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ORIGINAL ARTICLE

Spray volume and droplet spectrum in the control of *Bidens pilosa* and *Ipomoea triloba* with the Fomesafen herbicide[1]

Volume de calda e espetro de gotas no controle de *Bidens pilosa* e *Ipomoea triloba* com o herbicida Fomesafen

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HIGHLIGHTS:

Spray volumes greater than 65 L ha^{-1} with very coarse droplets promote satisfactory control of hairy beggarticks.
Fomesafen applied with a coverage percentage exceeding 10% provides satisfactory control of hairy beggarticks.
Fomesafen dose of 0.25 kg a.i. ha^{-1} does not satisfactorily control littlebell plants.

ABSTRACT: Among weed control methods, chemical control using herbicides is one of the most widely employed due to its practicality and efficiency. However, there is still a lack of reliable information regarding the effectiveness of low-volume spraying and the droplet spectrum for contact herbicides, such as fomesafen. The objective was to determine the spray volume and droplet spectrum for applying the fomesafen herbicide and its efficacy in controlling hairy beggarticks (*Bidens pilosa*) and littlebell (*Ipomoea triloba*). The herbicide was applied using a CO_2-pressurized knapsack sprayer with TT11002 spray tip spaced at 0.50 m, operating at pressures of 100 kPa (very coarse droplets) and 400 kPa (medium-sized droplets) with spray volumes of 35, 70, 140, and 280 L ha^{-1}, obtained by varying the application speed. At the time of application, the percentage of covered area and droplet density (droplets cm^{-2}) were evaluated on water-sensitive paper labels using the DropScope® program. The best control results for hairy beggarticks were achieved when the application was performed with very coarse droplets at a pressure of 100 kPa, with a spray volume between 65 and 280 L ha^{-1}, droplet density exceeding 60 droplets cm^{-2}, and coverage greater than 10%. Fomesafen does not provide effective control of littlebell.

Key words: low-volume, coverage, droplet density

RESUMO: Dentre os métodos de controle de plantas daninhas, o químico, por meio de herbicidas, é um dos mais utilizados devido à sua praticidade e eficiência. No entanto, ainda faltam informações confiáveis sobre a eficácia de aplicações em baixo volume e o espectro de gotas a ser utilizado para herbicidas de contato, como o fomesafen. O objetivo deste trabalho foi determinar o volume de calda e espectro de gotas para aplicação do herbicida fomesafen, bem como a eficácia no controle de picão-preto (*Bidens pilosa*) e corda-de-viola (*Ipomoea triloba*). O herbicida foi aplicado utilizando pulverizador pressurizado por CO_2, com pontas TT11002 espaçadas de 0,50 m, operando nas pressões de 100 kPa (gotas muito grossas) e 400 kPa (gotas médias) nos volumes de calda de 35, 70, 140 e 280 L ha^{-1}, obtidos por meio da variação na velocidade de aplicação. No momento da aplicação foram avaliados a porcentagem de área coberta e a densidade de gotas (gotas cm^{-2}) em etiquetas de papel hidrossensível, utilizando o programa DropScope®. Melhores índices de controle do picão-preto são obtidos quando a aplicação foi realizada com gotas muito grossas, na pressão de 100 kPa, com volume de calda entre 65 e 280 L ha^{-1}, densidade de gotas superior a 60 gotas cm^{-2} e cobertura maior que 10%. O fomesafen não controla a corda-de-viola.

Palavras-chave: baixo volume, cobertura, densidade de gotas

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Introduction

Weeds compete with crops for environmental resources such as water, light, and nutrients (Hijano et al., 2021). There are several methods for weed control, with chemical control using herbicides being the most widely employed due to its practicality and efficiency (Griesang & Ferreira, 2021).

It is important to integrate knowledge of herbicide characteristics and weed properties with factors related to application technology, such as droplet size and spray volume, to ensure the efficacy of the chemical method (Graziano et al., 2017; Buosi et al., 2023).

