Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Sensitivity of common bean plants to the herbicide dicamba applied at pre-sowing

Sensibilidade do feijoeiro ao herbicida dicamba aplicado em pré-semeadura

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Submission: September 11th, 2025 | Acceptance: December 20th, 2025

ABSTRACT

Dicamba is an herbicide with residual activity in the soil and may affect crops sown after its application, mainly eudicotyledon species, as common bean (*Phaseolus vulgaris* L.). Thus, this work was developed with the objective of evaluating the sensitivity of common bean plants (Carioca cultivar BRS Estilo) to the herbicide dicamba applied at pre-sowing, based on different herbicide rates and different intervals between application and sowing. Three experiments were carried out, two under greenhouse and one under field (experimental beds) conditions. One of the greenhouse experiments was carried out to assess the correlation between different dicamba rates (720, 480, 240, 120, and 60 g ha^{-1}) and the sensitivity of common bean plants, with checkplots without herbicide. The other two experiments, one in greenhouse and other in field conditions, were carried out to evaluate the different intervals between dicamba application and common bean sowing. The evaluated intervals were 28, 21, 14, 7 and zero days, including checkplots without herbicide. Considering these intervals, lower symptoms were found under greenhouse conditions. In this environment, 14 days were sufficient to ensure the emergence and initial development of common bean plants. In the field experiment, 28 days were needed for a satisfactory emergence and initial development of common bean plants. On average, 14 days were sufficient for dissipation of more than 90% of the herbicide applied. A 28-day interval after dicamba application is recommended for a safe sowing of common bean crops.

KEYWORDS: Auxin herbicides. Phytotoxicity. Residual activity. Burndown.

RESUMO

O dicamba é um produto que possui atividade residual no solo, podendo afetar as culturas semeadas após sua aplicação, sobretudo as espécies eudicotiledôneas, como o feijoeiro. Assim sendo, objetivou-se avaliar a sensibilidade do feijoeiro, cultivar carioca BRS Estilo, ao herbicida dicamba quando aplicado em pré-semeadura, variando-se a dose do produto, bem como o intervalo entre as pulverizações e a data de semeadura. Para tanto, três experimentos foram realizados, sendo dois em casa-de-vegetação e um em canteiros experimentais. Um experimento foi realizado em casa-de-vegetação, de modo a se observar a relação entre diferentes doses de dicamba (720, 480, 240, 120, 60 g ha^{-1}) e a sensibilidade do feijoeiro, além de testemunha sem aplicação. Dois outros experimentos, um em canteiros e outro em casa-de-vegetação, foram realizados avaliando os diferentes intervalos de tempo entre a pulverização de dicamba e a semeadura do feijoeiro. Neste caso, avaliaram-se períodos de 28, 21, 14, 7 e zero dias, além de testemunha sem aplicação do herbicida. Considerando-se os mesmos intervalos de tempo entre a aplicação de dicamba e a semeadura do feijoeiro, menores sintomas foram observados em condição de casa-de-vegetação. Neste ambiente, 14 dias foram suficientes para garantir a emergência e o desenvolvimento inicial das plantas de feijoeiro. Em campo, 28 dias foram necessários para a perfeita emergência e desenvolvimento inicial do feijoeiro. Em média, 14 dias foram suficientes para dissipação de mais de 90%

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do produto aplicado. Para semeadura segura da cultura, recomendam-se 28 dias de intervalo após aplicação de dicamba.
PALAVRAS-CHAVE: Herbicidas auxínicos. Fitotoxicidade. Atividade residual dessecação. Burndown.

INTRODUCTION

One of the main problems connected to weed management in Brazil is the resistance of biotypes of different species to herbicides. Currently, there are 57 different confirmed cases of weed resistance to herbicides, involving several mechanisms of action, such as inhibition of ALS, ACCase, PROTOX, and photosystems, as well as resistance to the herbicide glyphosate (HEAP 2024).

