Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Scientific Paper
Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v42n4e20220004/2022

USE OF ULTRA COARSE DROPLETS AT DIFFERENT SPRAY VOLUMES TO CONTROL WEEDS WITH DICAMBA AND GLYPHOSATE HERBICIDES

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KEYWORDS

spray nozzles, chemical control, droplet spectrum, application technology.

ABSTRACT

The use of ultra-coarse droplets for herbicide application reduces the risk of drift but may compromise the coverage and efficacy of the treatment. The objective of this work was to evaluate the use of ultra-coarse droplets, in different spray volumes, in the application of dicamba herbicide in association with glyphosate, for the control of weeds in two field trials. The first trial was conducted in a 5 x 2 factorial design, with five spray volumes (58, 72, 96, 144, and 177 L ha^{-1}) and two air induction flat-fan spray tips (MUG 110015 - MagnoJet and TTI 110015 - Teejet). The control efficiency of *Commelina benghalensis* and the spray deposition on the target were evaluated by detecting a tracer using spectrophotometry. The second was conducted in a 2 x 2 factorial scheme, using two volumes (100 and 125 L ha^{-1}) and two tips (MUG 11002 and TTI 11002). The control efficiency of *Conyza* spp. and fresh matter were evaluated. The different spray volumes and tips did not differ in relation to the deposition of the tracer. The use of ultra-coarse droplets was adequate for weed control. The TTI and MUG tips gave similar and adequate control performance starting at 96 L ha^{-1}. Increasing the volume above 100 L ha^{-1} did not result in better control.

INTRODUCTION

Chemical weed control using glyphosate herbicide in no-till systems has provided efficient post-emergence management. However, several weed species have recently been reported to be resistant to this herbicide (Heap & Duke, 2018; Goggin et al., 2016). Therefore, alternatives are necessary to prevent or delay the emergence of resistant biotypes, enabling effective control by farmers. In this sense, using herbicides with an alternative mechanism of action such as dicamba has emerged as an option to integrate weed management programs, especially with the recent development of dicamba-resistant soybean, which will allow its use safely (Egan & Mortensen, 2012).

Dicamba is a synthetic auxin active in many dicot species. Early effects on susceptible plants are characterized by growth abnormalities, chloroplast damage, chlorosis, destruction of membranes, and lower vascular system integrity (Grossmann et al., 1996; Cobb & Reade, 2010).

The use of coarse droplets created with air induction tips has been the recommended application method of this auxin herbicide to minimize possible problems related to drift. Although they all have a Venturi system for air insertion inside the droplets, the different designs can produce a spectrum of droplet velocities characteristic of each model, which can interfere in reducing drift and in the deposition of the mixture on the desired target (Cunha et al., 2020). Therefore, knowing these differences is essential for successful application (Ferguson et al., 2015).

More recently, spray tip manufacturers have launched models with air induction that generate extremely coarse to ultra-coarse droplet spectrum, according to the classification proposed by Asabe (2020). At the same time,

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Area Editor: Renildo Luiz Mion
Received in: 1-11-2022
Accepted in: 6-30-2022

using herbicides in ever-smaller volumes of spray is becoming commonplace, as it decreases spraying costs and increases sprayers' operational capacity. However, little is known about the interaction between the use of ultra-coarse droplets and different spray volumes and their impact on herbicide efficacy. Ferguson et al. (2018) evaluated the effect of droplet spectrum on the control of various weeds and concluded that the use of ultra-coarse droplets is feasible for some modes of action, reinforcing the need for further studies.

According to Bueno et al. (2013a), reducing the spray volume may lead to reduced target coverage, compromising the efficiency of the application. Additionally, increasing the size of the spray droplets also promotes a reduction in target coverage, which may cause a reduction in control efficacy. In this sense, besides the characteristics of the herbicide and the spray mixture, knowledge of the application technology, such as the spray tips, is essential to identify if the product is being deposited on the target efficiently.

Comparing the effect of different spray volumes on the effectiveness of phytosanitary treatments, there are reports in the literature of increased deposition with increasing (Derksen et al., 2008) or decreasing volume (Alves et al., 2020), which generates uncertainty. Higher volumes may help transport and coverage by the active ingredient on the target. However, the amount of spray should also be adjusted according to the retention capacity of the target, as exceeding this level may result in runoff to the soil (Cunha et al., 2011).