Smaller droplets provide greater coverage but are more susceptible to drift, compromising application effectiveness (Ferguson et al., 2018). Spray volume also affects coverage; higher volumes result in greater coverage. However, excessively high volumes reduce the operational efficiency of the application equipment due to increased refueling stops (Freitas et al., 2022).

The ideal target coverage varies depending on the type of product being applied (Freitas et al., 2022). Thus, for systemic herbicides like glyphosate and 2,4-D, which translocate through the xylem and phloem, high coverage is not necessarily due to their redistribution within different plant organs (Mota et al., 2021). Conversely, contact herbicides such as protoporphyrinogen oxidase (PROTOX) inhibitors, like fomesafen, exhibit low mobility within the plant, requiring increased coverage (Silva et al., 2009).

Given the limited availability of detailed information on the application technology of herbicides, the present study aims to determine the spray volume and droplet spectrum for the application of the fomesafen herbicide, as well as its efficacy in the control of hairy beggarticks (*Bidens pilosa*) and littlebell (*Ipomoea triloba*).

Material and Methods

The study was conducted from July to December 2021 in a greenhouse located at the Teaching, Research, and Extension Unit Diogo Alves de Melo, which is part of the Department of Agronomy at the Universidade Federal de Viçosa (20° 46' 05" S, 45° 52' 09" W, and altitude of 648 m), in Viçosa, MG, Brazil.

The experiment was conducted in a 4 × 2 factorial scheme, distributed in a randomized block design with four replications. The factors consisted of four spray volumes (280, 140, 70, and 35 L ha^{-1}) and two droplet spectra (very coarse droplets and medium droplets) using the Turbo Teejet (TT11002) spray tip. Droplet sizes were obtained by varying the pressure from 100 kPa (very coarse droplet) to 400 kPa (medium-sized drop). The spray volumes were achieved through the combination of flow rates generated by the spray tip operating at pressures of 100 kPa (0.46 L min^{-1}) and 400 kPa (0.91 L min^{-1}), along with different working speeds, as specified in Table 1. The nozzles were spaced 0.50 m apart on the sprayer boom in all scenarios.

In this study, *B. pilosa* and *I. triloba* plants were cultivated in pots containing 4.0 dm^3 of the soil classified as Latossolo Vermelho Amarelo distrófico, corresponding to an Oxisol (Soil Survey Staff, 2014). The soil was corrected with fertilization based on soil analysis and recommendations from the 5th edition of Recommendations for the use of soil correctives and fertilizers in Minas Gerais (Ribeiro et al., 1999).

The sowing of *I. triloba* and *B. pilosa* was conducted with ten seeds per pot. In the case of *I. triloba*, seed scarification with sandpaper was performed before sowing to overcome dormancy (Pazuch et al., 2015). After emergence and establishment, thinning was conducted, leaving five plants per pot for *B. pilosa* and three plants per pot for *I. triloba*.

When *B. pilosa* plants had two to three pairs of leaves (four to six fully expanded leaves) (Figure 1A), and *I. triloba* plants had two to three fully expanded leaves (Figure 1B), the fomesafen herbicide (Flex®) was applied at a dose of 0.25 kg a.i. ha^{-1}., along with 0.5% v/v of non-ionic adhesive surfactant (Silwet L-77Ag®).

For herbicide application, a CO_2-pressurized knapsack sprayer equipped with a three-nozzle spray boom (TT11002) spaced 0.5 m apart and set at a height of 0.5 m from the target was used. The sprayer was attached to a tractor, and the boom was positioned laterally to the rear wheel of the tractor to facilitate application to the pots, which were arranged approximately 0.50 m from the outer face of the tractor's rear wheel.

The meteorological conditions were monitored during spraying using a portable digital thermo-hygrometer-anemometer (Lutron, LM-8000A). The meteorological conditions were 25 ± 1 °C, relative air humidity of 70 ± 5%, and wind speed between 5 and 6 km h^{-1}.

