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Insecticide spray drift reduction with different adjuvants and spray nozzles[1]

Redução da deriva de inseticida por diferentes adjuvantes e pontas de pulverização

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HIGHLIGHTS:

AXI and J3D nozzles combined with Oro-solve or Wetcit Gold generated the largest DMVs and the smallest drift at 5 m.
The AXI nozzle combined with Oro-solve had the lowest drift at 10 m and at 15 m with the Oro-solve.
The JFC nozzle produced droplets with greater homogeneity of size.

ABSTRACT: Insecticide spray drift can lead to reduced control efficiency and loss of product to the environment. Thus, we conducted a study to evaluate the effect of different spray nozzles and the addition of adjuvants in insecticide spray on the resulting droplet spectrum and wind tunnel drift. All experiments were conducted in a completely randomized design with four repetitions using a 5 × 3 factorial scheme. Five spraying solutions were studied; one contained only water and the other four comprised thiamethoxam + lambda-cyhalothrin (no adjuvant, Oro-solve, Wetcit Gold, and Orobor N1), in combination with three spray nozzles (AXI, JFC, and J3D). The droplet spectrum was evaluated through the volumetric median diameter, relative amplitude, and percentage of the droplet volume with diameter ≤ 100 μm. The drifts were evaluated in a wind tunnel at 5, 10, and 15 m. Data were subjected to analysis of variance and means were compared using the Tukey's test. In addition, a principal component analysis was performed. Application of the insecticide with the adjuvants combined with the different nozzles changed the droplet spectrum and the risk of drift. The AXI nozzle and the J3D associated with the Oro-solve and Wetcit Gold adjuvants resulted in a greater volumetric median diameter of the droplets and drifts were observed at 5 m.

Key words: application technology, droplet spectrum, wind tunnel

RESUMO: A deriva da pulverização de inseticidas pode proporcionar a redução da eficiência de controle e perda para o ambiente. Desta forma, foi conduzido um estudo com o objetivo de estudar o efeito de diferentes pontas de pulverização e adição de adjuvantes na calda inseticida, em relação ao espectro de gotas e deriva em túnel de vento. Os experimentos foram conduzidos no delineamento inteiramente casualizado, com quatro repetições, no esquema fatorial 5 × 3, constituído por cinco caldas, uma apenas com água e outras quatro com inseticida tiametoxam + lambda-cialotrina (sem adjuvante, Oro-solve, Wetcit Gold e Orobor N1), combinadas com três pontas de pulverização (AXI, JFC e J3D). Foi avaliado o espectro das gotas, através do diâmetro mediano volumétrico, amplitude relativa e porcentagem do volume de gotas com diâmetro ≤ 100 μm. A deriva foi avaliada em túnel de vento, a diferentes distâncias: 5, 10 e 15 m. Os dados foram submetidos à análise de variância e as médias comparadas pelo teste de Tukey. Além disso, foram realizadas análises de componentes principais. A aplicação do inseticida com os adjuvantes combinados com as diferentes pontas de pulverização alterou o espectro de gotas e o risco da deriva. A ponta AXI e a J3D associada aos adjuvantes Oro-solve e Wetcit Gold apresentaram maiores diâmetros medianos volumétricos das gotas e deriva a 5 m.

Palavras-chave: tecnologia de aplicação, espectro de gotas, túnel de vento

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Introduction

The spraying of insecticides to control brown stink bugs in soybean agriculture is predominantly carried out when plants reach a maximum leaf area, requiring applications with maximum capacity to penetrate the leaf mass and cover the surface (Antuniassi et al., 2004).

In order to successfully apply phytosanitary products, it is necessary to master the appropriate techniques to ensure that the product reaches the target efficiently, thereby minimizing losses and reducing environmental contamination (Cunha et al., 2005). Therefore, it is necessary to study strategies to improve these techniques, particularly targeting control targets located at the bottom of the crop canopy, as these require increased deposition of sprayed drops (Cunha et al., 2008; 2016).

The correct selection of spray nozzles can increase the quality of the application by favoring the penetration of droplets, and thus promoting greater efficiency in the control of insects, pathogens, or weeds (Viana et al., 2010; Ferreira et al., 2011; Constantin et al., 2012).

The formation of droplets on the nozzles is often quite uneven (Cunha et al., 2007). However, this can be mitigated by adding adjuvants to the spray solution (Thebaldi et al., 2009) to alter its physico-chemical characteristics (Antuniassi, 2006). This can affect both the application mode and the activity of the chemical product (Aguiar Júnior et al., 2011), and reduce the number of drops susceptible to drift (Oliveira et al., 2015).