Glyphosate-resistant weeds directly affect pre-sowing management practices, as glyphosate is the most used molecule for burndown (ALVARENGA et al. 2023). Herbicides with alternative mechanisms of action are often added to the spray solution for the control of glyphosate-resistant weed biotypes, including auxin mimic herbicides (2,4-D and dicamba), ACCase-inhibiting herbicides (clethodim and haloxyfop), and PROTOX-inhibiting herbicides (saflufenacil, flumioxazin, and carfentrazone) (ALVARENGA et al. 2023, BORNELLI et al. 2022, CUNHA et al. 2022, CANTU et al. 2021, CASSOL et al. 2019, CORREIA & DURIGAN 2009).

Horseweed species (*Conyza* genus) stands out among weed species with glyphosate-resistant biotypes in Brazil due to a high number of cases reported in the country and the large agricultural area affected (MENDES et al. 2021). In this sense, biotypes of *C. bonariensis* (L.) Cronquist, *C. Canadians* (L.) Cronquist, and *C. sumatrensis* (Rets.) Cronquist were reported as resistant to glyphosate in Brazil (HEAP 2024). These species have a high ecological adaptability and produce large number of seeds, with a high dispersion potential (BORNELLI et al. 2022, GAZZIERO et al. 2015, SANSOM et al. 2013). According to BRAZ et al. (2017), horseweed species cause severe damage to agricultural crops, mainly due to the selection of biotypes resistant to multiple mechanisms of herbicide action.

Therefore, auxin mimic herbicides, such as 2,4-D, dicamba, and triclopyr, have been added to the spray solution to achieve effective burndown of areas infested with horseweeds, with dicamba standing out for its high efficacy (CANTU et al. 2021, OSIPE et al. 2017, SILVA et al. 2020, SOARES et al. 2012). Dicamba, a benzoic acid herbicide, is also classified as a growth regulator or synthetic auxin. When applied to eudicotyledon plants, the first visible symptom is epinasty of leaves and petioles. Other metabolic functions are affected few days after application, resulting in several symptoms, including deformities in leaf vein and leaf blade (cupping), callus formation at the petiole base, stunting plant growth, flower abortion, meristematic changes, and ultimately, a slow death of susceptible plants within three to five weeks after application (CARVALHO et al. 2023, CUNHA et al. 2022, OLIVEIRA JUNIOR 2011).

Dicamba is an important alternative for combining with glyphosate to achieve a more effective pre-sowing burndown; however, it has residual activity in the soil and may injure crops sown after its application (AGUIAR et al. 2020, CARVALHO et al. 2022). The persistence and dissipation of herbicides in the soil are affected by several factors related to local edaphoclimatic conditions, soil texture and organic matter contents, soil microbial community and its metabolic activity, water availability, and air

temperature (AGUIAR et al. 2023, GILREATH et al. 2006, SILVA et al. 2020). In this sense, it is essential to respect the minimum recommended interval between dicamba application and sowing of sensitive crops.

In general, eudicotyledon plants are highly sensitive to auxin mimic herbicides (BARARPOUR & TSENG 2023, CARVALHO et al. 2022, MOHSENI-MOGHADAM et al. 2016); however, there is limited information on their effects on common bean (*Phaseolus vulgaris* L.), an important crop in Brazil. Therefore, this work was developed with the objective of evaluating the sensitivity of common bean plants (Carioca bean cultivar BRS Estilo) to the herbicide dicamba applied at pre-sowing, using different herbicide rates and different intervals between the application and sowing.

MATERIAL AND METHODS

Three experiments were carried out in Machado, MG, Brazil (21°40'S; 45°55'W; altitude of 850 meters) between November 2023 and January 2024: two in greenhouse and one in field (experimental beds) conditions. The field experiment was carried out using a randomized block design with six treatments and four replications, totaling 24 experimental units. The treatments consisted of different intervals between dicamba application to the plots and sowing of common bean plants (28, 21, 14, 7, and 0 days), along with checkplots without herbicide application. The reference dicamba rate used was 720 g a.e. ha^{-1}, with an anti-drift adjuvant (1% v v^{-1}).

Four parallel experimental beds (effect of blocks) were raised in a clayey texture soil (53.2% clay), whose chemical attributes are shown in Table 1. The beds were mechanically raised 20 cm above ground level on November 23, 2023, using a bed sharper, with an effective width of 1.20 m and a total length of 20 m. Six 3-meter plots were implemented in each bed. The beds were maintained without weeds by applying herbicides selective to common bean plants. The beds were raised and herbicides (1,920 g ha^{-1} of S-metolachlor and 25 g ha^{-1} of flumioxazin) were applied 28 days before sowing. Weeds were eliminated during the 28-day period between bed raising and common bean sowing by applying glyphosate (960 g a.e. ha^{-1}) or diquat (300 g ha^{-1}), herbicides with no residual activity in the soil.