Water-sensitive paper labels were placed at plant apex height under wooden stakes to quantify droplet density and coverage percentage. After application, the labels were collected

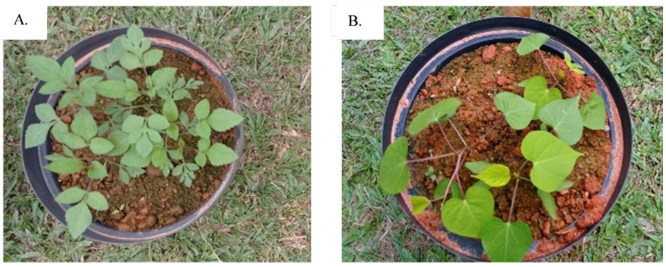

Figure 1. Hairy beggarticks (*Bidens pilosa*) plants with two to three pairs of leaves (A) and littlebell (*Ipomoea triloba*) plants with two to three fully expanded leaves (B)

Table 1. Approximate spray volume from the TT11002 spray tip spaced 0.50 m apart according to the pressure and tractor speed in km h^{-1}

Pressure (kPa)	Flow (L min^{-1})	Spray volume (L ha^{-1})				
		2 km h^{-1}	4 km h^{-1}	8 km h^{-1}	16 km h^{-1}	32 km h^{-1}
100 $^{(VC)}$	0.46	280	140	70	35	-
400 $^{(M)}$	0.91		280	140	70	35

VC - Very coarse droplet; M - Medium-sized drop. Spray quality classifications and associated droplet size spectrum as defined by ASABE (2009): Medium (236-340 μm) and Very coarse (404-502 μm) in paper envelopes and stored in a Styrofoam box containing silica to prevent exposure to ambient moisture. The readings of the labels and subsequent data evaluation were performed using a scanner and the DropScope® software.

For the analysis of weed control efficiency, a visual assessment was conducted 21 days after application (DAA) using a percentage scale (ALAM, 1974), where 0 corresponds to the absence of symptoms, and 100 indicates plant death. Additionally, the accumulation of above-ground plant dry matter was determined. The above-ground plant parts were cut at ground level, placed in paper bags, and placed in a forced-air circulation oven at a temperature of 70 ± 1 °C for 72 hours. Then, the material was weighed on a precision scale (0.1 mg) to obtain the dry matter per pot.

The data were analyzed through analysis of variance and regression. For dry matter, means were compared with the control treatment using the Dunnett's test at $p \leq 0.05$. Model selection was based on the significance of regression coefficients, using the t-test at $p \leq 0.05$ and the biological relevance of the phenomenon under study. All data were analyzed using the R statistical program (R Core Team, 2019). The graphs were created in Sigma Plot 14.0 (Systat Software, San Jose, CA, USA).

Results and Discussion

The data for droplet density and coverage percentage are presented in Figures 2A and 2B, where it can be observed that an increase in the spray volume results in higher droplet density and coverage percentage. The droplet density was highest when the application was performed with medium-sized droplets at a pressure of 400 kPa, with an increase of 0.79 droplets cm^{-2} for each unit of spray volume. In contrast, for the application with very coarse droplets, the increment was 0.38 droplets cm^{-2} per liter of spray volume. (Figure 2A). The increase in pressure reduces the droplet size, leading to a higher droplet density, as also observed by Ferguson et al. (2016) and Shan et al. (2021).

A greater increase in the coverage percentage with an increase in the spray volume was achieved when using medium-sized droplets compared to very coarse droplets, as evidenced by the steeper slope in the line for medium-sized droplets, showing an increase of 0.14% for each unit increase in spray volume, which is higher than the increase obtained for very coarse droplets, which was 0.09.

