ISSN 2359-6562 (ONLINE) 2359-6562 (CD-ROM)

ESPECTRO DE GOTAS E ÍNDICE DE DERIVA NA PULVERIZAÇÃO DE ASSOCIAÇÕES DE DICAMBA COM *GLYPHOSATE*

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** Artigo extraído da tese do primeiro autor.*
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RESUMO: O objetivo foi avaliar o potencial de deriva de novas formulações de dicamba associados ao *glyphosate* com diferentes pontas de pulverização. Os tratamentos foram agrupados a partir de dois tamanhos de orifícios das pontas utilizadas ("ISO 02" e "ISO 04"), dois volumes de calda propostos (50 e 100 L ha^{-1}) e das pressões de pulverização (3 e 6 bar). Cinco tipos de pontas (TTI, AI, AITTJ, ULD, AIXR) e caldas compostas da mistura de 3,0 L p.c. ha^{-1} de uma formulação SL de *glyphosate* sal potássico (480 g e.a. L^{-1}) com duas formulações SL de dicamba sal diglicolamina (350 e 480 g e.a. L^{-1}), nas doses de 2,06 e 1,5 L p.c. ha^{-1}, respectivamente. O espectro de gotas foi avaliado em tempo real por meio da técnica de análise por imagem - PDIA e o índice de deriva física foram estimados por meio de túnel de vento. Cada agrupamento foi analisado através de delineamento em esquema fatorial (pontas x caldas), seguido do teste de Tukey. A ponta de pulverização TTI 11004 apresentou os parâmetros mais adequados ao conceito de redução do risco de deriva, considerando a aplicação das misturas de *glyphosate* com dicamba 350 e dicamba 480.

Palavras-chaves: formulações, deriva, pontas de pulverização, túnel de vento.

DROPLET SPECTRUM AND POTENTIAL DRIFT BY NOZZLE WITH AIR INDUCTION IN SPRAYING DICAMBA ASSOCIATIONS WITH *GLYPHOSATE*

ABSTRACT: The objective of this study was to evaluate the drift potential of new dicamba formulations associated with *glyphosate* with different nozzles. The treatments were grouped on the basis of different nozzle orifice diameters ("ISO02" and "ISO04"), combinations of two concentrations of the products in the spray solution (50 and 100 L ha^{-1}) and spraying pressures (3 and 6 bar). Five types of nozzles (TTI, AI, AITTJ, ULD, AIXR) and spray solutions composed of a mixture of 3.0 L p.c. ha^{-1} of an SL formulation of *glyphosate* potassium salt (480 g a.a. L^{-1}) with two SL formulations of dicamba diglycolamine salt (350 and 480 g a.a. L^{-1}) were used at doses of 2.06 and 1.5 L p.c. ha^{-1}, respectively. The droplet spectrum was evaluated in real time via the image analysis technique PDIA, and the physical drift index was estimated via a wind tunnel. Each cluster was analyzed through a factorial design (nozzle × solutions), followed by the Tukey test. The TTI 11004 spray nozzle presented the most suitable parameters for reducing the risk of drift, considering the application of mixtures of *glyphosate* with dicamba 350 and dicamba 480.

Keywords: formulations, drift, spray nozzle, wind tunnel.

1 INTRODUCTION

Genetically modified (GM) crops have attracted the interest of farmers because they are tolerant to herbicides such as *glyphosate. However, after 20 years of using this technology with sequential applications of the same herbicide, natural selection of glyphosate*-resistant weed populations has occurred.

The difficulty in controlling weeds has driven research into the development of the next generation of crops resistant to multiple herbicides, such as 2,4-D and dicamba. These herbicides are selective for the control of dicotyledonous plant species, although when associated with nonselective herbicides, such as *glyphosate*, they can be applied with a broader control spectrum. It is selective, systemic, absorbed by the leaves and translocated throughout the plant (Lewis; Tzilivakis, 2017).

With the development of soybean plants that are tolerant to nonselective herbicides, producers have found a solution to control resistant weeds in this first cycle (Adegas *et al.*, 2017). The possibility of producing crops that are tolerant to different herbicides that coexist in the same environment increases the risk of losses due to drift in nontolerant crops. The efficiency of this herbicide at low concentrations results in concern about the movement of particles outside the target area (drift), causing damage to other species.

