

Association between air-assistance and electrically charged droplets on whitefly control in soybean¹

Associação de assistência de ar e carregamento de gotas no controle de mosca-branca na soja

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HIGHLIGHTS:

Electrically charged application-maintained droplet size consistent with conventional spraying.

Surveying whiteflies avoids extra applications, as treatments had no impact on soybean yields compared to the control.

Air assistance and charged droplets preserved the droplet spectrum of hollow cone nozzles.

ABSTRACT: The whitefly has worried producers about crops such as *Glycine max* due to the serious damage they can cause. Air-assisted spraying aims to improve droplet penetration within the crop canopy, while spraying with electrically charged droplets improve coverage of the abaxial leaf surface, where whiteflies predominantly inhabit. The objective of present study was to evaluate the effect of air-assisted spraying and electrically charged droplets on *Bemisia tabaci* control in soybeans, focusing on surface coverage, pesticide deposition, droplet size, and crop yield. The experiment, conducted in a greenhouse during the 2020/21 season, utilized a randomized block design with five treatments: conventional spraying, air-assisted spraying, electrically charged droplets, combined air-assisted and charged droplet spraying, and an untreated control, each with four replicates. Droplet electrification and air assistance did not alter droplet size or increase surface coverage. However, charged droplets and their combination with air assistance improved foliar pesticide deposition compared to conventional spraying. Whitefly nymph numbers were reduced relative to the control. The spraying carried out with the aid of air in association with electrically charged drops in the settings of the sprayers that are used in the productive crops did not change the yield of the soybean and the control of the whitefly concerning the conventional application. As there was no significant positive impact in whitefly control, the use of air assistance and charged droplets can be dispensed with in some situations, reducing production costs without compromising efficacy.

Key words: *Bemisia tabaci*, *Glycine max*, application technology, droplet electrification, air assistance

RESUMO: A mosca-branca preocupa produtores em culturas como soja (*Glycine max*) pelos sérios danos que pode causar. A pulverização assistida de ar melhora a penetração das gotas no dossel da cultura, enquanto gotas eletricamente carregadas ajudam na cobertura da face abaxial da folha, local preferencial do inseto. O objetivo do presente estudo foi avaliar o efeito da pulverização com assistência de ar e gotas carregadas no controle de *Bemisia tabaci* em soja, além de avaliar cobertura superficial, deposição de produtos fitossanitários, tamanho de gotas e produtividade. O experimento foi conduzido em casa de vegetação em Jaboticabal, São Paulo, em 2020/21, em blocos ao acaso, com cinco tratamentos: pulverização convencional, assistência de ar, gotas carregadas, assistência de ar com gotas carregadas e testemunha não tratada, com quatro repetições. A eletrificação das gotas e a assistência de ar não alteraram o tamanho das gotas nem aumentaram a cobertura superficial. No entanto, o carregamento de gotas e a associação com assistência de ar aumentaram o depósito do produto em alguns terços foliares, comparado à pulverização convencional. O número de ninfas de mosca-branca por folíolo foi reduzido nos tratamentos em relação à testemunha. A pulverização com assistência de ar associada a gotas carregadas, nas regulagens utilizadas, não alterou a produtividade da soja nem o controle da mosca-branca em relação à aplicação convencional. Como não houve impacto positivo significativo no controle da mosca-branca, o uso de assistência de ar e gotas carregadas pode ser dispensado em algumas situações, reduzindo os custos de produção sem comprometer a eficácia.

Palavras-chave: *Bemisia tabaci*, *Glycine max*, tecnologia de aplicação, eletrificação de gotas, ar assistido

INTRODUCTION

Brazil leads global soybean (*Glycine max* L. Merrill) production, reaching 147.4 million tons in 2023/2024 (CONAB, 2024). However, pests such as the whitefly (*Bemisia tabaci* (Gennadius, 1889) biotype B; Hemiptera: Aleyrodidae) can reduce yield by up to 70% through sap-sucking, virus transmission, and promoting sooty mold. As one of the most significant phytophagous pests affecting soybeans, whiteflies present challenges in controlling both nymphs and adults (Saleem et al., 2021). Their feeding behavior causes direct damage by extracting phloem sap and indirectly by injecting toxins that disrupt plant development. Effective control is further complicated by their preference for inhabit on the abaxial leaf surface (Mahmood et al., 2022).