Thus, research on the efficacy, target deposition, and application technology is necessary to have a correct technical position on this subject. The objective of this work was to evaluate the use of ultra-coarse droplets, generated by different spray tips, using different spray volumes, in the application of the herbicide dicamba in association with glyphosate, for the control of *Commelina benghalensis* and *Conyza* spp.

MATERIAL AND METHODS

The work was divided into two trials at different locations.

Test 1

Trial 1 was conducted in 2020 at Fazenda Capim Branco (Municipality of Uberlândia-MG-Brazil), using a randomized block design with four repetitions in a 5 x 2 factorial scheme with five spray volumes and two spray tips. The total area of each plot was 60 m^2 (6 x 10 m), disregarding 1 m from each extremity for evaluation purposes.

The trial included one application, as desiccation of the weeds in the area. The spray solutions were composed of glyphosate herbicide (Roundup Transorb R®, Potassium salt of N-(phosphonomethyl)glycine, 480 g equivalent acid (ea) L^{-1}, soluble concentrated formulation (SL)) at a dose of 2 L ha^{-1}, and dicamba (Atectra®, 3,6-dichloro-o-anisic acid, 480 g ea L^{-1}, soluble concentrated formulation (SL)) at a dose of 1 L ha^{-1}. The concentration of the solution was changed according to the carrier volume to maintain the same dose applied. The spray volumes tested were 58, 72, 96, 144, and 177 L ha^{-1}. The air induction flat spray tips MUG 110015 (MagnoJet) and TTI 110015 (Teejet) were tested. According to the manufacturer's catalog, both have an ultra-coarse droplet pattern at the pressure used.

Applications were made with a hydraulic sprayer mounted with a 400 L tank and 12 m boom, with nozzles spaced at 0.5 m. Herbicides were applied to each plot using a half boom. For both tips, a pressure of 2 bar (200 kPa) was used, and the speed for each volume was 2.78 m s^{-1} (58 L ha^{-1}), 2.22 m s^{-1} (72 L ha^{-1}), 1.67 m s^{-1} (96 L ha^{-1}), 1.11 m s^{-1} (144 L ha^{-1}) and 0.89 m s^{-1} (177 L ha. $^{-1}$).

During the applications, the meteorological conditions were monitored using a thermo-hygrometer: the temperature varied from 27.6 to 28.4 °C, the relative humidity from 63 to 65%, and the wind speed from 1.33 to 2.28 m s^{-1}.

The plots were installed in an area with a predominant natural infestation of *Commelina benghalensis* (trapoeraba). At the time of the applications, the plants had an average height between 0.15 and 0.25 m. Control efficacy evaluations were made at 14, 21, and 28 days after application (DAA), following a visual scale of grades ranging from 0% (no injury symptoms) to 100% (completely dead plants) (Alam, 1974).

The spray deposition on weeds (*Commelina benghalensis*) was evaluated using spectrophotometry. For this, the tracer Bright Blue was added to the solution at a fixed dose of 400 g ha^{-1}. After application, a 0.25 x 0.25 m square was spread twice in each plot, and the aerial part of the plants inside this square was collected and placed in plastic bags. In the laboratory, 0.2 L of distilled water was added to each plastic bag for tracer extraction. After mechanical agitation for 15 min at 105 rpm, the solutions were placed in plastic cups and left undisturbed for 24 h for subsequent reading in a spectrophotometer (Biospectro, SP22, Curitiba, PR, Brazil) at a wavelength of 630 nm.

The absorbance data were converted into mg L^{-1} using a calibration curve of the tracer. Knowing the dry mass of the weeds, which were dried in an oven at 65 °C for 72 h, the results in µg of dye per g of dry mass of plants were obtained.

Test 2

Trial 2 was conducted in 2021 at the Proteplan Experimental Station (Primavera do Leste-MT-Brazil), in a randomized block design with six repetitions, in a 2 x 2 factorial scheme, with two spray volumes and two spray tips. The total area of each plot was 140 m^2 (7 x 20 m), disregarding 1 m from each extremity for evaluation purposes.

The trial included one application, as desiccation of the weeds in the area. The solutions were composed of glyphosate herbicide (Roundup Transorb R®) at a dose of 2 L ha^{-1}, dicamba (Xtendicam®, 3,6-dichloro-o-anisic acid, 480 g ea L^{-1}, soluble concentrated formulation (SL)) at a dose of 1 L ha^{-1} and the adjuvant Xtend Protect® (drift and volatility reducing adjuvant) at a dose of 1.0 L ha^{-1}. The spray volumes tested were 100 and 125 L ha^{-1}. The air induction flat spray tips MUG 11002 (MagnoJet) and TTI 11002 (Teejet) were tested. According to the manufacturer's catalog, both have an ultra-coarse droplet pattern at the pressure used.