Table 1. Chemical attributes of the clayey soil of the experimental beds, which was also used in the greenhouse experiment. Machado, MG, Brazil, 2024.

pH	OM	P_{res}	K	Ca	Mg	H+Al	SB	CEC	BS	AS
$CaCl_2$	g kg^{-1}	mg dm^{-3}	$mmol_c$ dm^{-3}	$mmol_c$ dm^{-3}					%	%
5.6	28.5	77.0	5.22	35.9	18.0	22.2	59.1	81.3	73.0	0.0

OM = organic matter; CEC = cation exchange capacity; BS = base saturation; AS = aluminum saturation.

Common bean seeds (Carioca cultivar BRS Estilo) were sown in the experimental units on December 21, 2023, following the final dicamba application. Two planting rows spaced 0.50 m apart were stablished in each plot, with 15 planting holes per row. The seeds were sown using a hand seeder-fertilizer spreader, distributing three seeds and 5.5 g of a 10-30-10 NPK fertilizer formulation per hole. The seeds were pre-treated with thiamethoxam (Cruiser® 350 FS) at a rate of 3.0 mL c.p. kg^{-1}. The experiment was

subjected to the natural rainfall regime of Machado in November, December, and January, which provided adequate water availability since the bed raising (Figure 1).

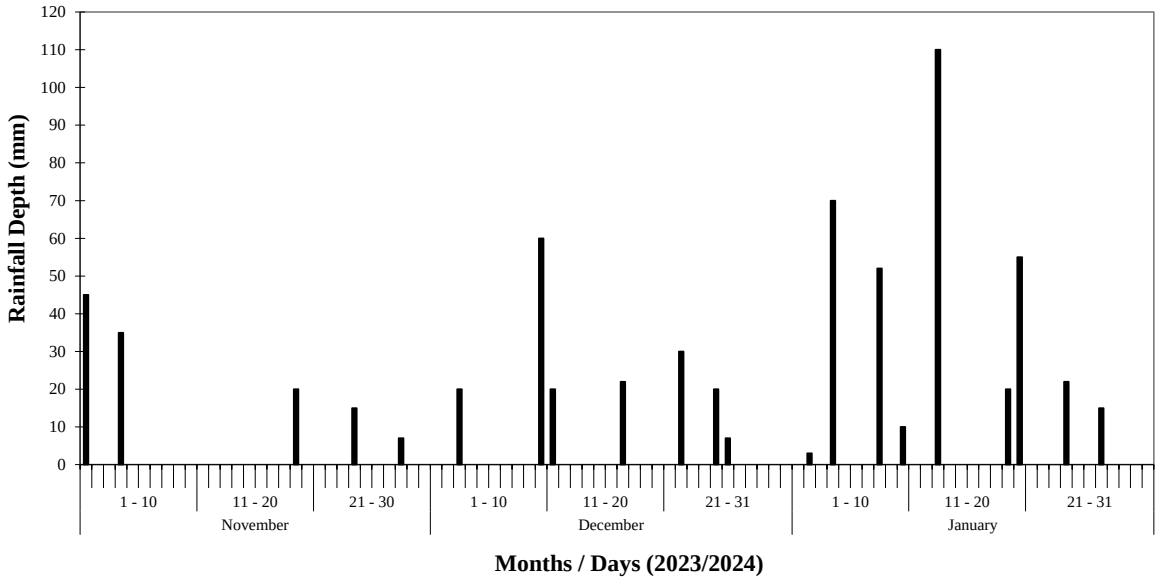


Figure 1. Daily rainfall depths recorded during plant development in the field experiment (experimental beds). Machado, MG, Brazil, 2023.