Conventional chemical insecticide spraying is the primary method for whitefly control. However, this approach often fails to efficiently deposit active ingredients on the abaxial leaf surface, reducing efficacy and contributing to selecting insecticide-resistant individuals (Mahmood et al., 2022). Spraying with hydraulic spray tips is more commonly used for insecticide applications, although, this type of tip forms uneven droplets with varying sizes and is subject to drift (Hong et al., 2021). Electrifying droplets after their formation through hydraulic energy can enhance deposition by promoting attraction to plant surfaces (Zhou et al., 2024).

Electrically charged droplets, influenced by their mass and charge, can curve toward plant surfaces due to the electric field generated between the charged liquid and the plant (Zhou et al., 2024). This process increases coverage and improves droplet distribution, particularly on the underside of leaves (Martin & Latheef, 2017). Charged sprays increased deposition by two to three times on adaxial and abaxial surfaces of top canopy leaves compared to uncharged sprays (Martin & Latheef, 2017). However, in crops with dense foliage, charged droplets often deposit primarily on the top canopy, leading to poor distribution on the middle and lower thirds.

Air-assisted application technology improves droplet deposition within crop canopies, particularly for plants with a high leaf area index (Dai et al., 2023). By generating an air jet through a fan near the spray boom, air-assisted sprayers can open the crop canopy, directing droplets more precisely to the target. This method reduces drift losses and enhances deposition efficiency on plants with dense foliage (Martin & Latheef, 2017).

Given the potential for air-assisted spraying with electrically charged droplets to improve whitefly control, this study aimed to evaluate its efficacy in managing *B. tabaci* populations.

MATERIAL AND METHODS

The experiments were conducted in a greenhouse in Jaboticabal, São Paulo, Brazil (21° 14' 23" S, 48° 17' 20" W; 583 m altitude) to evaluate whitefly control in soybean using air-assisted spraying and electrically charged droplets. The first experiment was sown on October 15, 2020, and the second, serving as a replicate was sown on October 30, 2020. Plants were irrigated through sprinklers according to crop

requirements (Dimov et al., 2020). During the experiments, mean temperatures and relative humidity were 24.2 °C and 70.3% for the first experiment, and 24.1 °C and 71.3% for the second. Meteorological data were recorded from October 15, 2020, through February 2021, when the experiments concluded.

Soybean plants were cultivated from Pioneer® 95R95IPRO seeds, an early-maturity cultivar with a 105-day average growth cycle and an upright growth habit, reaching up to 95 cm. Seeds were pre-treated with Standak® Top fungicide and insecticide (200 mL of commercial product per 100 kg of seeds; 25 g L⁻¹ Pyraclostrobin, 225 g L⁻¹ Thiophanate Methyl, and 250 g L⁻¹ Fipronil) per label instructions. These treatments are not specifically recommended for whitefly control. Polyethylene pots (5 L capacity) were filled with a 3:1:1 (v v⁻¹) mixture of soil, sand, and organic compost as the substrate. Five seeds were sown per pot, and thinning was performed 30 days after emergence, leaving two plants per pot. Whitefly infestations occurred naturally.

The experimental design was randomized in blocks with four application forms plus a control, as follows: 1) conventional (a common sprayer, just with spray tank, spray bar and spray nozzle); 2) air-assisted spraying; 3) spraying with electrically charged droplets; 4) spraying with electrically charged droplets and air-assistance; and 5) no application (untreated control). The experimental design used was in blocks due to the difference in insect infestation inside the greenhouse. The sprayer wind speed was the same and measured by a digital anemometer GM816 (B-Max®) (6 m s⁻¹). Each experimental plot consisted of five pots with two plants per pot, using four blocks per treatment.