In the study by Sperry et al. (2021), the coverage percentage of the TT11002 and XR11002 spray tip (coarse and fine droplets, respectively) was assessed across different spray volumes (140, 70, 105, 35, 14, and 7 L ha^{-1}). The authors observed a 2% higher coverage for the TT11002 spray tip. This result should be highlighted, as previous research indicated that applications with smaller droplets typically provide greater coverage (Ferguson et al., 2016). A possible explanation for this observation was that droplets may have drifted in the applications with the XR spray tip.

The droplet density and coverage percentage values within each spray volume are shown in Table 2. Droplet density was similar for applications with 35 and 70 L ha^{-1}, while for 140 and 280 L ha^{-1}, higher rates were observed for applications with medium-sized droplets. However, regarding coverage percentage, there was only a significant difference for the spray volume of 280 L ha^{-1}, with higher rates for the application with medium-sized droplets at 400 kPa.

The technique of evaluating pesticide application using water-sensitive paper is efficient, simple, quick, and feasible and should be considered as a parameter for assessing the effectiveness of agricultural pesticides. However, droplets smaller than 100 µm are not satisfactorily accounted for by the software, which may lead to the non-detection of these droplets (Cunha et al., 2019). The TT11002 spray tip, operating at a pressure of 400 kPa, generates 10% of droplets with a diameter smaller than 100 µm. This fact may result in undercounting these droplets, constituting 10% of the sprayed volume.

Figure 3 presents images of the water-sensitive paper labels illustrating droplet density and coverage provided by the fomesafen application with an adjuvant using the TT11002 spray tip at different working pressure and spray volume combinations.

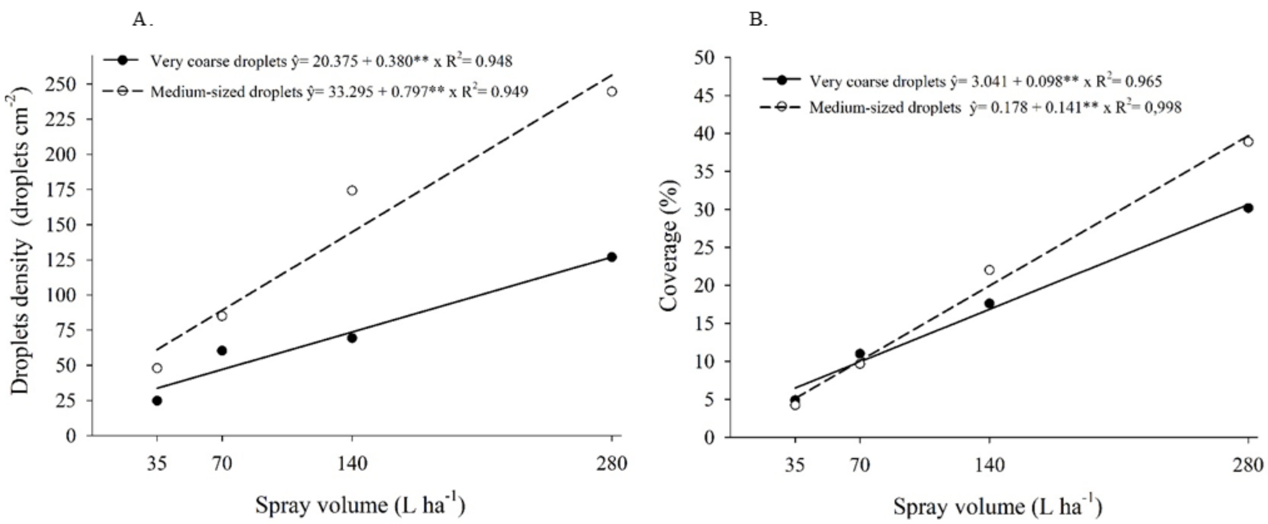

Figure 2. Droplet density (droplets cm^{-2}) (A) and coverage percentage (B) in the application of the fomesafen herbicide with an adjuvant (Silwet L-77Ag®) using TT11002 spray tip operating at 100 kPa (very coarse droplets) and 400 kPa (medium-sized droplets) according to the spray volume

