

Research Article

Spray nozzles, working pressures and use of adjuvant in reduction of 2,4-D herbicide spray drift

João D. Godinho Jr.^{a*}, Lucas C. Vieira^a, Renato A.A. Ruas^a, Alberto Carvalho Filho^a, Vinícius R. Faria^a, Pedro I.V.G. God^a

^a Universidade Federal de Viçosa, Rio Paranaíba, MG, Brasil.

INFORMATION ARTICLE

Received: May 6, 2019
Accepted: July 10, 2020

Keywords:

agricultural mechanization
application technology
quality control
air induction
droplet size
wind tunnel

*Corresponding author:

<joao.godinho@ufv.br>

Cite this article:

Godinho Jr JD, Vieira LC, Ruas RAA, Carvalho Filho A, Faria VR, God PIVG. Spray nozzles, working pressures and use of adjuvant in reduction of 2,4-D herbicide spray drift. *Planta Daninha*. 2020;38:e020223622.
<https://doi.org/10.1590/S0100-83582020380100070>

Conflict of Interest:

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Copyright: This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided that the original author and source are credited.



HIGHLIGHTS

- Adjuvants must be used according to the nozzle model, application method, and spray mixture.
- The empty cone nozzle with induction had the smallest increase the drift of 2,4-D with the pressure variation.
- The conventional simple fan jet nozzle has a high potential to cause damage with the drift of 2,4-D.

ABSTRACT

Background: The study of the interactions between equipment, application methods, and spray mixtures is fundamental to optimize the application of pesticides. The determination of the best combination of these factors can reduce the drift during the application of the herbicide 2,4-dichlorophenoxyacetic acid (2,4-D).

Objective: The objective this paper is to study the influence of nozzle models, working pressures, and surfactant adjuvant in reducing the drift of 2,4-D.

Methods: The spectrum of nozzle drops was determined for a conventional flat jet; flat jet with air induction; double plane jet with air induction; deflector flat jet with air induction; and an empty cone with air induction at pressures of 200, 300, 400, and 500 kPa. This was quantified in a wind tunnel with four drifts: water; water + surfactant adjuvant; water + 2,4-D; and water + 2,4-D + surfactant adjuvant, applied by the five nozzle models at four working pressures. The data was evaluated by analysis of variance and, when significant, by the Tukey test and regression at 5% significance level.

Results: The interactions between the nozzle models, working pressure, and spray mixture directly influenced the 2,4-D drift.

Conclusions: The use of surfactant adjuvant must be carried out carefully, according to the nozzle model, working pressure, and spray mixture. The conventional single fan jet nozzle is more sensitive to increased working pressure and has a high potential to cause drift compared with the models with air induction.

1 INTRODUCTION

The proper regulation and calibration of spray equipment is one of the most effective ways to reduce

losses during pesticide application. During calibration, the spray application volume can be increased by changing the nozzle model, decreasing the operation speed, and/or increasing the working pressure.

In rural properties, the most common approach to increase pesticide flow is by increasing the pressure, because there is no cost associated with acquiring additional sets of nozzles of different flow rates nor losses in operational capacity by reducing the speed of operation. However, the pressure increase not only increases the flow and number of droplets produced, but also decreases the diameter of these droplets, making the spray jet more susceptible to evaporative losses and/or transport by wind. Moreover, depending on the application conditions, it can generate drift (Boller and Raetano, 2011).

Drifting of the spray solution applied to control invasive plants is a major problem in modern agriculture. For example, in the application of the herbicide 2,4-dichlorophenoxyacetic acid (2,4-D, NORTOX®), which has hormonal action, even if only small amounts of its active ingredient reach sensitive nontarget plants, great losses will occur (Egan et al., 2014). To reduce these losses, the proper use of application technology is essential by defining the nozzle, working pressure, and spray solution that best suits each situation. The selection of the correct nozzle model is a fundamental step to reduce drift and reach the application target (Ferguson et al., 2015a; Gandolfo et al., 2013).