Two applications were carried out per experiment at the same phenological stages of the soybean crop to control the whitefly. These applications were carried out outside the greenhouse, on an agricultural experiment terrace. The first application was carried out at the R1 stage (50 days after emergence), as the suggested level of action for whitefly management is 10 nymphs per leaflet (Bortolotto et al., 2015). The second application was carried out 15 days after the first application, at the R3 stage (65 days after emergence). The second application, performed 15 days later at the R3 stage (65 days after emergence), targeted newly hatched nymphs, and disrupted the pest's reproductive cycle.

The applications were carried out with an air-assisted sprayer and electrically charged droplets, designed by Aldemir Chaim from Embrapa Meio Ambiente in Jaguariúna, São Paulo state, on a quadricycle (Honda® 4 × 4 Fourtrax Fuel Injection) (Figure 1A). A boom containing a Teejet model TXA80015VK spray nozzle at 379.212 kPa and filter 50 mesh, producing fine droplets, was coupled to the sprayer equipped with a 6 kV high voltage source (Figure 1B) and a fan above an air duct that supports the nozzle. To ensure proper overlap of the distribution jets, two passes were made, with the jets intersecting precisely over the plants. The electric charges generated by the high voltage source reach a ring that conducts electric current, which is coupled around the spray tip (induction electrode) (Figure 1C). The droplets were electrically charged as they passed through this ring, while the

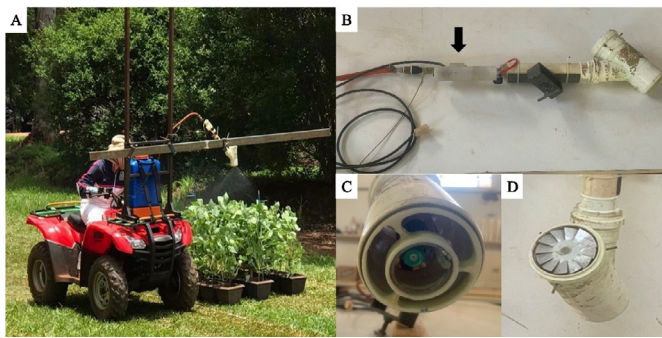


Figure 1. Sprayer mounted on a quadricycle (A); a 6-kV high-voltage source (B), nozzle surrounded by a ring-shaped induction electrode (C), and air-assistance system (D)

fan turned on and directed the droplets to the crop canopy (Figure 1D).

The treatments were applied using the same sprayer, with air assistance and electric droplet charging systems activated or deactivated according to the application technique. For the conventional treatment, both systems were turned off. The charging system was only activated in the charged droplet treatment. For air-assisted spraying, only the fan was operational, while both systems were simultaneously activated for the combined air-assistance and charged droplets treatment. The spray nozzle was maintained at a height of 50 cm above the crop canopy. The nozzle model and pressure settings used are standard in insecticide and fungicide applications by soybean farmers in Brazil and other regions of the Americas.

For equipment configuration, the sprayer is battery-electric (Jacto DJB-20), which activates the motor-pump set (electric motor and membrane pump, JEP-80), whose pressure used was measured during spraying and if kept stable. As for air assistance, it was used for transport and not for the production of drops. The informed fan and the electric charging of drops had a quadricycle battery (12 V) as a source of electrical energy. The air-assistance wind was measured with a digital anemometer for all spray passes of the treatments and it was found to remain constant. The treatments were applied with the

same sprayer. For this, the systems of air-assistance and electric charging of droplets were turned on and off, according to the application technique. In practice, as soon as the charging device was turned on, it was observed that drops changed trajectory and repelled each other due to charging.