Table 2. Droplet density (droplets cm^{-2}) and coverage percentage generated by the TT11002 spray tip operating at pressures of 100 and 400 kPa according to each spray volume

Pressure (kPa)	Droplet size	Spray volume (L ha^{-1})				CV (%)
		35	70	140	280	
		Droplet density (droplets cm^{-2})				
100	VC	24.8 a	60.33 a	59.77 b	126.95 b	23.33
400	M	47.98 a	84.93 a	206.19 a	244.47 a	
		Coverage (%)				
100	VC	4.88 a	10.98 a	17.60 a	30.18 b	17.57
400	M	4.23 a	9.66 a	22.02 a	38.89 a	

For the same spray volume, means followed by different letters in the columns significantly differ from each other ($p \leq 0.05$), according to the F-test. CV - coefficient of variation; VC - Very coarse droplets; M - Medium-sized droplets. Spray quality classifications and associated droplet size spectrum as defined by ASABE (2009): Medium (236-340 μm) and Very coarse (404-502 μm)

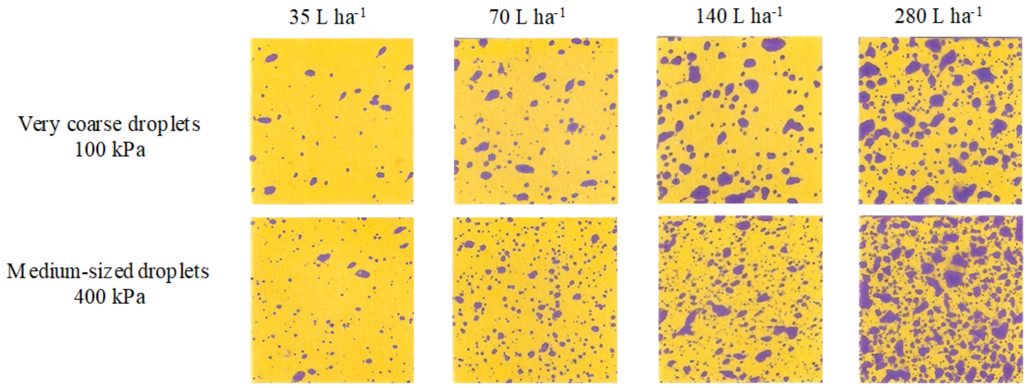

Figure 3. Coverage pattern provided by the fomesafen application according to the spray volume and droplet spectrum

The data for *B. pilosa* control and dry matter obtained 21 days after the application (DAA) of fomesafen is presented in Figures 4A and B. A plateau effect is observed, with an increase in the control index according to the increase in spray volume, followed by stabilization for the two evaluated droplet spectra. According to the curve equation in Figure 4A, stabilization for the control indexes by applying very coarse droplets occurs at a spray volume of 65 L ha^{-1} with a control rate of 79.2%.

When fomesafen was applied at a pressure of 400 kPa with medium-sized droplets, stabilization occurred at 52 L ha^{-1}, with control rates lower than those obtained for very coarse droplets, at 68.5% (Figure 4A). The data obtained in this study, such as the better control index for fomesafen (a contact herbicide) with very coarse droplets compared to medium-sized droplets, contradict the recommendation of ANDEF (2004), which suggests the use of medium-sized droplets for this group of herbicides. However, it should be considered that the lower control index obtained at a pressure of 400 kPa is probably due to the higher proportion of droplets with a diameter of less than 100 μm generated under this condition, which may have hindered the herbicide deposition on the target.