An available option is the use of air-induced nozzle models equipped with “venturi” technology and holes at strategic points, which allow air to enter the spray nozzle, with a significant pressure reduction inside. This air mixes with the spray mixture, generating larger droplets with air bubbles inside (Vallet and Tinet, 2013). Another option is the use of specific types of adjuvants, which are added to the spray mixture to make it less susceptible to adverse weather conditions at the time of application (Nascimento et al., 2012; Hilz and Vermeer, 2013; Vilela and Antuniassi, 2013), thus reducing drift losses (Oliveira et al., 2013).

However, its effect on the droplet spectrum may vary according to the nozzle model (Cunha et al., 2010; Gandolfo et al., 2013), as different models respond differently to changes in the spray solution (Dorr et al., 2013; Ferguson et al., 2015b). The use of adjuvants alters the physical characteristics of the spray solution and influences the diameter of the droplets produced; however, this varies, mainly, according to the nozzle model and spray pressure (Spanoghe et al., 2007; Iost and Raetano, 2010; Costa et al., 2014). In addition, the effect of adjuvants on the physicochemical characteristics of the spray solution depends on their chemical composition and

interaction with the applied pesticide (Cunha et al., 2017). Thus, the objective of this work is to analyze the combination of nozzle models, working pressures, and adjuvant in reducing the drift of 2,4-D.

2 MATERIALS AND METHODS

The experiment was carried out in the laboratory, first by determining the technical characteristics of nozzle models, and then evaluating the spray drift in a wind tunnel.

2.1 Technical characterization of hydraulic nozzles

The determination of the technical characteristics of nozzles follows a completely randomized design in a subdivided plot, with four replications. Five nozzle models (plots) with flow equal to 1.14 L min⁻¹ were evaluated: conventional flat jet (JSF110-03), flat jet with air induction (Magno AD-IA110-03), flat deflector jet with air induction (Teejet TTI110-03-VP), double flat jet with air induction (Magno AD-IA/D110-03), and empty cone with air induction (Magno CV-IA100-03) operating at four working pressures (subplots): 200, 300, 400, and 500 kPa. First, the droplet spectrum of nozzle models was analyzed at working pressures, applying only water (ASAE, 2009).

The droplet spectrum was determined with the aid of a laser particle analyzer (Spraytech, Malvern Instruments Ltd., Malvern, Worcestershire, United Kingdom). The following variables were measured: volumetric median diameter (VMD), diameter of the drop that divides the volume of a population of droplets into two equal parts; and the relative amplitude of the drop population (SPAN) (Equation 1).

$$SPAN = \frac{D_{v\ 0,9} - D_{v\ 0,1}}{D_{v\ 0,5}} \quad (\text{eq. 1})$$

where $D_{v\ 0,9}$: droplet diameter in which 90% of the volume of the sprayed liquid consists of droplets of a smaller size. $D_{v\ 0,1}$: droplet diameter in which 10% of the volume of the sprayed liquid consists of droplets of a smaller size. $D_{v\ 0,5}$ ou VMD: droplet diameter in which 50% of the volume of the sprayed liquid consists of droplets of a smaller size.

The percentage of the sprayed volume containing drops with a diameter of less than 150 µm was also determined, which indicates the potential risk of drifting during the application (Cunha et al., 2004).

The focal distance was 750 mm, and the device to count the droplet size was adjusted to 0.10-2,500 µm. An electric motor was used to rotate the spraying bar, so that the entire jet that came out of the nozzle

passed cross-sectionally for 3 s through the beam of light emitted by the laser scanner. Each hydraulic nozzle was positioned 0.3 m from the laser device.

2.2 Drift assessment in wind tunnel

The drift assessment was performed following a completely randomized design, in a sub-subdivided plot, with four replications. The plots consisted of four spray solutions: water; water + surfactant adjuvant; water + 2,4-D; and water + 2,4-D + surfactant adjuvant, and the subplots the five hydraulic nozzle models mentioned above. In the sub-subplots, we had four spraying pressures: 200, 300, 400, and 500 kPa.

Drift assessment was performed in a wind tunnel with an open circuit and a closed test section with length, height, and width of 4.8, 0.56, and 0.6 m, respectively. The wind current was produced by a three-propeller fan driven by an electric motor with 200 W of power. At 0.10 m from the ventilator, two screens were positioned, one made of nylon (2 mm mesh) and the other made of metal (6 mm mesh). At 0.15 m in front of the screens, a beehive made of 560 metal rectangles was made, with height, width, length, and wall thickness of 2, 3, 5, and 0.2 cm, respectively. The purpose of the screens and hives is to standardize and generate laminar flow of air from the fan.