Applications were made with a sprayer with a 2000 L tank and 18 m boom, with nozzles spaced at 0.5 m. Herbicides were applied to each plot using a half boom. For both tips, a pressure of 3 bar (300 kPa) was used, and the velocity for each spray volume was 2.64 m s^{-1} (100 L ha^{-1}) and 2.11 m s^{-1} (125 L ha^{-1}).

During the applications, the meteorological conditions were monitored using a thermo-hygrometer. The temperature varied from 22.5 to 28.0 °C, relative humidity from 50 to 65%, and wind speed from 3.6 to 2.1 m s^{-1}.

The plots were installed in an area with natural weed infestation, predominantly dicotyledons such as *Conyza* spp. (buva). Before applying herbicides, five *Conyza* plants per plot were marked. These plants were divided into two groups, one with plants less than 0.10 m tall and the other with plants greater than 0.10 m tall, and evaluated separately for statistical analysis purposes. The control for each treatment was assigned to each Conyza plant separately.

The efficacy evaluations were made at 14, 21, and 28 days after application (DAA), following a visual scale of grades ranging from 0% (no injury symptoms) to 100% (completely dead plants). During the last evaluation, the plant material present in one square meter of each experimental plot was collected and weighed on analytical scales to determine the fresh matter.

Droplet spectrum

Aiming to characterize the treatments better, the droplet spectrum of the spray tips TTI 110015 and MUG 110015, working at 200 kPa (Assay 1) and 300 kPa (Assay 2) and using the solutions used in the field as the test liquid, was evaluated with the use of a particle analyzer in real-time by the Laboratory of Spraying Machines of the Faculty of Agronomic Sciences (FCA/UNESP), in Botucatu/SP, Brazil using laser beam diffraction. In this system, the droplet spectrum is estimated through the deviation of the trajectory that the laser suffers when reaching the sprayed droplets. We used the equipment Helos-Vario/KR (Sympatec Inc., Clausthal, Germany), equipped with an R3 lens. A spray chamber was used with the equipment mounted so that the whole sprayed jet passed transversally through the laser beam of the analyzer, obtaining the spectrum of droplets for each desired condition directly. The spray nozzle was located 0.30 m above the laser. The volumetric median diameter (VMD), the percentage of the sprayed volume in droplets smaller than 150 µm (V150), and the relative amplitude (RA) were determined, employing five repetitions.

Statistical analyses

The data collected were tested for the assumptions of variance analysis, i.e., normality and homoscedasticity. When the assumptions were met, the data were used in an analysis of variance. Comparisons between means were made using Tukey's test ($p<0.05$). In trial 1, for deposition and efficacy data, regression analysis was not performed because the effect of the spray volume was not significant. Although the spray volume's effect was significant for the droplet spectrum, no significant statistical model was found ($p<0.05$).

RESULTS AND DISCUSSION

Test 1

Droplet spectrum

In the analysis of the droplet spectrum, the interaction between tips and spray volumes was significant, indicating the dependence between the factors. It is noted that, although both have a spectrum of ultra-coarse droplets, the MUG 110015 tip has larger droplets and fewer droplets smaller than 150 µm when compared to TTI 110015 (Table 1). Regarding the RA, the tips did not differ in volumes from 72 to 144 L ha^{-1}. Similar results were found by Ferreira et al. (2020), evaluating MUG 11003 and TTI 11003 tips in spraying different mixtures with the herbicide dicamba. Regardless of the adjuvant or herbicide added to the spray, these authors found that the MUG tip provided the lowest potential risk of drift.

TABLE 1. Volumetric median diameter, relative amplitude, and percentage of sprayed volume in droplets smaller than 150 µm generated by two spray tips working with two spray volumes and a mixture of glyphosate and dicamba herbicides.