Therefore, a study was carried out with the objective of studying the effect of different spray nozzles and addition of adjuvants to the insecticide spray in relation to the spectrum of droplets and drift in a wind tunnel.

Material and Methods

This study was carried out in two stages. The first was performed to determine the spectrum of droplets, and the second studied the drift in a wind tunnel. The experiments were conducted in a completely randomized design with four repetitions in a 5 × 3 factorial scheme, consisting of five spray solutions combined with three hydraulic spray nozzles of the Jacto brand (Table 1).

The applications were carried out using the insecticide lambda-cyhalothrin (141 g L^{-1}) + thiamethoxam (106 g L^{-1}) (Engeo Pleno®, Syngenta), which was chosen based on the results of cooperative trials of insecticide efficacy in the control of brown stink bugs in soybeans in the 2013/2014 harvest. This product was observed to combine good control of brown stink bugs, relative productivity, and a lower rate of chopped soybeans (Roggia et al., 2018).

The choice of adjuvants was the result of a public-private partnership between Embrapa Soja and Orange Oil for Agriculture (ORO AGRI®). The selected adjuvants present in their orange peel oil formulation are: Oro-solve®, a simple mineral fertilizer with nanoparticulate sulfur (585 g L^{-1}), Wetcit® Gold, a surfactant based on orange peel oil (60 g L^{-1}), and Orobor ™ N1, a mixed leaf fertilizer composed of nitrogen (10.23 g L^{-1}), and boron (2.05 g L^{-1}).

Some important characteristics were decisive in the selection of the spray nozzle models, namely, the ability to work at the application dose of 100 L ha^{-1}, the fine droplet size, and the variety of types and/or angles of the produced jet. The chosen models of jet spray nozzles were AXI 11002 (a ceramic, simple flat jet nozzle), JFC 80015 (a ceramic, full tapered jet nozzle), and J3D 100015 (a plastic, flat angled jet nozzle).

The droplet spectrum was characterized by laser diffraction using a particle analyzer (Mastersizer S version 2.19). An optical unit in this equipment determined the diameter of the droplets of the sprayed spectrum by measuring the deviation of the trajectory suffered by the laser following contact; the smaller the particle, the greater the degree of diffraction that the light beam undergoes (Etheridge et al., 1999). The equipment was adjusted to evaluate drops from 0.5 to 900 mm (300 mm lens). An exhaust fan, located on the equipment at the point of spraying, removed the particles that were suspended in the air, so as not to compromise the accuracy of the analysis.

The applications were performed in a controlled environment, and the meteorological variables were monitored with the aid of a digital thermo-hygrometer: temperature (21.9 ± 0.5 °C), and relative humidity of air (59.2 ± 4.1%). The variables evaluated in the droplet spectrum included median volumetric diameter (VMD), relative amplitude (RS), and percentage of droplet volume with diameter ≤ 100 µm (Drops ≤ 100).

Table 1. Description of treatments

Treatments	Spray solution[1]	Dose (mL 100L^{-1})	Nozzle	Pressure (kPa)	Flow rate (m^3 s^{-1})
1	Water	10^5	AXI	206.84	1.1x10^{-5}
2			JFC	379.21	1.25x10^{-5}
3			J3D	482.63	1.1x10^{-5}
4	No adjuvant	0	AXI	206.84	1.1x10^{-5}
5			JFC	379.21	1.25x10^{-5}
6			J3D	482.63	1.1x10^{-5}
7	Oro-solve	1500	AXI	206.84	1.1x10^{-5}
8			JFC	379.21	1.25x10^{-5}
9			J3D	482.63	1.1x10^{-5}
10	Wetcit Gold	250	AXI	206.84	1.1x10^{-5}
11			JFC	379.21	1.25x10^{-5}
12			J3D	482.63	1.1x10^{-5}
13	Orobor N1	250	AXI	206.84	1.1x10^{-5}
14			JFC	379.21	1.25x10^{-5}
15			J3D	482.63	1.1x10^{-5}

[1]All spraying solutions contain the insecticide Engeo Pleno (250 mL 100L^{-1}) except water

The applications for determining the drift in a wind tunnel were carried out using a spraying system with a working principle (pressure control, hydraulic circuit, return) including a spraying system for agricultural machines used in the field. The methodology for collecting and analyzing solutions from the wind tunnel was the same as that described by Moreira Júnior & Antuniassi (2010).