The surfactant adjuvant based on lecithin and propionic acid (LI 700[®]) was used at a proportion of 0.5 L for each 100 L of spray solution. The dose of 2,4-D was 670 g i.a. ha⁻¹ at a dosage of 1 L ha⁻¹ and spray volume of 200 L ha⁻¹. Bright blue food tracer dye (FCF Blue Dye, Duas Rodas Industrial), internationally cataloged by "Food, Drug & Cosmetic" as FD&C Blue n.1, was added to all spray solutions at a concentration of 5 g L⁻¹.

To detect the displacement of the sprayed liquid inside the wind tunnel, three 2 mm diameter nylon collecting wires (ISO, 2005) were positioned transversely to the air flow at 0.10, 0.25, and 0.40 m from the tunnel floor. Once the air flow stabilized, spraying was carried out for 20 s, followed by an interval of 25 s for drying the drops on the wires; followed by the removal of the collecting wires for the evaluations.

The wires were placed in transparent plastic bags containing 50 mL of distilled water and agitated for 30 s. Then, the solutions obtained from washing the wires were analyzed in a digital spectrophotometer (Visible Spectrophotometer - Model Evolution 300 UV)

at a wavelength of 630 nm and band detection of bright blue (Palladini et al., 2005).

A calibration curve was plotted with eight known concentrations of the spray solution containing the dye (Figure 1). Thus, the concentration of the dye in grams per liter was determined in each sample collected in the wind tunnel. The quantity found at the collection points was transformed into a percentage in relation to the total amount in the spray solution, and then the average drift of the three collection heights was calculated.

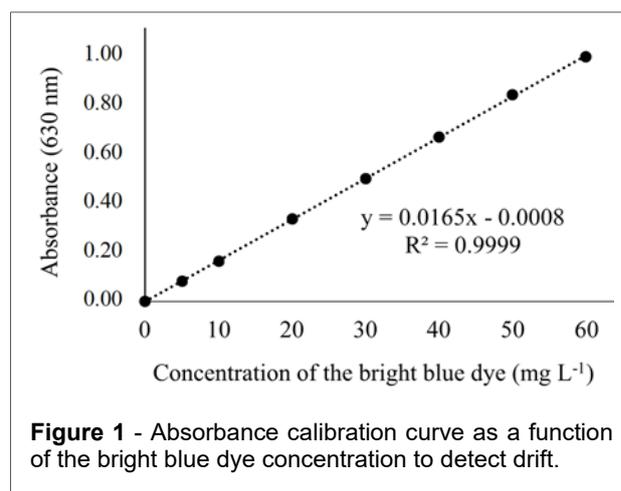


Figure 1 - Absorbance calibration curve as a function of the bright blue dye concentration to detect drift.

During the evaluations, the average temperature was 21.77 °C and relative humidity of 68.18%, monitored with the THAL-300 portable digital thermo-hydro-anemometer. The wind speed generated by the fan during the application was 2 m/s, which was also measured with the thermo-hydro-anemometer at the place where the nozzle was inserted into the wind tunnel.

The spray nozzle was positioned 1.8 m from the ventilator at a height of 0.5 m from the tunnel floor. The spraying system consisted of a piston pump model BPF 22, with a flow between 14 and 22 L min⁻¹; three pistons driven by a single-phase electric induction motor with a power of 1.5 kW; and manual control and a glycerin manometer to adjust and measure the spraying pressure, respectively. Before the evaluations, the manometer was calibrated using a test bench model RB 500, equipped with a reference manometer for measurement (Rücken brand, model RMP, accuracy class A3 ABNT ($\pm 0.25\%$ FDE)).

Data collection and analysis were performed according to the principles of experimental statistics, independent samples, and homoscedasticity and normality of data. Homoscedasticity and normality were verified by Levene and Shapiro-Wilk tests,

respectively. The analysis of variance was carried out at 5% significance level and, when necessary, the averages were compared using the Tukey test at 5% significance level for nozzle models and spray solutions. The spraying pressures were analyzed by regression, choosing the equation model that best fit the analysis of variance of the regression and the behavior of the assessed phenomenon.