Applications were performed with a spray volume of 56 L ha⁻¹ at an application speed of 3.89 m s⁻¹, a speed commonly used by farmers. Meteorological conditions were monitored using a digital thermo-hygrometer and a GM816 digital anemometer (B-Max[®]) (Table 1). The crop protection products applied included the contact and translaminar insecticide pyriproxyfen (Tiger 100 EC, 100 g ai L⁻¹, EC formulation, Sumitomo Chemical do Brasil Representações Ltda.) at a dose of 250 mL ha⁻¹ for controlling whitefly nymphs, and the protective fungicide copper oxychloride (Difere[®], 588 g ai L⁻¹, SC formulation, Oxiquímica Agrociência Ltda.) at a dose of 1.0 L ha⁻¹. In this case, copper oxychloride was used to analyze the plant protection products' deposition after application. This combination of insecticide and fungicide was chosen to reflect common field practices. In the second experiment, approximately 10 mm of rainfall occurred 45 minutes after the first application.

Evaluations conducted during the experiments included surface coverage, droplet size on water-sensitive paper, and plant protection product deposition, all of which were assessed during the first application of each experiment. Additionally, whitefly control and soybean yield were evaluated.

Water-sensitive papers (76 × 26 mm; Syngenta, SYN7626) were used to determine surface coverage and droplet size, while acetate sheets (5 × 2.5 mm, PV Cristal, 0.15 µm) were used to evaluate plant protection product deposition. These materials were placed in the top (TT), middle (MT), and lower (LT) thirds of soybean plants, and affixed to leaves in two pots per experimental plot. Acetate sheets were positioned on both the adaxial and abaxial leaf surfaces for deposition analysis, categorized as total top (TTT), top adaxial (TTA), top abaxial (TTB), total middle (MTT), middle adaxial (MTA), middle

Table 1. Meteorological conditions during application times in both experiments

Experiment	Time (DAE ¹)	Treatment	Application time	Temp. ² (°C)	RH ³ (%)	Wind ⁴ (m s ⁻¹)
First	50	1	8:00 am	27.7	61.5	0.75
		2	8:05 am	28.6	58.8	0.86
		3	8:10 am	29.1	55.0	0.64
		4	8:15 am	30.0	55.0	0.78
		5	-	-	-	-
First	65	1	8:02 am	27.5	72.5	0.94
		2	8:08 am	27.2	71.3	1.39
		3	8:16 am	27.1	72.5	2.22
		4	8:23 am	28.0	70.0	1.83
		5	-	-	-	-
Second	50	1	7:59 am	27.2	74.3	1.00
		2	8:06 am	26.7	77.3	0.36
		3	8:11 am	27.6	75.3	0.61
		4	8:17 am	28.4	71.3	0.45
		5	-	-	-	-
Second	65	1	8:01 am	25.1	66.3	1.11
		2	8:07 am	24.6	67.5	1.39
		3	8:13 am	24.8	69.3	1.19
		4	8:20 am	25.2	68.5	0.69
		5	-	-	-	-

¹DAE - Days after crop emergence; ²Temp. - Air temperature; ³RH - Air relative humidity; ⁴Wind - Wind speed. Treatments: 1 - Conventional; 2 - Air assistance; 3 - Electrically charged droplets; 4 - Air assistance + electrically charged droplets; 5 - Untreated control

abaxial (MTB), total lower (LTT), adaxial lower (LTA), and lower abaxial thirds (LTB).

Water-sensitive papers were placed exclusively on the adaxial leaf surface for surface coverage and droplet size evaluations due to the difficulty of the software in reading droplets with diameters smaller than 80 μm (Salyani et al., 2013), which are sizes that most reach the abaxial surface. The water-sensitive papers were taken to the laboratory immediately after the applications to be digitized by a desktop scanner, enabling the quantification of the percentage of area covered by droplets relative to the total area of the paper and the droplet size, represented by the droplet diameter (μm) wherein 10, 50, and 90% of the sprayed volume was measured and represented by DV0.1, DV0.5, and DV0.9 values using the software Gotas[®] (Chaim et al., 2006).

Water-sensitive papers and acetate sheets were positioned at the same height and orientation across all treatments to align with the central portion of the spray cone. During application, plants were sprayed sequentially in a straight line.