Spray volume (L ha^{-1})	Spray tip TTI 110015	MUG 110015	Average
Volumetric median diameter (µm)			
58	734bB	956aC	845
72	740bAB	993aA	866
96	718bC	976aB	847
144	735bB	986aA	860
177	747bA	985aAB	866
Average	735	979	
CV (%)	0.65		
Relative amplitude			
58	1.07bAB	1.12aA	1.10
72	1.04aCD	1.05aC	1.05
96	1.08aA	1.09aB	1.09
144	1.05aBC	1.06aC	1.06
177	1.02bD	1.04aC	1.03
Average	1.05	1.07	
CV (%)	1.19		
Percent of spray volume in droplets smaller than 150 µm (%)			
58	1.67aAB	1.46bA	1.54
72	1.45aC	1.21bB	1.33
96	1.81aA	1.36bAB	1.59
144	1.57aBC	1.21bB	1.39
177	1.46aC	1.27bB	1.37
Average	1.59	1.29	
CV (%)	6.82		

Means followed by the same letters, lowercase in the rows and uppercase in the columns, do not differ by the Tukey test at α = 0.05. CV: coefficient of variation.

Although the two nozzles use air induction, the different geometries gave droplet sizes characteristic of each model, which can affect drift and the deposition of the mixture on the desired target (Cunha et al., 2020).

The effect of the spray volume was significant for the three evaluated parameters of the droplet spectrum; however, no clear relationship (significant model) was found between the variables. The droplet spectrum analysis was performed with a stationary spray nozzle. Thus, the spray volume impacted the concentration of herbicides in the spray, which may influence the droplet formation process. For the TTI tip, the VMD varied from 718 to 747 µm. Although it is not a very significant variation from the practical point of view, the experiment's low coefficient of variation (0.65%) made this difference significant, which helps explain the fact that no clear relationship was found between the spray volume and droplet size. Generally, the two tips showed a homogeneous droplet spectrum (RA ranging from 1.05 to 1.12) and low drift risk (V150 ranging from 1.21 to 1.81%).

By analyzing the droplet spectrum of the reference tips under the conditions established by standard S572.3 (Asabe, 2020), it was determined that the cumulative volumetric diameters of 10%, 50%, and 90% limits between the extremely coarse and ultra-coarse droplet class were 196, 520, and 811 µm, respectively, confirming that the evaluated tips produced an ultra-coarse droplet spectrum.

Spray deposition

Table 2 shows the deposition of the tracer on the weeds in the area. The interaction between spray tip and volume and the isolated effect of spray tip and spray volume were not significant, indicating no difference between the treatments.

TABLE 2. Tracer deposition (µg g^{-1}) on weeds from glyphosate+dicamba applications with two spray tips and five spray volumes.

Spray volume (L ha^{-1})	Spray tip TTI 110015	MUG 110015	Average
	---------------------µg g^{-1}---------------------		
58	616.4*	584.3	600.4
72	655.3	637.8	646.6
96	678.6	650.4	664.5
144	663.2	620.1	641.7
177	632.5	598.7	615.6
Average	649.2	618.3	
CV	22%		

* There was no significant response for the F statistic in the effects of treatments. CV: coefficient of variation.

In general, smaller spray volumes may not be adequate to promote good deposition when used with tips that produce ultra-coarse droplets. On the other hand, larger volumes may cause runoff. However, these effects were not pronounced to the point of being statistically significant. It should be noted that the tracer's dose (quantity/area) was the same in all treatments, which confirms the results. Furthermore, the fact that the tips were air-induction models favored the contact by the droplets containing air inside with the target, increasing the contact area (Bueno et al., 2013b).

Control Effectiveness

The control efficacy of *Commelina benghalensis* at 14, 21, and 28 DAA is shown in Tables 3, 4, and 5. The interaction between spray volume and tip was significant at the three evaluation periods, indicating the dependence between the factors. Therefore, this relationship was investigated. There was no spray volume effect; that is, the differences were not enough to distinguish the treatments. Thus, regression analysis was not performed. Bueno et al. (2013a) also found that the action of the herbicide was not affected by altering the carrier volume.

TABLE 3. Percentage control of *Commelina benghalensis* 14 days after glyphosate+dicamba applications with two spray tips and five spray volumes.

Spray volume ($L\ ha^{-1}$)	Spray tip TTI 110015	MUG 110015	Average
		---------------------%---------------------	
58	86a	81b	84
72	90a	82b	86
96	90a	87a	89
144	89a	86a	88
177	88a	87a	88
Average	89	85	
CV	6.9%		

Means followed by the same letters, lowercase in the rows do not differ by Tukey's test at α = 0.05. The effect of the spray volume was not significant. CV: coefficient of variation.

TABLE 4. Percentage control of *Commelina benghalensis* 21 days after glyphosate+dicamba applications with two spray tips and five spray volumes.