3 RESULTS AND DISCUSSION

In determining the technical characteristics of the hydraulic nozzle models, the analysis of variance was significant for the interaction between nozzle models and spraying pressure for the VMD, drift risk percentage (DRP), and SPAN variables. In the evaluation of the drift, there was significant interaction between the three factors evaluated: application mixtures, nozzle models, and spraying pressure.

The smallest and largest VMDs, regardless of the spraying pressure, were produced by the conventional flat jet and flat deflector jet with air induction, respectively (Table 1). However, it is important to note that although very small droplets (<100 µm) are undesirable because of their susceptibility to losses due to evaporation and/or transport by wind, very large droplets are also lost owing to runoff. Very large droplets (>800 µm), because of their greater weight, usually do not adhere easily to the target surface and fall to the ground. Moreover, these do not provide good coverage nor uniform distribution (Lefebvre, 1989).

Table 1 - Effect of spraying pressure on the volumetric median diameter (VMD) of the nozzle models: conventional flat jet (LS), conventional flat jet with air induction (LSI), double flat jet with air induction (LDI), flat jet deflector with induction (LII), and empty cone with air induction (CVI)

Nozzle model	VMD (µm)*			
	Spraying pressure (kPa)			
	200	300	400	500
LS	198.63 Ae	166.83 Be	153.90 Bd	148.00 Bd
LSI	513.43 Ac	482.15 Bc	446.87 Cb	422.30 Cb
LDI	441.77 Ad	394.33 Bd	343.28 Cc	303.05 Dc
LII	818.43 Aa	594.10 Ba	553.13 Ca	516.65 Da
CVI	612.90 Ab	545.00 Bb	452.33 Cb	420.33 Db

* Means followed by the same uppercase letters in the rows and lowercase letters in the columns, for each day, do not differ among themselves according to the Tukey test at 5% significance level.

The production of a droplet spectrum with a smaller VMD of the conventional flat jet nozzle, compared with the air induction nozzles, resulted in a higher DRP, regardless of the spraying pressure (Table 2). This was justified by the technology used in the construction of nozzle models with air induction, which produced larger droplets compared with conventional nozzles without induction (Vallet and Tinet, 2013). These droplets contained air bubbles

that altered their physical behavior, making their retention and wettability similar to those of small droplets. (Miller and Butler Ellis, 2000). Thus, spraying using air-inducing nozzles has great potential to reduce drift during pesticide application (Ferguson et al., 2016; Godinho Junior et al., 2017).

Table 2 - Effect of spraying pressure on the drift risk percentage (DRP) of the nozzles: conventional flat jet (LS), conventional flat jet with air induction (LSI), double flat jet with air induction (LDI), flat jet deflector with induction (LII), and empty cone with air induction (CVI)

Nozzle model	DRP (%)*			
	Spraying pressure (kPa)			
	200	300	400	500
LS	33.71 Ad	43.39 Be	48.64 Ce	50.76 De
LSI	6.63 Ab	7.87 BCc	9.62 DCc	11.35 Dc
LDI	10.27 Ac	12.86 Bd	17.04 Cd	19.14 Dd
LII	3.67 Aa	5.83 Bb	6.45 Bb	7.49 Bb
CVI	2.90 Aa	3.10 Aa	4.15 ABa	5.02 Ba

* Means followed by the same uppercase letters in the rows and lowercase letters in the columns, for each day, do not differ among themselves according to the Tukey test at 5% significance level.

Among the nozzles with anti-drift technology, the double plane jet with air induction generated the lowest VMD values and, consequently, the highest DRPs. On the other hand, the flat deflector jet nozzles with air induction and empty cone with air induction emerged as effective tools to reduce drift. Compared with the other models, regardless of the spraying pressure, the flat deflector jet with air induction produced the largest VMDs, whereas the empty cone with air induction provided the lowest SPAN (Table 3). The lower the SPAN value, the smaller the variation of the droplet diameters generated during spraying, and hence the better the quality of the application (Madureira et al., 2015).

