PR, Brazil. Source: Authors' archive.

The active ingredient diclosulam is an ALS‑inhibiting herbicide, belonging to the chemical group of triazolopyrimidines, registered for pre‑emergence weed control in soybean and sugarcane crops, depending on the commercial product (Rodrigues and Almeida, 2018). The field half‑life is 20 to 43 days (Shaner, 2014), and soil moisture and organic matter content are the main factors affecting herbicide adsorption, with a sorption coefficient (Kd) ranging from 0.6 to 3.8 L $kg^{-1}$ (Lewis et al., 2016). Therefore, greater injury symptoms of 68.75%, 85%, and 90% were observed at doses above 20.85, 35, and 70 g ai $ha^{-1}$, respectively, due to the presence of the herbicide molecule in the soil.

The doses of 20.85, 41.70, and 83.40 g ai $ha^{-1}$ affected the maize plants regarding plant height and shoot dry mass (SDM), whereas the number of emerged seedlings was not affected, with a general mean of 5.4 emerged plants at 28 DAE (Table 3). The number of emerged sorghum seedlings at the highest diclosulam dose (70 g ai $ha^{-1}$) was lower than the control in all evaluations. SDM values were lower at the doses of 20.85 g ai $ha^{-1}$ (0.02 g), 35 g ai $ha^{-1}$ (0.02 g), and 70 g ai $ha^{-1}$ (0.02 g) than in the control treatment (0.15 g). No statistical difference was observed for SDM up to the dose of 10.43 g ai $ha^{-1}$ compared to the control (Table 4). This reflects the importance of the dose in the residual effect of the herbicide.

The residual effect of a product varies with the dose (Timossi et al., 2020), environmental conditions, the herbicide's half‑life, and soil characteristics such as texture and organic matter. The higher the applied dose, the longer it will take to degrade the herbicide molecules, and the greater the likelihood of carryover (Fraga et al., 2019).

Growth arrest immediately after application of ALS inhibiting herbicides is among the symptoms reported for this mode of action (Braz et al., 2024; Mendes et al., 2022). Dry mass is generated by the conversion of water and nutrients into energy (Taiz et al., 2017). Thus, a plant with greater water use efficiency will have a higher chance of being more competitive with weeds, especially at the beginning of its development.

Rapid crop establishment is related to cultural weed management, in which the crop must occupy the environment, preventing or delaying weed development through rapid soil shading, which reduces light incidence and hinders weed germination (Rodrigues et al., 2010).

The higher the herbicide doses, the longer the time required for degradation. Carryover of products that are not selective for the subsequent crop is one of the challenges in weed management (Francischini et al., 2020; Silva et al., 2024). However, using doses within the recommended range and correctly positioning them within the plant‑back interval reduces the occurrence of negative impacts on the subsequent crop (Grint et al., 2022), even with reports of carryover cases involving ALS‑inhibiting herbicides (Oliveira Jr. et al., 2015). As verified in this study, sorghum emergence was reduced only at the highest dose (70 g ai $ha^{-1}$).

Sorghum is used as a bioindicator because it is an herbicide‑sensitive crop (Novais et al., 2021; Sousa Jonas et al., 2020). A reduction in shoot dry mass and yield has been observed in sorghum sown 115 days after the use of sulfentrazone (100 g ai $ha^{-1}$), diclosulam (35 g ai $ha^{-1}$), and imazethapyr (100 g ai $ha^{-1}$) (Dan et al., 2010), as well as a reduction in shoot dry mass when sown at an interval of 114–179 days after the use of fomesafen (250 g ai $ha^{-1}$), 96–139 days after the application of acifluorfen (170 g ai $ha^{-1}$), and 78–139 days after imazamox (40 g ai $ha^{-1}$) (Cobucci et al., 1998). Similarly, injury symptoms were observed in this study at 28 DAE in sorghum, along with growth arrest, as evidenced by the reduction in SDM starting from the dose of 20.85 g ai $ha^{-1}$.

The longer the interval between the application of residual herbicides and sorghum sowing, the lower the toxicity due to the product's residual effect.