The acetate sheets represented the deposition of plant protection products on leaves, as it was not feasible to separate products reaching the adaxial surface from those reaching the abaxial surface. Copper quantification (Cu^{2+}) from the copper oxychloride ($\text{Cu}_2(\text{OH})_3\text{Cl}$) was performed using the method described by Oliveira & Machado-Neto (2003). An atomic absorption spectrophotometer (Thermo Scientific, iCE 3000 Series) operating at a wavelength of 324.7 nm was used for analysis. Spectrophotometer readings were correlated with the acetate sheet areas to calculate the Cu^{2+} amount, expressed in $\mu\text{g cm}^{-2}$.

Cu^{2+} recovery from transparent acetate sheets was precisely quantified using ion recovery tests conducted before application. Results showed that 92.72% of copper was recovered during laboratory extraction. For comparison purposes, plant protection product deposition results were adjusted to 100% recovery.

Previous monitoring, considered in the experiments, was carried out the day before the first application. Insect nymph counts were performed at 3, 7, 14, 21, and 28 days after the first application (DAFA), with the second application being performed one day after the seventh evaluation. Nymphs were counted per trifoliate leaf in the middle third of all plants using a pocket magnifying glass (20 $\times$ magnification), reaching the number of nymphs per leaflet in soybean plants (Lima & Lara, 2004).

All soybean plants were manually harvested at full maturation (second half of February 2021) from each plot to evaluate yield. Grain production was collected, placed in labeled paper bags, and transported to the laboratory for weighing. Grain moisture content was measured using a G650i grain moisture meter (Gehaka[®]), and the weighing data for each plot were adjusted to a standard moisture level of 13%. Corrected values were then converted into yield (kg ha^{-1}), based on an estimated plant density of 19 plants per meter.

The data were transformed into $\sqrt[3]{(X + K)}$, where X is the data and K = 1, and the model assumptions were evaluated using the Shapiro-Wilk test for normality of errors and the Levene test for homoscedasticity, both at a 5% significance

level. The degrees of freedom were appropriately accounted for in the allocation of errors and the calculation of the test statistics, ensuring that the assumptions of normality and constant variance were statistically validated.

The results of surface coverage, plant protection products deposition, droplet size, and yield were subjected to analysis of variance by the F-test and the treatment means were compared by Tukey's test ($p < 0.05$). Moreover, the number of nymphs per leaflet was submitted to the repeated-measures analysis and two longitudinal factors (application technique and counting in days). The software R Development Core Team was used to perform the statistical analyses (R Core Team, 2023). Statistical packages used nortest, tidyverse, lawstat, ggpubr, gghighlight, skimr, ExpDes.pt and tibble.

RESULTS AND DISCUSSION

Droplet size results are shown in Figure 2A, B, and C for the first experiment and Figure 2D, E, and F for the second experiment. The application techniques did not produce different droplet sizes within each analyzed third for DV0.9, DV0.5, and DV0.1 in the first experiment. The second experiment showed differences only for DV0.9 in the top and lower thirds and DV0.5 in the top, middle, and lower thirds.