Table 3 - Effect of spraying pressure on the relative amplitude of the droplet population (SPAN) of the nozzles: conventional flat jet (LS), conventional flat jet with air induction (LSI), double flat jet with air induction (LDI), deflector flat jet with induction (LII), and empty cone with air induction (CVI)

Nozzle model	SPAN*			
	Spraying pressure (kPa)			
	200	300	400	500
LS	1.76 Ab	1.78 Ab	1.92 Ad	2.36 Bd
LSI	1.91 Bb	1.74 ABb	1.67 Bb	1.73 ABbc
LDI	1.89 Ab	1.73 Ab	1.75 Ac	1.72 Ab
LII	1.76 Ab	2.08 Bc	2.13 Bd	1.95 ABc
CVI	1.52 Aa	1.44 Aa	1.37 Aa	1.36 Aa

* Means followed by the same uppercase letters in the rows and lowercase letters in the columns, for each day, do not differ among themselves according to the Tukey test at 5% significance level.

At this point, it is interesting to note that although it does not produce the largest VMD, the empty cone nozzle with air induction generated the lowest DRPs owing to its lower SPAN compared with the deflector flat jet with air induction. Thus, the inverse correlation

between DRP and VMD should be used with caution, in which the higher the VMD, the lower the risk of drift (França et al., 2017). For a more rigorous comparison of the quality of the application between hydraulic nozzles models, one must also observe the SPAN produced by each equipment (Cunha et al., 2004).

The DRP was greatly influenced by the nozzle model; this parameter provides valuable information to predict the percentage of spray solution that can be carried by the wind, and thus lost by drift. This was confirmed with the data obtained in the wind tunnel, where the nozzles with air induction generated less drift (Figure 2), as they produced smaller droplets of <math><150\ \mu\text{m}</math> in the evaluation of the droplet spectrum.

In addition, the increase in spraying pressure decreased the VMD and increased the DRP and, consequently, the drift in the wind tunnel for all the nozzle models studied. Thus, it is evident that spraying pressure must be considered as it directly influences the spectrum of droplets formed during the application. However, among the analyzed nozzle models, observation of the slope of the regression curve indicates that the models with air induction were less sensitive to the increase in pressure, regardless of the spray solution.

When 2,4-D was present in the spray solution, the empty cone nozzle with air induction was the least sensitive to pressure increase. Compared with the flat