Similarly, the greenhouse experiment was carried out in a completely randomized design with four replications, using the same six dicamba treatments and the same soil (Table 1), however, with 4-liter pots. Soil from the beds was sieved before filling the pots, which were treated with the same dicamba rate applied to the field beds (720 g ha^{-1} + adjuvant) and subsequently arranged in the greenhouse. Common bean seeds were sown in the pots after at the different periods of dicamba permanence in the soil (28, 21, 14, 7, and zero days), including checkplots without application. Three small holes (3.0 cm deep) were dug in each pot, and then two common bean seeds were placed in each hole.

A third greenhouse experiment was carried out to assess the relation between the different dicamba rates and the sensitivity of common bean plants. Four-liter pots filled with the same clayey soil (Table 1) were used. The experiment was carried out in a completely randomized design with treatments consisting of five dicamba rates (720, 480, 240, 120, 60 g ha^{-1}) plus 1% anti-drift adjuvant (v v^{-1}), and checkplots without application. Immediately after the pre-sowing applications, common bean seeds were sown in the pots as described previously. Plants in both greenhouse experiments were maintained under daily automatic irrigation. Irrigation was monitored, with application of a mean daily water depth of 5 mm distributed over five irrigation shifts per day.

Herbicide treatments were applied to the field and greenhouse experiments using a CO_2-pressurized backpack sprayer equipped with a spray boom containing two TTI 110.02 nozzles, applying a solution volume equivalent to 200 L ha^{-1} at a pressure of 2.5 bar. All the herbicide applications were performed with satisfactory environmental conditions of temperature, wind speed and humidity. Phytotoxicity was assessed in all experiments at 14, 21, and 28 days after sowing (DAS).

A visual scale of phytotoxicity ranging from 0% (completely healthy plants) to 100% (dead plants) was used (SBCPD 1995). Additionally, emerged plants in the plots (pots and beds) were counted at 7 DAS in the experiments evaluating the interval between application and sowing. All the aerial parts of the plants available in the plots (pots and beds) were harvested at the end of the experiments (28 DAS) and then dried in a forced air circulation oven at 65 °C to constant weight. Dry matter data were expressed as a percentage of the checkplot of each block.

The data were subjected to analysis of variance and, when significant, qualitative data were grouped by the Scott-Knott test (SCOTT & KNOTT 1974). All tests were carried out at a 5% significance level. Quantitative data referring to the experiment evaluating the plant sensitivity to dicamba rates were fitted to a log-logistic model proposed by CARVALHO et al. (2010):

$$y = \frac{100}{1+\left(\frac{x}{C_{50}}\right)^{\alpha}} \quad (1)$$

In which, C_{50} is the dicamba rate causing 50% toxicity in common bean plants and α is the slope of the curve around the C_{50} value. This model predicts that as the dicamba rate tends to infinity (high rates), the toxicity to common bean plants is 100%.

RESULTS AND DISCUSSION

Adequate emergence of plants was found in the experimental checkplots at the first evaluation (7 DAS), with a mean of 5.8 plants per pot and 41.8 plants per plot in beds (Table 2). Regarding the intervals between dicamba application and common bean sowing, dicamba application on the day of sowing completely suppressed seedling emergence, causing 100% phytotoxicity in the plots (beds and pots). Slightly different data between the greenhouse and field experiments were found for the other intervals. The toxicity found in the field experiment was always higher than those in greenhouse, even for the 28-day interval (Table 2).

Table 2. Number of emerged common bean plants at seven days after sowing (DAS) and phytotoxicity at 14 DAS, evaluated under greenhouse and field (experimental beds) conditions after different intervals between dicamba application and common bean sowing. Machado, MG, Brazil, 2024.

Intervals [1]	Emerged plants – 7 DAS		Phytotoxicity – 14 DAS	
	Greenhouse	Field	Greenhouse	Field
Checkplots	5.8 A	41.8 A	0.0 A	0.0 A
0 days	0.0 C	0.0 C	100.0 C	100.0 D
7 days	2.5 B	0.3 C	72.0 B	100.0 D
14 days	4.8 A	30.8 B	15.0 A	35.0 C
21 days	4.5 A	30.5 B	3.3 A	25.3 C
28 days	4.5 A	36.5 A	1.3 A	17.5 B
$F_{treatment}$	9.618*	51.072*	57.693*	116.711*
CV(%)	36.65	22.13	35.60	17.16

[1]Intervals between dicamba application (720 g a.e. ha^{-1}) and common bean sowing; *F test significant at a 1% significance level; Means followed by the same letter in the columns are not significantly different from each other by the Scott-Knott test at a 5% significance level.