Spray volume ($L\ ha^{-1}$)	Spray tip TTI 110015	MUG 110015	Average
		---------------------%---------------------	
58	95a	89b	92
72	97a	94a	96
96	98a	96a	97
144	99a	98a	99
177	98a	97a	98
Average	97	95	
CV	5.8%		

Means followed by the same letters, lowercase in the rows, do not differ by Tukey's test at α = 0.05. The effect of the spray volume was not significant. CV: coefficient of variation.

TABLE 5. Percentage control of *Commelina benghalensis* 28 days after glyphosate+dicamba applications with two spray tips and five grout volumes.

Spray volume ($L\ ha^{-1}$)	Spray tip TTI 110015	MUG 110015	Average
		---------------------%---------------------	
58	91a	87b	89
72	93a	93a	93
96	94a	94a	94
144	95a	94a	95
177	93a	91a	92
Average	93	92	
CV	4.9%		

Means followed by the same letters, lowercase in the rows, do not differ by Tukey's test at α = 0.05. The effect of the spray volume was not significant. CV: coefficient of variation.

Regarding the tips, TTI promoted greater weed control when using the volumes of 58 L ha^{-1} in the three evaluations, and 72 L ha^{-1} at 14 DAA. There was no difference between tips with the other spray volumes used. In all treatments, control was considered very good or excellent (Alam, 1974). Osipe et al. (2017) highlighted the control efficiency of *Commelina benghalensis* with the herbicide dicamba. According to the authors, its association with glyphosate enhances the control of several dicotyledons, which helps to understand the results found.

Although the two tips produce an ultra-coarse droplet spectrum at the pressure used, the VMD is not the same. Therefore the target coverage differs, which may help to understand the difference for the smaller volumes.

Figure 1 shows how the low spray volume (58 L ha^{-1}), associated with the ultra-coarse droplets, results in reduced coverage (blue spots), which can be problematic for managing difficult-to-control weeds. In this scenario, increasing the spray volume may minimize the problem.

FIGURE 1. Example of the coverage obtained (blue spots) in one of the experimental plots with the application of ultra-coarse droplets at a volume of 58 L ha^{-1}.

Moraes et al. (2021) studied the control of weeds with glyphosate, fomesafen, and lactofen using different droplet spectra at a spray volume of 187 L ha^{-1}. They concluded that ultra-coarse droplets had similar control results to medium droplets. The authors pointed out that the spray tip selection was not the determining factor in the effectiveness of the herbicides since similar results were found regardless of the spray tip employed. It should be noted that the spray volume was higher than those used in this study, contributing to an increase in target coverage and minimizing the effect of droplet size.

Test 2

Droplet spectrum

In trial 2, the interaction between tips and spray volumes was not significant. Again, the MUG tip produced larger droplet sizes and lower drift risk than the TTI tip (Table 6). The volume of 125 L ha^{-1} and, therefore, less concentrated solution resulted in a smaller droplet size and higher V150. In this trial, an anti-drift adjuvant was used in the spray, which helps to understand the lower risk of drift in the more concentrated spray. Both herbicides and adjuvant were used in higher concentrations in the 100 L ha^{-1}.

TABLE 6. Volumetric median diameter, relative amplitude, and percentage of spray volume in droplets smaller than 150 µm generated by two spray tips working using two spray volumes with a mixture of glyphosate, dicamba, and anti-drift adjuvant.

Spray volume (L ha^{-1})	Spray tip TTI 11002	MUG 11002	Average
Volumetric median diameter (µm)			
100	690	1101	895A
125	665	1065	865B
Average	677b	1083a	
CV (%)	0.57		
Relative amplitude			
100	1.14	1.00	1.07B
125	1.17	1.02	1.10A
Average	1.16a	1.01b	
CV (%)	0.96		
Percent of spray volume in droplets smaller than 150 µm (%)			
100	2.02	0.82	1.42B
125	2.43	1.02	1.73A
Average	2.23a	0.92b	
CV (%)	5.01		

Means followed by the same letters, lowercase in the rows and uppercase in the columns, do not differ by the Tukey test at α = 0.05. CV: coefficient of variation.

Although the RA showed little change among the treatments, it varied from 1.00 to 1.17 and was the lowest in the MUG tip and a volume of 100 L ha^{-1}. The lower the value of this parameter, the more uniform the droplets (França et al., 2018). However, the magnitude of variance was not high.