This technology is an important tool for diversifying the mode of action in weed control; however, it should be used well to prevent weed wear. Through the development of dicamba-resistant crops, questions have arisen regarding the possible interactions of the herbicide dicamba with other herbicides, allowing combinations of mixtures in the sprayer tank (Behrens *et al.*, 2007).

The possibility of changing the sprayer configuration and the composition of the spray solution should minimize the production of droplets with smaller diameters (Ucar; Hall, 2001). According to Alves *et al.* (2017), after analyzing different spray tips and the potential for drift of solutions with only dicamba and other compositions of the mixture with *glyphosate*, they observed different droplet spectra in each situation evaluated. Butts *et al.* (2019) argued that even with systemic herbicides, such as growth regulators, there is a critical droplet size, and if the droplet size increases, weed control may be reduced.

The use of drift reduction techniques began in developed countries with the aim of encouraging the manufacture, marketing and use of spraying technologies that scientifically prove drift reduction when used (Hoffmann *et al.*, 2010). The use of good agricultural practices will be essential in the management of these cultivars.

The application of the herbicide dicamba should be carried out with application technology parameters that aim to reduce the potential for drift to nontarget crops. These parameters include the correct choice of spray tip and the concentration of the product in the solution to be applied, seeking balance and efficiency during application (Hewitt, 2000).

Thus, the objective of this research was to evaluate the drift potential of new dicamba formulations associated with *glyphosate* through the droplet spectrum and the drift index with spray tips that provide low drift.

2 MATERIALS AND METHODS

The experiment was carried out at the Spraying Machine Laboratory of the Agricultural Machinery and Tire Testing Center (NEMPA) in the Department of Rural Engineering of the Faculty of Agricultural Sciences (FCA/UNESP), Botucatu *Campus – SP*.

The droplet spectrum was evaluated in real time via the image analysis technique Particle/Droplet Image Analysis (PDIA). The equipment used to perform the analyses was *VisiSize* P15 together with integral software (Oxford Lasers, Imaging Division, Oxford, UK). On the basis of the droplet spectrum readings, the following parameters were determined: median volumetric diameter (MVD), relative amplitude (RA) and percentage of the sprayed volume with drops with a diameter less than 150 µm (V150).

V150 was used as an evaluation parameter in this work because it numerically represents the proportion of droplets most prone to drift within the spectrum generated in each spray. This reference value may vary from one study to another (Nuyttens *et al*., 2010). The physical drift index (ID) was estimated by means of a wind tunnel, following a methodology adapted according to the recommendations of the ISO standard (ISO 22856:2008: Crop protection equipment, Methods for the laboratory measurement of spray drift in wind tunnels). The total drift index was calculated by summing the deposition of all the threads for each repetition, as described by Chechetto. *et al.* (2013).

Table 1 presents the description of the herbicides and doses used for the drift and droplet spectrum analyses. The two mixtures used in all the evaluations were composed of a mixture of 3.0 L pc ha $^{-1}$ of an SL formulation of *glyphosate* potassium salt (480 g ae. ha $^{-1}$) with two SL formulations of dicamba diglycolamine salt (350 and 480 g ae. ha $^{-1}$), at doses of 2.06 and 1.5 L pc ha $^{-1}$, respectively.

To facilitate the presentation of herbicides in the treatment descriptions, the abbreviations “D+G” and “DRV+G” were used to indicate the syrup used, where “D” represents the diglycolamine salt dicamba, “DRV” represents the diglycolamine salt dicamba with a volatility reducer, and “G” represents *glyphosate* in the potassium salt. The doses used are described in Table 1 and were diluted in deionized water on the same day the analysis was carried out, simulating two application rates of 50 and 100 L ha $^{-1}$ and sprayed at pressures of 300 and 600 kPa (3 and 6 bar).

Table 1. Herbicide doses for spray dilutions.

Caldas	**Dicamba dose**	***Glyphosate* dose**
	g ae ha $^{-1}$	***g ae ha $^{-1}$***
DRV+G	721	1764
D+G	720	1764

Abbreviations: D, dicamba; RV, volatility reducer; G, *glyphosate*.

Considering the objectives of this work, a series of eight trials were developed as factorial designs, with the herbicide tips and sprays as factors. Analysis of variance (ANOVA) was used as the primary tool for statistical analysis of the data, and the F value was the basis for evaluating the significance of the factors (causes of variation) and their interactions.