This difference may be due to the irrigation applied to greenhouse plants, since the same soil was used in the field and greenhouse experiments. The field plots were subjected to natural rainfall, which was satisfactory, but not frequent as the daily irrigation in the greenhouse (Figure 1). Daily irrigation probably contributed to biological degradation of the herbicide in the pots, resulting in lower toxicity in greenhouse plants.

Additionally, dicamba has a recognized leaching potential (INOUE et al. 2003, SILVA et al. 2020) due to a weak sorption to soil colloids (Kd < 0,7; and log Kow = 2.21) (PUBCHEM 2025, AGUIAR et al. 2023, CARVALHO et al. 2022, MENASSERI et al. 2003). Its water solubility varies from 4,500 up to 8,310 mg L^{-1} (PUBCHEM 2025); therefore, water availabilities between 33 and 95 mm may result in herbicide leaching up to 10 cm depth (FRIESEN 1965, GROVER 1977).

AGUIAR et al. (2023) evaluated two contrasting soil types and found leaching ranging from 10 to 40 cm depth for dicamba after two 40-mm simulated rainfalls, which was attributed to the evaluated soil type and horizon. The field beds were subjected to intense rainfall during the experimental period (Figure 1); however, it was not sufficient to reduce phytotoxicity in common bean plants. Therefore, the biological degradation of dicamba might be a more significant factor for reducing phytotoxicity symptoms than leaching, considering the daily irrigation of greenhouse plants and periods of water shortage for field plants.

High toxicity to common bean plants were found at 21 and 28 DAS; the phytotoxicity found in the field experiment was higher than that in greenhouse (Table 3). According to the results, the pre-sowing dicamba application to common bean plants is only viable when using a minimum interval of 14 days between application and sowing. The phytotoxicity found at 21 DAS for the 14-day interval was equal to those found for 21- and 28-day intervals, denoting a safe application. However, the 28-day interval in the field experiment at 28 DAS significantly differed from the others, providing a higher safety for pre-sowing application of dicamba (Table 3).

Table 3. Phytotoxicity in common bean plants at 21 and 28 days after sowing (DAS), evaluated under greenhouse and field (experimental beds) conditions after different intervals between dicamba application and crop sowing. Machado, MG, Brazil, 2024.

Intervals [1]	Phytotoxicity – 21 DAS		Phytotoxicity – 28 DAS	
	Greenhouse	Field	Greenhouse	Field
Checkplots	0.0 A	0.0 A	0.0 A	0.0 A
0 days	100.0 C	100.0 C	100.0 C	100.0 D
7 days	63.8 B	100.0 C	58.8 B	100.0 D
14 days	18.3 A	26.3 B	17.5 A	31.3 C
21 days	6.5 A	21.3 B	4.0 A	27.5 C
28 days	1.5 A	13.8 B	0.0 A	15.0 B
$F_{treatment}$	55.058*	167.409*	51.269*	101.461*
CV(%)	34.94	15.84	38.02	18.94

[1]Intervals between dicamba application (720 g a.e. ha^{-1}) and common bean sowing; *F test significant at a 1% significance level; Means followed by the same letter in the columns are not significantly different from each other by the Scott-Knott test at a 5% significance level.

The results found for dry matter weight were similar to those for phytotoxicity (Table 4). In the greenhouse experiment, only the 28-day interval between herbicide application and sowing resulted in similar dry matter to the control without herbicide. In

the field experiment, the intervals of 14, 21, and 28 days did not significantly differ in dry matter weight.

Table 4. Dry matter weight of common bean plants at 28 days after sowing (DAS), evaluated under greenhouse and field (experimental beds) conditions after different intervals between dicamba application and common bean sowing. Machado, MG, Brazil, 2024.