The coverage percentage observed at a spray volume of 35 L ha^{-1} for the two evaluated droplet spectra, with rates below 10% (Table 2), was insufficient for the control of *B. pilosa* with the fomesafen herbicide, as indicated by the low control index for the spray volume applied (Figure 4A). Spray volume around 70 L ha^{-1} provided similar *B. pilosa* control rates (Figure 4A), with a droplet density of around 70 droplets cm^{-2} and coverage

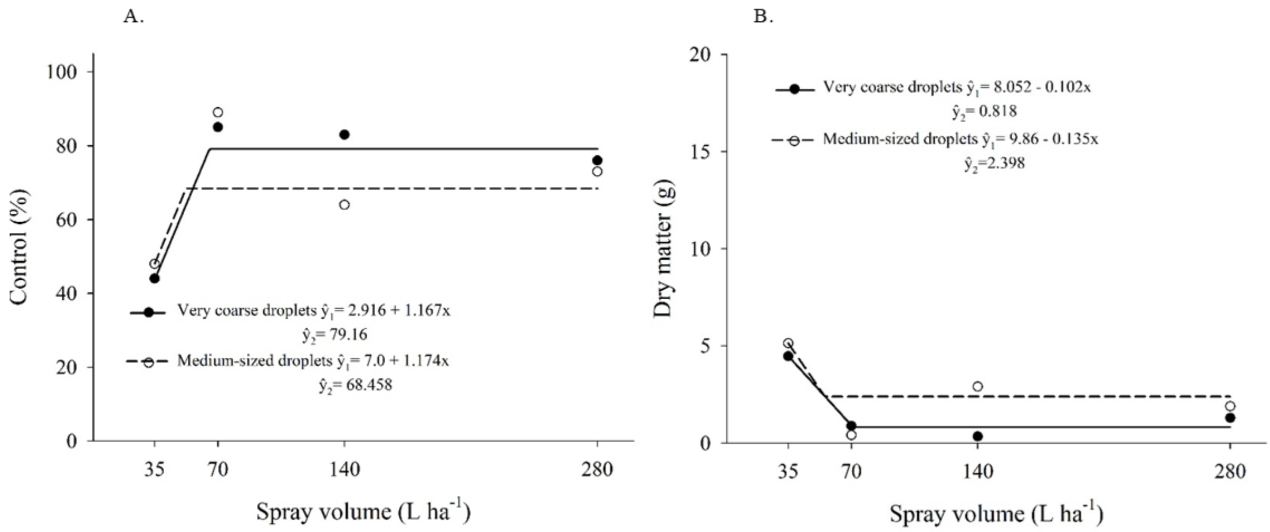

Figure 4. Percentage of control (A) and dry matter (B) of *B. pilosa* at 21 DAA according to the spray volume and droplet spectrum. ŷ1 and ŷ2 are the two models presented within each droplet sized

close to 10% (Table 2). These data align with the findings proposed by Magdalena et al. (2010), who classified a minimum density of 50 droplets cm^{-2} for a satisfactory control efficiency in herbicides of contact.

Control indexes below 80% observed at 21 DAA (Figure 4A) can be attributed to the growth stage of the *B. pilosa* plants at the time of application (two to three pairs of fully expanded leaves), as fomesafen is a contact herbicide positioned for early post-emergence application of weeds. It acts by inhibiting the enzyme protoporphyrinogen oxidase (PPO), leading to the accumulation of protoporphyrinogen in the chloroplast, which diffuses into the cytoplasm, ultimately transforming into protoporphyrin IX. Protoporphyrin IX acts in the cytoplasm as a photosensitive compound, which, in the presence of light, rapidly reacts with O_2, leading it to the singlet state, ultimately responsible for lipid peroxidation observed in plant cell membranes (Oliveira Júnior et al., 2021).

Marchioretto & Dal Magro (2017) observed 100% control of hairy beggarticks with two pairs of leaves at a dose of 0.25 kg a.i. ha^{-1}. It is worth noting that on the label of the fomesafen herbicide, Flex® commercial product, the application of 0.25 kg a.i. ha^{-1} is recommended for plants with two to six leaves (one to three pairs of leaves). Although this study did not observe an increase in *B. pilosa* control for spray volumes greater than 70 L ha^{-1}, Creech et al. (2015), evaluating spray volumes for lactofen application, another PROTOX inhibitor, found the need for 187 L ha^{-1} to provide control of *Kochia scoparia*, *Salsola tragus* L., and *Ambrosia trifida* L.