A randomized design (CRD) was used in all trials. Tukey's test at the 5% probability level was used to compare means when appropriate.

The eight tests corresponded to the combination of two concentrations of products in the mixture equivalent to diluting the herbicides to 50 and 100 L ha $^{-1}$, two sizes of tip orifices ("ISO 02" and "ISO 04") and two pressures (300 and 600 kPa). All tests were performed with three replications for data collection.

3 RESULTS AND DISCUSSION

Table 2 presents an accounting of the tests in which the interaction between factors was found in the factorial "Pontas x Caldas". It is clearly observed that, in any spraying situation, there is an interaction between tips and grout for V150 (this interaction was significant in the 8 datasets).

Thus, it is extremely safe to state that, for the generation of V150, an interaction between the spray solutions and the tips should (always) be expected. In other words, the V150 of a given tip will always be a function of the spray solutions, and vice versa. Although several authors (Miller; Ellis, 2000; Hilz; Vermeer, 2013; Alves *et al.*, 2017) have described in previous research how important the interaction between the performance of the tip and the spray solution is, the results obtained in this research reveal the percentage of finer droplets (V150) as the parameter evaluated to demonstrate the response of this significant interaction in a more relevant way.

The same reasoning should not be applied to the other variables studied. In the case of AR, the interaction between factors occurred for all tests of the lower flow tips (ISO 02), but in the case of the higher flow tips (ISO 04), the interaction between factors occurred only for the situations where there were 300 kPa and 100 L ha $^{-1}$.

In the case of DMV, the interaction between Tips and Broths occurred only at the lowest pressures for tip 2, whereas for tip 4, this interaction was significant only for the situation where the pressure was 600 kPa with a broth dilution of 100 L ha $^{-1}$.

Table 2. "Tips × Broth" interaction for each of the factors evaluated, within each tip orifice size (ISO 02 and ISO 04) and for each combination of pressure with the dilution of the broth.

Pressure	Dilution of the syrup	DMV		V150		AIR		ID
(kPa)	(L ha $^{-1}$)	02	04	02	04	02	04	04
300	50	X		X	X	X		
300	100	X		X	X	X	X	
600	50			X	X	X		
600	100		X	X	X	X		

Finally, no cases of interaction between tips and tails were observed for the ID analyses; however, the application technology is a process that involves a series of components at different stages that interact with other factors (Ebert; Downer, 2008).

Tables 3 and 4 show, in sequence, the spraying situations where isolated significance was obtained for tips or sprays, without any interaction between factors being observed.

Table 3. Statistical significance for the "Tips" factor for each of the factors evaluated, within each tip orifice size (ISO 02 or 04) and for each combination of pressure with the dilution of the solution

Pressure	Dilution of the syrup	DMV		V150		AIR		ID
(kPa)	(L ha $^{-1}$)	02	04	02	04	02	04	04
300	50		X				X	X
300	100		X					X
600	50	X	X				X	X
600	100	X					X	X

In the case of DMV, Table 3 shows that most spraying situations with the highest flow rate tips presented tip significance (5 out of the 4 subgroups considered), and the same occurred for AR. In the case of ID, the tip factor was significant in all spraying situations, showing that the tip is a preponderant factor for defining the ID obtained.

In fact, Table 4 shows that no situations were observed where the tail factor was significant for the ID in isolation, which confirms the importance of the tips in defining the ID.

Table 4. Statistical significance for the "bludge" factor for each of the factors evaluated, within each tip flow rate (ISO 02 or 04) and for each combination of pressure with the dilution of the mixture

Pressure	Dilution of the syrup	DMV		V150		AR		ID
(kPa)	(L ha^{-1})	02	04	02	04	02	04	04
300	50							
300	100		X					
600	50	X					X	
600	100	X					X	

Taking as a basis the premise that the application technology for sprays with the auxinic herbicide dicamba should prioritize the use of drift reduction techniques (DRTs), Table 5 presents a summary, indicating which spray tip represents the best DRT within each tip flow rate (ISO 02 or ISO 04) and for each combination of pressure with spray volume.

In this table, the selection of the tip considered that the best TRD represents the technique with the highest DMV, lowest V150 and lowest ID. When more than one tip was highlighted, this indicates that there was statistical equality between them.