Intervals [1]	Dry matter weight – 28 DAS	
	Greenhouse	Field
Checkplots	6.6 A	130.5 A
0 days	0.0 D	0.0 B
7 days	2.1 C	0.0 B
14 days	4.5 B	108.4 A
21 days	5.1 B	110.2 A
28 days	6.2 A	142.2 A
$F_{treatment}$	19.299*	37.976*
CV(%)	28.56	25.64

[1]Intervals between dicamba application (720 g a.e. ha^{-1}) and common bean sowing; * F test significant at a 1% significance level; Means followed by the same letter in the columns are not significantly different from each other by the Scott-Knott test at a 5% significance level.

Common bean is a highly dicamba-sensitive species, as the pre-sowing application at a rate of 60 g a.e. ha^{-1} caused more than 60% phytotoxicity (Table 5; Figure 2). Similar results were found for soybean crops subjected to pre-sowing application of the dicamba rate of 60 g ha^{-1}, which was considered critical to the crop (CARVALHO et al. 2022). In this sense, AGUIAR et al. (2020) evaluated the sensitivity of bioindicators of dicamba in the soil and found that soybean and common bean plants are highly sensitive to this molecule; the dicamba rate of 60 g ha^{-1} applied to sand caused phytotoxicity higher than 80% in common bean plants, and the C_{50} at 14 DAS was only 17.75 g ha^{-1}, which is consistent with the results found in the present work (Table 5).

Table 5. Log-logistic model parameters for toxicity of different dicamba rates to common bean plants. Machado, MG, Brazil, 2024.

Evaluations	Parameters of the model [1]		R^2
	C_{50}	α	
Phytotoxicity - 14 DAS	21.978	-2.205	0.999
Phytotoxicity - 21 DAS	30.269	-1.598	0.999
Phytotoxicity - 28 DAS	43.581	-1.660	0.998
Dry matter	24.939	1.851	0.999

[1]Log-logistic model parameters; Equation: $y = 100 / (1+(x/C_{50})^{\alpha})$; C_{50} = rate that causes 50% phytotoxicity or 50% decrease in dry matter; α = slope of the curve; R^2 = coefficient of determination.

Considering the results shown in Figure 2 and Tables 2, 3, and 4, the herbicide dicamba had a high dissipation/degradation in the experiments. In the greenhouse experiment, the minimum interval of 14 days between application and sowing was sufficient to dissipate more than 95% of the initial rate applied (720 g ha^{-1}), ensuring plant emergence, with phytotoxicity between 15% and 35% (Table 2). Despite a rapid molecule dissipation, the presence of residues in the soil, although at low concentrations, was sufficient to cause toxicity to common bean plants (Figure 2).