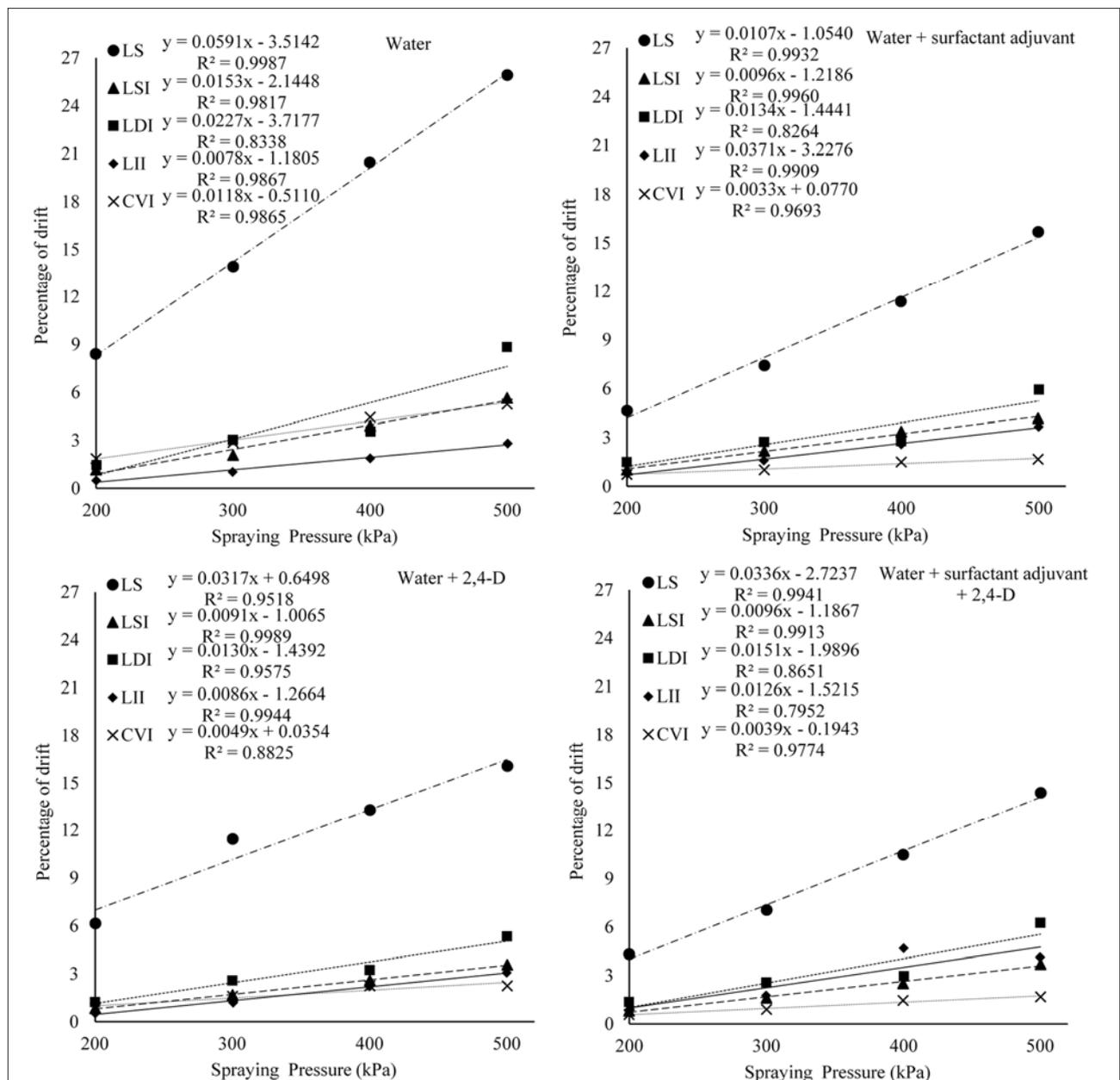


Figure 2 - Percentage of drift collected by spraying four mixtures (water, water + surfactant adjuvant, water + 2,4-D, and water + surfactant adjuvant + 2,4-D) in a wind tunnel using five nozzle models: flat jet conventional (LS), conventional flat jet with air induction (LSI), double flat jet with air induction (LDI), flat deflector jet with induction (LII), and empty cone with air induction (CVI) at four spraying pressures (200, 300, 400, and 500 kPa).

jet models, the standard empty cone nozzles without air induction produced a higher DRP and had greater risk of causing drift (Cunha et al., 2004). However, the addition of the air induction system on the empty cone nozzles significantly reduced the drift production and maintained a desirable characteristic of these nozzle models, i.e., their smaller variation in the droplet spectrum with increased pressure (Cunha et al., 2004).

For the interaction between spray solutions and hydraulic nozzles (Table 4), regardless of the spray solution when using the herbicide, the highest and lowest drift values were observed with the conventional flat jet and empty cone with air induction, respectively. When the adjuvant is not added to the spray solution, the flat deflector jet nozzle with air induction reduced the drift to levels similar to that of an empty cone with induction.

Table 4 - Percentage of drift in a wind tunnel resulting from the interaction between spray solutions and nozzle models: conventional flat jet (LS), conventional flat jet with air induction (LSI), double flat jet with air induction (LDI), flat deflector jet with induction (LII), and empty cone with air induction (CVI)

Spray solution	Percentage of drift (%)*				
	Nozzle model				
	LS	LSI	LDI	LII	CVI
Water	17.17 Ed	3.20 Bc	4.22 Db	1.55 Aa	3.61 Cc
Water + adjuvant	9.77 Eb	2.68 Cb	3.23 Da	2.15 Bc	1.23 Aa
Water + 2,4-D	11.74 Dc	2.18 Ba	3.10 Ca	1.76 Ab	1.74 Ab
Water + 2,4-D + adjuvant	9.05 Ea	2.16 Ba	3.29 Da	2.87 Cd	1.16 Aa

* Means followed by the same uppercase letters in the rows and lowercase letters in the columns, for each day, do not differ among themselves according to the Tukey test at 5% significance level.

The addition of the adjuvant reduced the drift of the herbicide spray solution by approximately 23% on the conventional flat jet nozzle, and by more than 33% on the empty cone nozzle with induction. On the nozzles with conventional and double flat jets with air induction, there was no effect. On the deflector jet with induction, there was a negative effect, with the surfactant adjuvant increasing the drift of the spray solution with the herbicide 2,4-D by 63%.