Control Effectiveness

The analysis of variance between the factors studied also showed no significance for the interaction between tips (TTI and MUG) and spray volumes (100 and 125 L ha^{-1}). For the isolated factors, there was also no significance for the control of *Conyza* taller than 0.10 m, at 14, 21, and 28 DAA, and for the fresh matter. This result indicates that the variations in the spray tips and volumes did not cause changes in the control efficacy when combining dicamba and glyphosate, producing results without significant difference. Thus, the TTI and MUG spray tips offered similar control performance, and the increase in the carrier volume from 100 to 125 L ha^{-1} did not result in improved control, regardless of the tip used, corroborating the results of trial 1.

Almeida et al. (2015) concluded that the ultra-coarse droplet class is efficient in the desiccation of *Urochloa ruziziensis* at volumes up to 50 L ha^{-1}. However, they also found that reducing the spray volume increases the possibility of regrowth of *Conyza* spp., suggesting that there may be a difference between the species studied. In this sense, Ferguson et al. (2018) also demonstrated the maintained efficacy of using several herbicides with ultra-coarse droplets compared to medium and fine droplet spectra. However, these authors worked with a fixed volume of 100 L ha^{-1}.

In this trial, only the evaluation in *Conyza* smaller than 0.10 m at 28 DAA was significant for the spray volume factor. When changing from 100 to 125 L ha^{-1}, there was a significant difference in the response compared to the control, regardless of the spray tip used (Figure 2), with lower control for the higher spray volume. Although this significant difference was observed, it is understood that this response to the variation of the spray volume should not be considered relevant in practice since the percentage of control was high (above 95%) in both treatments. The low value of the coefficient of variation of the trial in this analysis (CV = 3%) should also be considered, which certainly contributed to the indication of this significant difference.

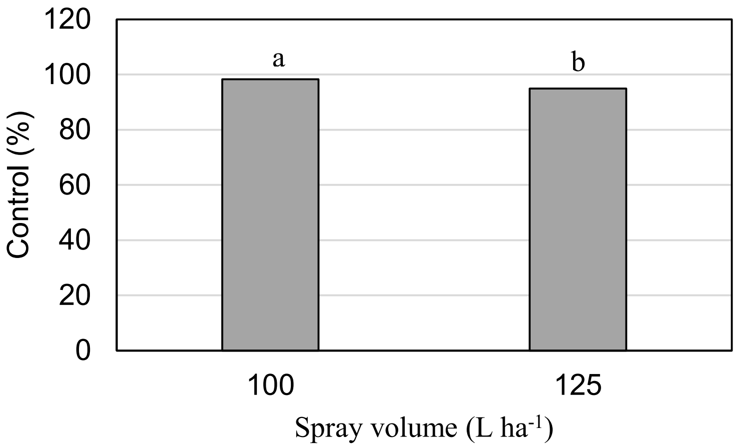

FIGURE 2. Control of *Conyza* smaller than 0.10 m (%) at 28 DAA as a function of spray volume. Different letters differ statistically by the Tukey test at α = 0.05.

Regarding the control efficacy of *Conyza* taller than 0.10 m, values of 79 to 85% were observed at 28 DAA. For *Conyza* smaller than 0.10 m, the final control varied between 92 and 98%. As for the fresh matter, the average values varied between 45 and 66 g, with no significant difference between the treatments.

These results show that using ultra-coarse droplets is feasible for applying the spray containing dicamba and glyphosate, constituting an important strategy for reducing the risk of drift. However, the application moment may interfere with the results obtained depending on the weed stage. The control of *Conyza* plants of smaller size was excellent, while the control of larger plants was very good (Alam, 1974). Similarly, Bressanin et al. (2014) found that the greater the phenological development of *Conyza bonariensis,* the lower the effectiveness of control using glyphosate and chlorimuron-ethyl; that is, it is more difficult to control more developed weeds.

In this sense, Butts et al. (2018) suggested combining satisfactory weed control and reduced risk of drift of dicamba herbicide by using droplets with VMD of 900 µm and spray volumes of 187 L ha^{-1}. However, the authors caution that factors other than droplet spectrum and spray volume, including weather conditions and weed species, may greatly interfere with application quality.

CONCLUSIONS

The use of ultra-coarse droplet spectrum was shown to adequately control *Commelina benghalensis* and *Conyza* spp., regardless of the spray volume, using a mix of glyphosate and dicamba.

The different spray volumes did not influence the spray deposition on weeds.

The TTI and MUG tips gave similar control performance from 96 L ha^{-1}, indicating greater consistency of performance at volumes above this value. However, increasing volume above this level did not improve control, regardless of the tip used.

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