Table 5. Indications of the tips that offered the best conditions for reducing the risk of drift (highest DMV, lowest V150 or lowest ID), within each tip flow rate (ISO 02 or 04) and for each combination of pressure with the dilution of the mixture

Pressure	**Dilution of the syrup**	**Largest DMV**		**Smallest V150**		**Minor drift**
(kPa)	**(L ha $^{-1}$)**	**02**	**04**	**02**	**04**	**04**
300	50	TTI	TTI	TTI	TTI/AITTJ	TTI/ULD
300	100	TTI	TTI	TTI	TTI/AITTJ	TTI/ULD
600	50	TTI	TTI	TTI/AITTJ	TTI/AITTJ	TTI/ULD
600	100	TTI	TTI	TTI	TTI/AITTJ	TTI/ULD

From this perspective, the TTI tip represents the best TRD for the application of dicamba, as in all the datasets, the TTI tip always has the highest DMV, the lowest V150 and the lowest ID. . However, it is important to note that for tip 04, in the V150 analysis, there was no significant difference from the AITTJ tip, and for ID, the statistical tie was with the ULD tip. This means that, depending on the factor analyzed, the TTI tip could have competitors with statistically similar performance.

For example, if the primary TRD evaluation parameter is V150 (as is primarily the case in the US), the AITTJ tip could be considered similar to the TTI for a flow rate of 04. On the other hand, if the physical drift index (ID) was the preferred evaluation parameter (as is the case in Europe), the ULD tip would also be evaluated in terms of the TRD as the TTI tip.

This fact shows that, preferably, the TRD evaluation should take into account all available parameters (DMV, V150 and ID) and should not be focused on just one or another isolated parameter. The same type of reasoning was used to choose which dicamba formulation would be considered the best TRD on the basis of the results obtained (Table 6).

Table 6. Indications of the spray solutions (D+G and DRV+G) that offered the best conditions for reducing the risk of drift (highest DMV, lowest V150 or lowest ID), within each peak flow rate (ISO 02 or 04) and for each combination of pressure with spray solution dilution

Pressure	**Dilution of the syrup**	**Largest DMV**		**Smallest V150**		**Minor ID**
(kPa)	**(L ha $^{-1}$)**	**02**	**04**	**02**	**04**	**04**
300	50	D+G	D+G/DRV+G	D+G	DRV+G	D+G/DRV+G
300	100	D+G	D+G	D+G	DRV+G	D+G/DRV+G
600	50	D+G	D+G/DRV+G	D+G	DRV+G	D+G/D RV+G
600	100	D+G	D+G	D+G	D+G/DRV+G	D+G/DRV+G

In this case, the dicamba 480 formulation appears in most spraying conditions as the one that presents the lowest risk of drift, with several situations where the 480 and 350 formulations present a statistical tie. Only in some of the analyses did formulation 350 prove to be the best TRD alone. In this case, some trends can be considered: formulation 480 was the best TRD in all the DMV and V150 analyses for tip 02, whereas for tip 04, there were cases in which no significant difference occurred, as did some combinations that indicated the 350 formulation as the best TRD.

On the other hand, there was a difference between the formulations for all combinations of pressure and spray volume when the parameter evaluated was ID. In general, this analysis shows that it is necessary to deepen the comparative study between the formulations to generate more evidence of the existence of better performance, such as TRD, between the 480 and 350 formulations.

4 CONCLUSIONS

The TTI 11002 and TTI 11004 spray tips presented droplet spectra most suited to reduce the risk of drift among the models evaluated, considering the application of mixtures of *glyphosate* with dicamba 350 and dicamba 480.

For the ID parameter (physical drift index in the wind tunnel), the ULD 11004 spray tip performed similarly to the TTI 11004 tip, with the lowest drift potential compared with the other tips analyzed.

There was a significant interaction between the nozzles and the spray solutions in most of the analyses performed, with an emphasis on V150, where this significant interaction occurred for all combinations of pressure and spray volume evaluated. This fact reinforces the hypothesis that the performance of the nozzles depends on the spray solutions and, similarly, that the performance of the spray solutions depends on the nozzles used.

The differences in behavior between treatments, in the various combinations, showed that V150 alone should not be prioritized as a selection parameter for TRD, since DMV, V150 and ID often indicate different paths in selecting the best TRD.

The overall results of this work show that it is necessary to deepen the comparative study between the formulations to generate more evidence of the existence or lack of better performance as the TRD between the 480 and 350 formulations increases.

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