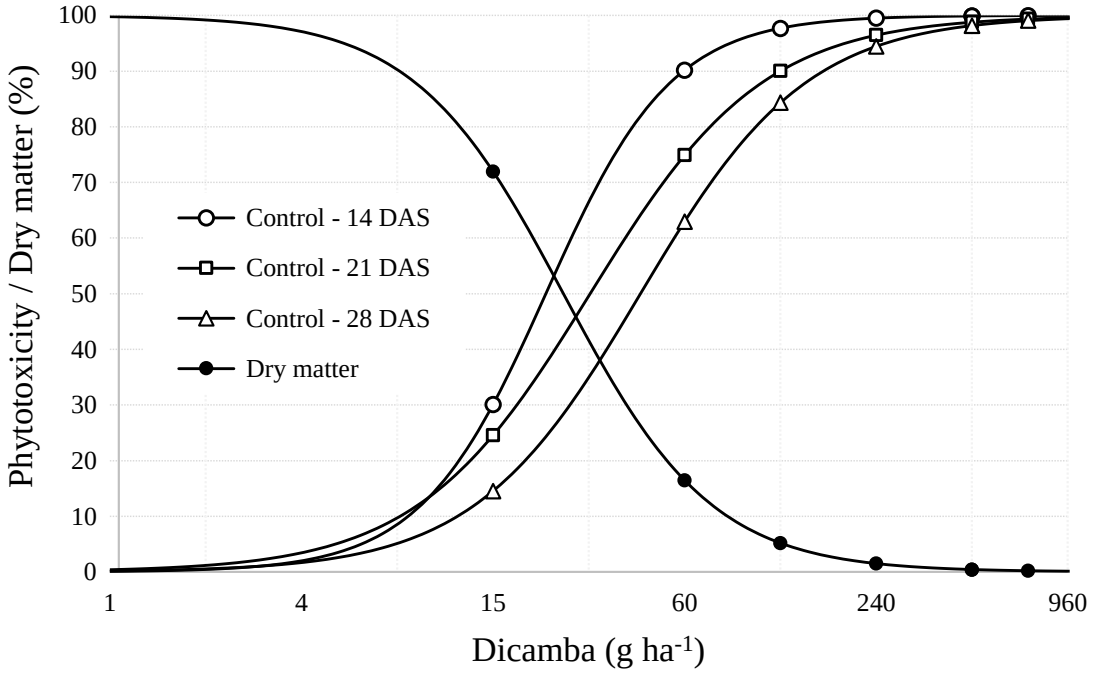


Figure 2. Sensitivity of common bean plants to different dicamba rates applied at pre-sowing, according to phytotoxicity at 14, 21 and 28 days after sowing (DAS) and dry matter at 28 DAS. Machado, MG, Brazil, 2024.

The persistence of some auxin herbicides in soils is connected to local edaphoclimatic characteristics, including soil type and characteristics, water regime, and temperature (SILVA et al. 2020); additionally, their degradation is affected by soil microbial activity, moisture, and temperature (COMFORT et al. 1992, GILREATH et al. 2006). In this sense, soils with higher organic matter contents and microbial biomass have greater retention of molecules; however, a higher degradation can also occur (AGUIAR et al. 2023, COMFORT et al. 1992, VOOS & GROFFMAN 1997).

VOOS & GROFFMAN (1997) showed evidence that the effect of edaphic conditions on dicamba dissipation pathways may be more significant than microbial activity in the short term. They reported that dicamba degradation had a negative correlation with microbial biomass and soil organic matter. Therefore, the sorption and leaching of the molecule are important, as they are affected by soil physical factors, such as texture, pH, and organic matter (KAH et al. 2007, VOOS & GROFFMAN 1997). However, AGUIAR et al. (2023) found a rapid degradation of dicamba in the A horizon of two soils, with 90% herbicide dissipation within approximately 14 days, which is consistent with the results found in the present study.

The effects of dicamba leaching and degradation could not be isolated in the experiments, as they occurred simultaneously. However, a short interval was sufficient for the herbicide dissipation/degradation, allowing for a safe common bean sowing 28 days after herbicide application. However, water availability is an important factor for dicamba persistence in the soil, as it affects molecule leaching and degradation pathways. Thus, the safe interval between pre-sowing dicamba application and common bean sowing can be altered, considering local microclimate and rainfall regimes.

Therefore, less phytotoxicity symptoms were found under greenhouse compared to field conditions at the same intervals between dicamba application and common bean sowing. Microbial degradation of herbicide was probably more intense under greenhouse conditions, potentially explaining the lower phytotoxicity.

CONCLUSION

In the greenhouse experiment, 14 days were sufficient to ensure emergence and initial development of common bean plants, whereas 28 days were needed in the field experiment. On average, 14 days were sufficient for over 90% herbicide dissipation. A 28-day interval after dicamba application is recommended for safe common bean sowing.

NOTES

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis, Saul Jorge Pinto de Carvalho and Ramiro Fernando López Ovejero; software and validation, Saul Jorge Pinto de Carvalho and Leonardo dos Santos Caixeta; investigation, Saul Jorge Pinto de Carvalho and Leonardo dos Santos Caixeta; resources and data curation, Saul Jorge Pinto de Carvalho, Gilmar José Picoli Júnior and Dyrson Abbade Neto; writing-original draft preparation, Saul Jorge Pinto de Carvalho and Leonardo dos Santos Caixeta; writing-review and editing, Ramiro Fernando López Ovejero, Gilmar José Picoli Júnior and Dyrson Abbade Neto; visualization, Saul Jorge Pinto de Carvalho; supervision, Ramiro Fernando López Ovejero; project administration, Gilmar José Picoli Júnior and Dyrson Abbade Neto; funding acquisition, Gilmar José Picoli Júnior and Dyrson Abbade Neto. All authors have read and agreed to the published version of the manuscript.

FUNDING

This work was not supported by any funding agency.

INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable for studies not involving humans or animals.

INFORMED CONSENT STATEMENT

Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT

The data can be made available under request.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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