Two spray nozzles with a spacing and height of 0.5 m were used. The spray jets produced by the J3D model were interspersed, with one pointing forward and one backward. Twenty liters of spray solution were prepared for each treatment and a blue gloss marker was added at a concentration of 6 g L^{-1}. The meteorological variables were monitored during the evaluation, using a digital thermo-hygrometer, and measured a temperature of 29.7 ± 2.1 °C and relative air humidity of 61.7 ± 6.0%. The wind speed was 2.0 m s^{-1}, as measured by an anemometer. The drift was quantified by analyzing the marker, collected in 2 mm nylon threads inside the wind tunnel at distances of 5, 10, and 15 m from the spray boom and 0.3, 0.5, 0.7, 0.9, and 1.1 m from the wind tunnel floor.

After spraying, the wires corresponding to each sample were placed inside 0.50 m long PVC tubes, where 25 mL of distilled water was added for washing by means of manual agitation for a constant time of 1 min, and then stored in plastic jars identified according to treatment. The solutions from the samples were analyzed in a spectrophotometer to quantify the absorbance values in the spectral range of 630 nm and to subsequently determine the marker quantities.

The wind tunnel analysis variables were the drifts at 5, 10, and 15 m, in which the sum of the vertical wires (0.3, 0.5, 0.7, 0.9, and 1.1 m) was considered for each horizontal distance.

All data were checked for the normality of errors and homogeneity of variances, using the Shapiro-Wilks ($p > 0.05$) and Bartlett ($p > 0.05$) tests, respectively. When the previous assumptions were not met, they were transformed according to the methodology proposed by Box & Cox (1964).

The data were submitted to analysis of variance, and the means were compared using the Tukey's test ($p < 0.05$). Principal component analysis was also performed to detail and quantify the importance of each variable in the variability of the data. All statistical analyses were performed in R (R Core Team, 2019).

Results and Discussion

There was a significant effect of the interaction between the spray solution and nozzle in the variables VMD, RS, and Drops ≤ 100 (Table 2). These results corroborate those found by Ferreira et al. (2013), who observed that the effect of adjuvants on the droplet spectrum was dependent on the interaction between the product and the spray nozzle used.

Regarding the AXI nozzle, the spraying solutions were not significantly different in terms of VMD. However, for the JFC nozzle, the insecticide and the mixture with the adjuvants decreased the VMD and for the J3D nozzle, the mixture with the adjuvants increased the VMD (Table 3).

Table 2. Summary of analysis of variance of the spray solution and nozzle on the volumetric median diameter (VMD), relative amplitude (RS) and percentage of droplet volume with diameter ≤ 100 μm (Drops ≤ 100)

SV	DF	VMD MS	RS MS	Drops ≤ 100 MS
Spray solution	4	76.7*	0.002	17.23*
Nozzle	2	3947.1*	0.010*	541.57*
Spray solution x Nozzle	8	200.2*	0.013*	30.71*
Residue	30	23.6	0.001	2.75

SV - Sources of variation; DF - degrees of freedom; MS - Mean square; * Significant at $p < 0.05$ by F's test

Table 3. Volumetric median diameter (VMD), relative amplitude (RS) and percentage of droplet volume with diameter ≤ 100 μm (Drops ≤ 100) means in five spray solutions and three nozzles

Spray solution	Nozzle		
	AXI	JFC	J3D
	VMD (μm)		
Water	159.65 aA	131.91 aB	129.58 bB
No adjuvant	165.83 aA	128.99 bB	129.42 bB
Oro-solve	158.89 aA	127.48 bB	153.35 aA
Wetcit Gold	157.91 aA	126.49 bB	151.75 aA
Orobor N1	162.46 aA	128.18 bC	148.55 aB
	RS		
Water	1.19 bC	1.55 aA	1.32 aB
No adjuvant	1.33 abB	1.31 bB	1.50 aA
Oro-solve	1.28 bA	1.24 bA	1.38 aA
Wetcit Gold	1.32 abA	1.29 bB	1.43 aA
Orobor N1	1.49 aA	1.18 bB	1.33 aA
	Drops ≤ 100 (%)		
Water	18.82 aB	30.73 aA	31.78 aA
No adjuvant	17.57 aB	30.50 aA	33.52 aA
Oro-solve	18.86 aC	30.30 aA	23.20 bB
Wetcit Gold	20.25 aC	31.50 aA	23.89 bB
Orobor N1	19.88 aC	30.95 aA	23.78 bB

Means followed by different lowercase letters in the column and uppercase letters in the row, differ by Tukey's test ($p < 0.05$)

For both the water and the insecticides, the AXI nozzle presented the highest VMD. In the mixture with Oro-solve and Wetcit Gold, the AXI and J3D nozzles presented the largest VMD, and Orobor N1 applied with the AXI nozzle obtained the largest VMD, followed by the J3D and JFC nozzles. Although the insecticide and the mixture with adjuvants changed the VMD of the spray droplets, their droplet size class remained 'fine' (100-175 μm), according to standard ASAE (2009).