The addition of adjuvants to the spray solution can significantly influence the droplet formation process by altering the physicochemical characteristics of the spray solution, such as the surface tension and viscosity (Cunha et al., 2010). However, many of the problems associated with the use of adjuvants are due to the lack of knowledge on their mode of action, and consequently their effects on the efficiency of the application (Antuniassi, 2006).

With regard to the interaction between spray solutions and spraying pressures, the increase in

pressure always increased the percentage of drift (Table 5). However, the addition of the surfactant adjuvant reduced the drift at 200, 300, and 400 kPa. At the highest pressure (500 kPa), the addition of the adjuvant did not produce a significant change in the percentage of drift.

Table 5 - Effect of the interaction between spray solutions and spraying pressures on the percentage of drift in a wind tunnel

Spray solution	Percentage of drift (%)*			
	Spraying pressure (kPa)			
	200	300	400	500
Water	2.67 Ac	4.68 Bd	6.75 Cc	9.69 Dc
Water + adjuvant	1.73 Aa	2.99 Bb	4.31 Ca	6.23 Db
Water + 2,4-D	1.92 Ab	3.83 Bc	4.59 Cb	6.06 Da
Water + 2,4-D + adjuvant	1.60 Aa	2.78 Ba	4.42 Ca	6.03 Da

* Means followed by the same uppercase letters in the rows and lowercase letters in the columns, for each day, do not differ among themselves according to the Tukey test at 5% significance level.

4 CONCLUSIONS

The interactions between the hydraulic nozzle model, spraying pressure, and spray solution directly influence the 2,4-D drift. The use of surfactant adjuvant must be carried out carefully, according to the hydraulic nozzle model, spraying pressure and the spray solution.

The addition of the adjuvant to 2,4-D reduced the drift at the ends of the conventional flat jet and empty cone with air induction; it had no effect on the drift of the nozzles with conventional and double fan air induction. The adjuvant also increased the drift at the flat deflector jet nozzle with induction, and reduced the drift in applications at spraying pressures of 200, 300, and 400 kPa.

The conventional single fan jet nozzle is more sensitive to increased working pressure and has a high potential to cause drift compared with models with air induction. Among these models, the double flat jet nozzle produced greater drift during application. Regardless of the working pressure, the flat deflector jet nozzle with air induction produced the largest VMD, whereas the empty cone with induction provided the most uniform droplet diameters.

5 CONTRIBUTIONS

JDGJ and LCV: bibliographic research, carrying out the experiment, presenting and discussing the results. RAAR and ACF: project design, scientific support in conducting the experiment and review of the article. VRF and PIVGG: planning and statistical analysis of the experiment, and review of the article.