The dry matter values at 21 DAA (Figure 4B) were consistent with the control data, where a lower accumulation of dry matter was observed when very coarse droplets were used, stabilizing from 70 L ha^{-1}, with 0.81 g per pot. When the application was performed with medium-sized droplets, the plateau stabilization occurred with 2.40 g per pot and a spray volume of 55 L ha^{-1}. With the fomesafen application at a spray volume of 35 L ha^{-1}, the control rates were not satisfactory for either of the evaluated droplet spectra, with a higher accumulation of dry matter than with the higher spray volume application; as evidenced by the linear equations with positive β1 values for control (Figure 4A) and negative values for dry matter (Figure 4B), indicating an increase and decrease, respectively.

Table 3 presents the dry matter values of the above-ground part of hairy beggarticks plants subjected to fomesafen application at different spray volumes and droplet spectra, compared to the untreated control, which obtained an average of 30 g per pot, a value significantly higher than that obtained in all herbicide application treatments, with a maximum value of 5.13 g per pot.

Despite the low values of dry matter accumulation in hairy beggarticks compared to the control (Table 3), uncontrolled plants tend to reestablish their growth rate and can cause interference in the crop's final growth stage, affecting harvesting operations and the quality of the final product (Lage et al., 2017). This is a common occurrence in bean (*Phaseolus vulgaris*) cultivation, where manual harvesting becomes compromised, as poorly controlled hairy beggarticks infest the area at the end of the cycle, making manual harvesting difficult (Araújo et al., 2018).

The data for the control of *I. triloba* and dry matter obtained 21 days after the application (DAA) of fomesafen are presented in Figures 5A and B. The control was inefficient, regardless of the spray volume and droplet spectrum.

Table 3. Dry matter of *B. pilosa* plants subjected to fomesafen application according to the droplet spectrum and spray volume, compared with plants without herbicide application (control), at 21 days after application

Droplet size	Spray volume (L ha^{-1})	Dry matter (g per pot)
Very coarse droplet (100 kPa)	35	4.47*
	70	0.88*
	140	0.34*
	280	1.30*
Medium-sized droplet (400 kPa)	35	5.13*
	70	0.41*
	140	2.90*
	280	1.89*
Control		29.99

The means with an asterisk in the column differ from the control by Dunnett's test ($p \leq 0.05$). Spray quality classifications and associated droplet size spectrum as defined by ASABE (2009): Medium (236-340 μm) and Very coarse (404-502 μm)