The result of altering VMD with adjuvants differs from that found by Sasaki et al. (2015), where all tested products decreased VMD. However, the author used only adjuvants in the spraying solutions, without any phytosanitary products. Therefore, it is important to consider that the insecticide itself can interfere with the characteristics of the spray solution in relation to water, as verified in the present study.

Lower VMD values are associated with greater penetration into the canopy (Matthews, 2000), which is highly desirable in the control of brown stink bugs, which are less exposed at the top of the plants. Very low VMD is associated with spray solution losses, both due to drift caused by wind and evaporation before reaching the target (Antuniassi, 2012). Thus, knowing the effect of the interaction of adjuvants with insecticide spray nozzles is important to establish the best application technology in the different available environmental conditions.

The mixture with the adjuvant, Orobor N1, increased the RS when using the AXI nozzle. With the JFC nozzle, there was a decrease in RS, for all solutions, except for the spray solution with water. With the J3D nozzle, there were no differences between the mixtures applied. However, there was a reduction in RS when the insecticide mixtures with the adjuvants Wetcit Gold and Orobor N1 were applied with the JFC nozzle. These results differ from those found by Cunha et al. (2010), where the droplet size RS was not influenced by any of the evaluated factors.

Lower RS values indicate greater droplet homogeneity, which is highly desirable when the VMD has been adequately sized for the needs of the spray. In these smaller conditions, RS provides a greater volume of optimal drops, distributed close to the VMD, with reduced presence of excessively small drops, which are very susceptible to drift, or excessively large, which have a low penetration capacity in the canopy of the soybean crop.

Droplets ≤ 100 μm are considered highly susceptible to drift losses; it is therefore desirable that the droplets of the spectrum in this range are minimal. With the nozzles AXI and JFC, the spraying solutions did not differ from each other. However, with the J3D nozzle, mixing with adjuvants decreased the drops to ≤ 100 μm. With the AXI nozzle, the water and no adjuvant mixtures showed the lowest drop rate of ≤ 100 μm, and the mixture with adjuvants showed a similar behavior between the mixtures, in which the AXI, J3D, and JFC nozzles presented an increasing percentage order of Drops ≤ 100.

There was a significant effect of the interaction between the spray solution and nozzle in the variable drift at 5 m, a simple effect of the spray solution and nozzle in the variable drift at 10 m, and a simple effect of only the spray solution on the variable drift at 15 m (Table 4).

For the AXI nozzle, the insecticide and the mixture of adjuvants decreased the drift to 5 m; however, for the JFC nozzle, the mixture with Wetcit Gold and Orobor N1 increased the drift. For the J3D nozzle, the mixture with Oro-solve and Wetcit Gold decreased the drift. Considering the water, the AXI nozzle showed greater drift, and the addition of the insecticide reversed the behavior, that is, less drift was seen for the AXI nozzle and drift was greater for the other nozzles. With the addition of adjuvants, the JFC nozzle showed greater drift, followed by the J3D and AXI nozzles, except for Wetcit Gold, where the nozzles did not significantly differ (Table 5).

The spray with insecticide, the mixture with the adjuvants, and the AXI nozzle reduced the drift to 10 m; however, the mixture with Orobor N1 did not differ from the application of

Table 4. Summary of analysis of variance of the spray solution and nozzle on the drift at 5 m (Drift 5), drift at 10 m (Drift 10) and drift at 15 m (Drift 15)

SV	DF	Drift 5 MS	Drift 10 MS	Drift 15 MS
Spray solution	4	0.084*	2.45*	7.44*
Nozzle	2	0.181*	0.45*	0.09
Spray solution x Nozzle	8	0.062*	0.05	0.04
Residue	44	0.005	0.04	0.11

SV - Sources of variation; DF - Degrees of freedom; MS - Mean square; * Significant at $p < 0.05$ by F test

Table 5. Drift in a wind tunnel collected at 5 m obtained from in five spray solutions and three nozzles