6 ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

7 REFERENCES

- ASAE - American Society of Agricultural Engineers. 2009. Spray nozzle classification by droplet spectra. ASAE S572.1. St. Joseph, MI: American Society of Agricultural Engineers; 2009. p.4.
- Antuniassi UR. Pesticide application technology. *Rev Plantio Direto*. 2006;15:17-22.
- Boller W, Raetano CG. Hydraulic power spray nozzles and nozzles, adjustments and calibration of boom sprayers. In: Antuniassi UR, Boller W, orgs. Application technology for annual crops. Aldeia Norte, Passo Fundo, Brasil: 2011. p.51-80.
- Costa AGF, Velini ED, Rossi CVS, Corrêa MR, Negrisola E, Fiorini MV, et al. Adjuvants on spray drift of 2,4-D + glyphosate in field conditions. *Ciênc Rural*. 2014;44:387-92.
- Cunha JPAR, Teixeira MM, Vieira RF, Fernandes HC, Coury JR. Droplet spectrum of standard flat fan and hollow cone spray nozzles. *Pesq Agropec Bras*. 2004;39:977-85.
- Cunha JPAR, Bueno MR, Ferreira, MC. Droplet spectra of spray nozzles with agricultural adjuvants. *Planta Daninha*. 2010;28:1153-8.
- Cunha JPAR, Alves GS, Marques RS. Surface tension, hydrogen-ion potential and electrical conductivity in spray solutions of plant protection products and adjuvants. *Rev Ciênc Agron*. 2017;48:261-70.
- Dorr GJ, Hewitt AJ, Adkins SW, Hanan J, Zhang H, Noller B. A comparison of initial spray characteristics produced by agricultural nozzles. *Crop Protection*. 2013;53:109-17.
- Egan JF, Barlow KM, Mortensen DA. A meta-analysis on the effects of 2,4-D and dicamba drift on soybean and cotton. *Weed Science*. 2014;62:193-206.
- Ferguson JC, O'Donnell CC, Chauhan BS, Adkins SW, Kruger GR, Wang R, et al. Assessing the deposition and canopy penetration of nozzles with different spray qualities in an oat (*Avena sativa* L.) canopy. *Crop Protection*. 2015a;81:14-9.
- Ferguson JC, O'Donnell CC, Chauhan BS, Adkins SW, Kruger GR, Wang R, et al. Determining the uniformity and consistency of droplet size across spray drift reducing nozzles in a wind tunnel. *Crop Protection*. 2015b;76:1-6.
- Ferguson JC, Chechetto RG, O'Donnell CC, Dorr GJ, Moore JH, Baker GJ, et al. Determining the drift potential of venturi nozzles compared with standard nozzles across three insecticide spray solutions in a wind tunnel. *Pest Manag Sci*. 2016;72:1460-6.
- França JAL, Cunha JPAR, Antuniassi UR. Spectrum, velocity and drift of droplets sprayed by nozzles with and without air induction and mineral oil. *Eng Agrícola*. 2017;37:502-9.
- Gandolfo MA, Chechetto RG, Carvalho FK, Gandolfo UD, Moraes ED. Influence on spray drift of nozzles and adjuvants with a glyphosate spray solution. *Rev Ciênc Agron*. 2013;44:474-80.
- Godinho Junior JD, Vieira LC, Pereira LOA, Ruas RAA, Faria VR, Carvalho Filho A. Herbicide drift 2,4-d in hydraulic jet tapes type leque. *Rev Bras Ciênc Agrárias*. 2017;12:550-4.
- Hilz E, Vermeer AWP. Spray drift review: the extent to which a formulation can contribute to spray drift reduction. *Crop Protection*. 2013;44:75-83.
- lost CAR, Raetano CG. Dynamic surface tension and contact angle of water solutions with spray surfactants in artificial and natural surfaces. *Eng Agrícola*. 2010;30:670-80.
- ISO - International Organization for Standardization. Equipment for crop protection - Methods for field measurement of spray drift, ISO/FDIS 22866:2005. Geneva: ISSO; 2005. p.22.
- Lefebvre AH. Atomization and sprays. New York: Hemisphere Publishing Corporation; 1989. p.421.
- Madureira RP, Raetano CG, Cavaliere JD. Interaction spray nozzle-adjuvant to estimate potential risk of spray drift. *Rev Bras Eng Agric Amb*. 2015;19:180-5.
- Miller PCH, Butler-Ellis MC. Effects of formulation on spray nozzle performance for applications from ground-based boom sprayers. *Crop Protection*. 2000;19(8):609-15.
- Nascimento A, Oliveira G, Balan M, Higashibara L, Abi Saab O. Glyphosate deposition and use adjuvant for different spray tips and time of application. *Appl Res Agrotechn*. 2012;5:105-16.
- Oliveira RB, Antuniassi UR, Mota AAB, Chechetto RG. Potential of adjuvants to reduce drift in agricultural spraying. *Eng Agrícola*. 2013;33:986-92.
- Palladini LA, Raetano CG, Velini ED. Choice of tracers for the evaluation of spray deposits. *Sci Agrícola*. 2005;62:440-5.
- Spanoghe P, Schampheleire M, Meeren PV, Steubaut W. Influence of agricultural adjuvants on droplet spectra. *Pest Manag Sci*. 2007;63:4-16.
- Vallet A, Tinet C. Characteristics of droplets from single and twin jet air induction nozzles: a preliminary investigation. *Crop Protection*. 2013;48:63-8.
- Vilela CM, Antuniassi UR. Droplet evaporation of spray solutions with fungicides and adjuvants on a surface. *En Agric*. 2013;28:65-73.