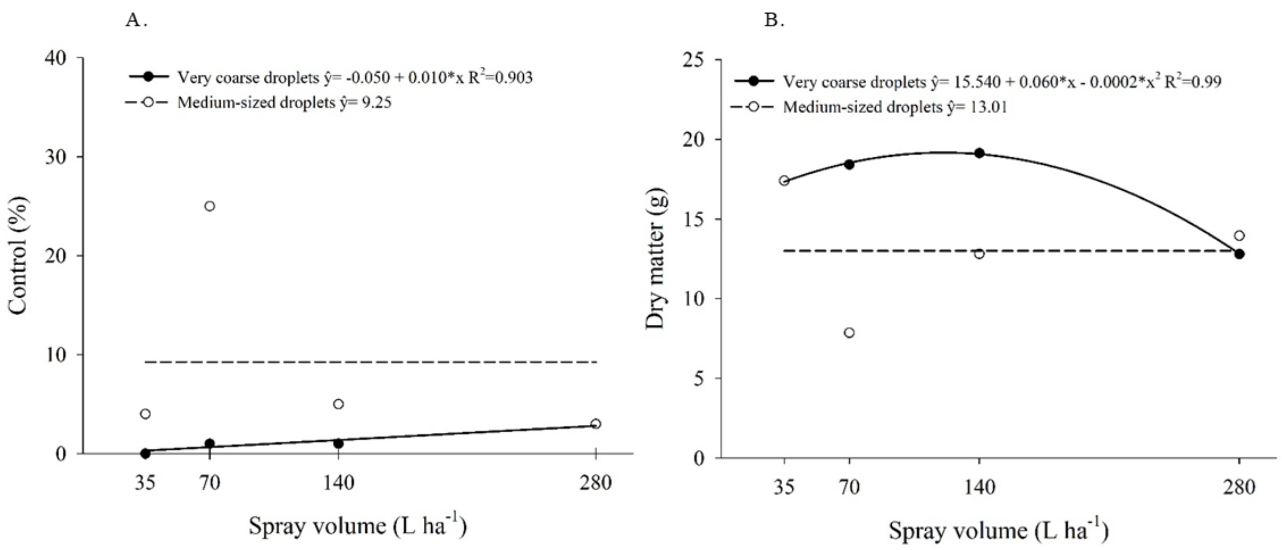

Figure 5. Percentage of *I. triloba* control (A) and dry matter (B) at 21 days after fomesafen application according to the spray volume and droplet spectrum

The dry matter values (Figure 5B) were consistent with the control data, where the droplet spectrum and spray volume effects were observed. Greater dry matter was observed with application at spray volumes of approximately 140 L ha^{-1}, which decreased up to 280 L ha^{-1}, where there was no longer any difference compared to the application with medium-sized droplets, for which there was no variation in dry matter accumulation with spray volume.

The dry matter data obtained from the combinations of spray volume and droplet spectrum, along with the treatment without herbicide application (control), are shown in Table 4. It can be observed that only the treatment involving the fomesafen application using medium-sized droplets at a spray volume of 70 L ha^{-1} differed from the control.

Despite the reduction in accumulated dry matter obtained, it cannot be asserted that the control was efficient. Considering that *I. triloba* is a highly aggressive species, the plants are likely to reestablish their growth rate and compete with the target crop, in addition to complicating the harvesting process. Therefore, in practice, the control of *I. triloba* with fomesafen was inefficient, regardless of the spray volume and droplet spectrum employed.

In the study conducted by Vitorino & Martins (2012), the efficacy of PROTOX-inhibiting herbicides under water stress conditions for controlling *I. triloba* was assessed. The authors observed that fomesafen and lactofen controlled *I. triloba*, irrespective of the water deficit condition. Despite reports of the control of *I. triloba* with fomesafen, Cao et al. (2023) documented resistance of *Ipomoea nil* to fomesafen herbicide.

The data from this study clearly demonstrate that fomesafen application should be conducted when *B. pilosa* plants are in the early developmental stage, with a maximum of two pairs of leaves, and spray volume between 70 and 100 L ha^{-1} can be used. Fomesafen should not be recommended for the control of *I. triloba*.

Table 4. Dry matter of *I. triloba* plants subjected to fomesafen application according to the droplet spectrum and spray volume, compared with plants without herbicide application (control), at 21 days after application

Drop size	Spray volume (L ha^{-1})	Dry matter (g per pot)
Very coarse drop	35	17.41 ^{ns}
	70	18.41 ^{ns}
	140	19.13 ^{ns}
	280	12.81 ^{ns}
Medium-sized drop	35	17.41 ^{ns}
	70	6.41*
	140	19.13 ^{ns}
	280	13.95 ^{ns}
Control		19.29

The means with an asterisk in the column differ from the control according to Dunnett's test; ns – Not significant; *Significant at ($p \leq 0.05$). Spray quality classifications and associated droplet size spectrum as defined by ASABE (2009): Medium (236-340 μm) and Very coarse (404-502 μm)

Conclusions

1. The highest control index for *B. pilosa* is achieved by applying fomesafen at spray volumes exceeding 65 L ha^{-1} and 52 L ha^{-1} for very coarse and medium-sized droplets, respectively.

2. Fomesafen did not control *I. triloba* plants, regardless of the spray volume and droplet spectrum used.

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