**Table 3.** Number of emerged plants at 7, 14, 21, and 28 days after emergence (DAE), plant height, and shoot dry mass (SDM) at 28 DAE in maize in response to pre‑emergence diclosulam doses.

| Doses | Number of emerged seedlings [ns] | | | | Height (cm)* | SDM (g)* |
|---|---|---|---|---|---|---|
| (g ai ha$^{-1}$) | 7 DAE | 14 DAE | 21 DAE | 28 DAE | | |
| 0.00 | 4.0 | 5.5 | 5.5 | 5.5 | 5.8 a | 0.9 a |
| 5.23 | 5.0 | 5.7 | 5.7 | 5.7 | 3.3 ab | 0.4 b |
| 10.43 | 6.0 | 6.0 | 5.7 | 5.2 | 3.4 ab | 0.5 ab |
| 20.85 | 5.5 | 5.7 | 5.5 | 5.5 | 2.0 b | 0.3 b |
| 41.70 | 5.5 | 5.7 | 6.0 | 5.2 | 2.6 b | 0.3 b |
| 83.40 | 5.2 | 6.0 | 5.5 | 5.5 | 1.6 b | 0.2 b |
| Mean | 5.2 | 5.7 | 5.6 | 5.4 | 3.1 | 0.4 |
| CV | 22.3 | 7.4 | 9.3 | 13.4 | 14.0 | 5.2 |

*Means followed by the same letters in the column do not differ from each other according to Tukey's test at 5% probability; ns: not significant; CV: coefficient of variation.

**Table 4.** Number of emerged plants at 14, 21, and 28 days after emergence (DAE) and shoot dry mass (SDM) at 28 DAE in sorghum in response to pre‑emergence diclosulam doses.

| Doses | Number of emerged seedlings | | | SDM (g) |
|---|---|---|---|---|
| (g ai ha$^{-1}$) | 14 DAE | 21 DAE | 28 DAE | |
| 0.00 | 4.25 a | 5.75 a | 5.75 a | 0.15 a |
| 5.21 | 5.00 a | 5.00 a | 5.00 a | 0.18 a |
| 10.43 | 4.75 a | 4.25 ab | 4.50 ab | 0.11 ab |
| 20.85 | 2.75 a | 3.75 ab | 3.75 ab | 0.02 b |
| 35.00 | 3.75 a | 3.75 ab | 3.75 ab | 0.02 b |
| 70.00 | 0.00 b | 2.25 b | 2.25 b | 0.02 b |
| Mean | 3.41 | 4.12 | 4.16 | 0.08 |
| CV | 12.73 | 26.03 | 25.04 | 1.84 |

Means followed by the same letters in the column do not differ from each other according to Tukey's test at 5% probability; CV: coefficient of variation.

Concenço et al. (2018) concluded that sorghum can be sown 70 days after application in areas where the herbicides clomazone (1.25 kg ai ha$^{-1}$), trifloxysulfuron (0.0075 kg ai ha$^{-1}$), trifluralin (2.4 kg ai ha$^{-1}$), and sulfentrazone (0.6 kg ai ha$^{-1}$) were used. However, they observed that greater caution is needed for diclosulam (0.042 kg ai ha$^{-1}$) and imazethapyr (0.15 kg ai ha$^{-1}$) due to the potential damage these herbicides may cause to sorghum.

Therefore, the dose, the subsequent crop, and the herbicide's half‑life need to be considered when using residual herbicides to avoid carryover problems. Sorghum is a plant sensitive to many herbicides, including diclosulam. These results show that both maize and sorghum are affected by the presence of diclosulam residues in the soil. Thus, proper planning of the subsequent crop is essential to prevent losses, making it important to know the field's management history.

## 4. Conclusions

Residual doses equal to or greater than 20.85 g ai ha$^{-1}$ of the active ingredient diclosulam are detrimental to the initial development of maize and sorghum. Sorghum showed no damage to the crop up to the dose of 10.43 g ai ha$^{-1}$.

## Authors' Contribution

Conceptualization and methodology: Ana Ligia Giraldeli, Neriane Hijano; data collection and curation: Gustavo Stoinski, Gustavo Figueiredo da Silva, Higor Henrique dos Santos Garcia, Leonardo Marques da Costa; formal analysis: Ana Ligia Giraldeli; data interpretation: Ana Ligia Giraldeli, Neriane Hijano; project administration: Gustavo Stoinski; supervision: Ana Ligia Giraldeli, Neriane Hijano; original draft preparation: Ana Ligia Giraldeli; writing -review and editing: Neriane Hijano, Gustavo Stoinski, Gustavo Figueiredo da Silva, Higor Henrique dos Santos Garcia, Leonardo Marques da Costa. All authors read and approved the final version of the manuscript.

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