Spray solution	Nozzle		
	AXI	JFC	J3D
	Drift 5 (μL cm^{-2})		
Water	4.24 aA	2.51 bB	2.51 aB
No adjuvant	2.51 bB	4.06 abA	4.00 aA
Oro-solve	1.40 cC	3.91 abA	1.74 bB
Wetcit Gold	1.84 bB	4.50 aA	1.71 bB
Orobor N1	2.69 bB	4.81 aA	2.80 aAB

Means followed by different lowercase letters in the column and uppercase letters in the row, differ by Tukey's test ($p < 0.05$)

Table 6. Drift in a wind tunnel collected 10 m from the spray solution and nozzle and 15 m from the spray solution

Drift 10 (μL cm^{-2})	
Spray solution	
Water	2.51 a
No adjuvant	1.80 b
Oro-solve	0.79 d
Wetcit Gold	1.23 c
Orobor N1	2.02 b
Nozzle	
AXI	1.45 b
JFC	1.87 a
J3D	1.73 a
Drift 15 (μL cm^{-2})	
Spray solution	
Water	2.51 a
No adjuvant	1.25 b
Oro-solve	0.45 d
Wetcit Gold	0.79 cd
Orobor N1	0.98 bc

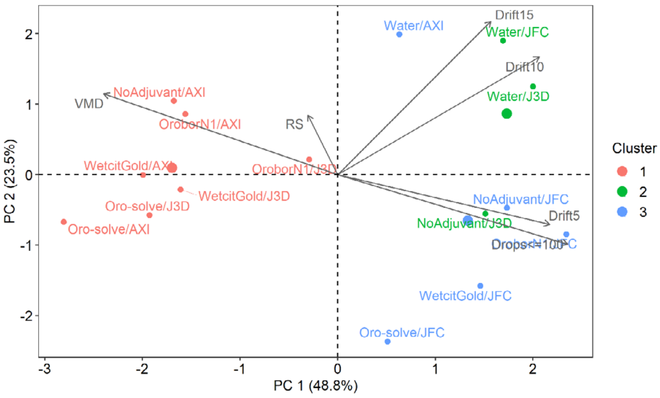
Means followed by different letters differ by Tukey's test ($p < 0.05$)

the insecticide alone (Table 6). A similar behavior was observed in the spraying solutions for the drifts at 10 and 15 m.

Principal component analysis (PCA) was successfully applied to identify clusters in relation to the characteristics of the droplet spectrum with the spray drift. The first two main components were selected, which together explained 72.3% of the total variation (48.8% and 23.5% for Component 1 and Component 2, respectively).

In addition, PCA facilitated the identification of three clusters (Figure 1). The first cluster was characterized by the treatments applied with the AXI and J3D nozzles, while application with the water spray solution formed the second cluster (with the exception of the application of No adjuvant/J3D), and the third cluster represented treatments applied with the JFC nozzle (with the exception of the application of Water/AXI). The treatments applied with the JFC nozzle favored the drift collected at 5 m (Drift 5) and the percentage of drops with a volume ≤ 100 μm (Drops ≤ 100). Meanwhile, those applied with the AXI nozzle were associated with the volumetric median diameter (VMD), while those applied with the water spray were related to the drift collected at 10 m (Drift 10) and at 15 m (Drift 15).

The results of the PCA indicate that the greater the 5 m Drift, the greater the Drops ≤ 100, and the lower the VMD (Figure 1). The drift collected at 10 and 15 m also showed a positive correlation. The results of the relationship between VMD and Drops ≤ 100 corroborate those found by Oliveira & Antuniassi (2012).



VMD - Volumetric median diameter; RS - Relative amplitude; Drops ≤ 100 - Percentage of droplet volume with diameter ≤ 100 μm; Drift 5, 10 and 15 m - Drift in wind tunnel collected at 5, 10 and 15 m distance

Figure 1. Dispersion of treatments and interrelation of the variables based on scores of the two first principal components (PC1 and PC2)

Conclusions

1. The use of the AXI nozzle with all the spray solution, and of the J3D nozzle with the Oro-solve and Wetcit Gold adjuvants provided a greater volumetric median diameter;

2. The JFC nozzle produced greater homogeneity in droplet size for all spray solutions, except water;

3. The AXI nozzle had lower potential risk of drift for all spray solutions;

4. The use of an AXI nozzle with and without adjuvant and the J3D, Oro-solve, and Wetcit Gold adjuvants decreased the drift collected at 5 m;

5. The spray solution with the Oro-solve adjuvant and AXI nozzle reduced the drift to 10 m, and only with the Oro-solve adjuvant decreased the drift to 15 m.

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