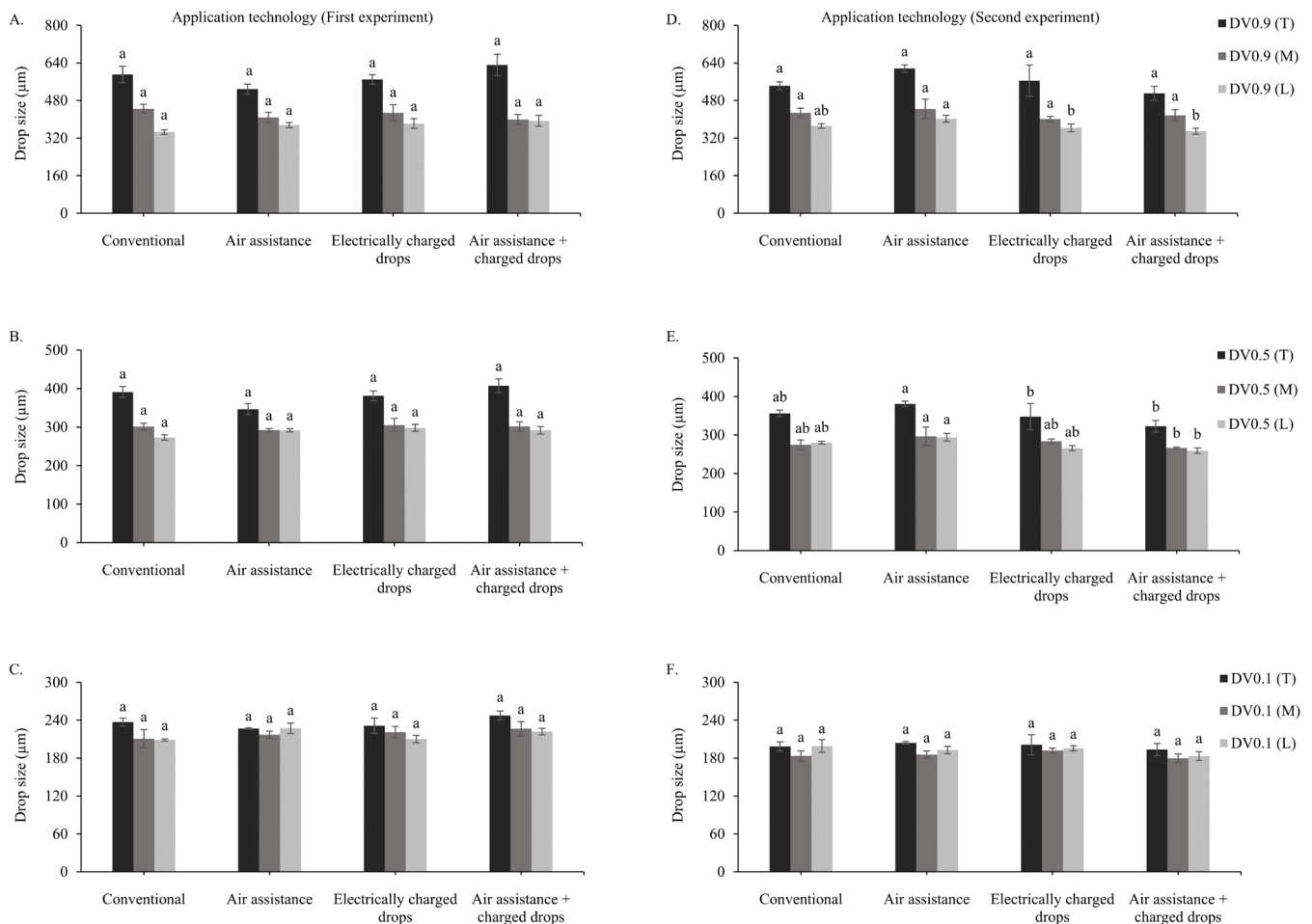
Droplets sprayed in the field stain the water-sensitive papers and may not represent the actual droplet diameter due to the expansion that the spots undergo when they reach the papers (Li et al., 2021). In addition, very small droplets can evaporate on the way to the target and drift, not being deposited on the paper, increasing the difference in droplet diameters observed by this method. Therefore, this droplet analysis was used to compare applications for different field techniques and not to classify droplet size.

The spray droplet spectra (DV0.9, DV0.5, and DV0.1) did not show differences between treatments for the first experiment. Martin & Latheed (2017) observed similar results when using an electrostatic sprayer (on and off) and a rotating nozzle, which did not result in differences in the droplet spectrum. Thus, droplet electrification and adding air-assistance in the spray jet did not change the droplet size with the use of the hydraulic spray tip (TXA80015VK) in the first experiment. Nonetheless, electrification and air-assistance changed droplet spectrum to DV0.9 in the top and lower thirds and DV0.5 in the top, middle, and lower thirds in the second experiment.

The difference present only in the second experiment for some thirds, and volumetric diameters may be due to the light color of small droplets on the paper enhancing the dimension of larger ones, which have a dark center with markedly lighter halos (Li et al., 2021).

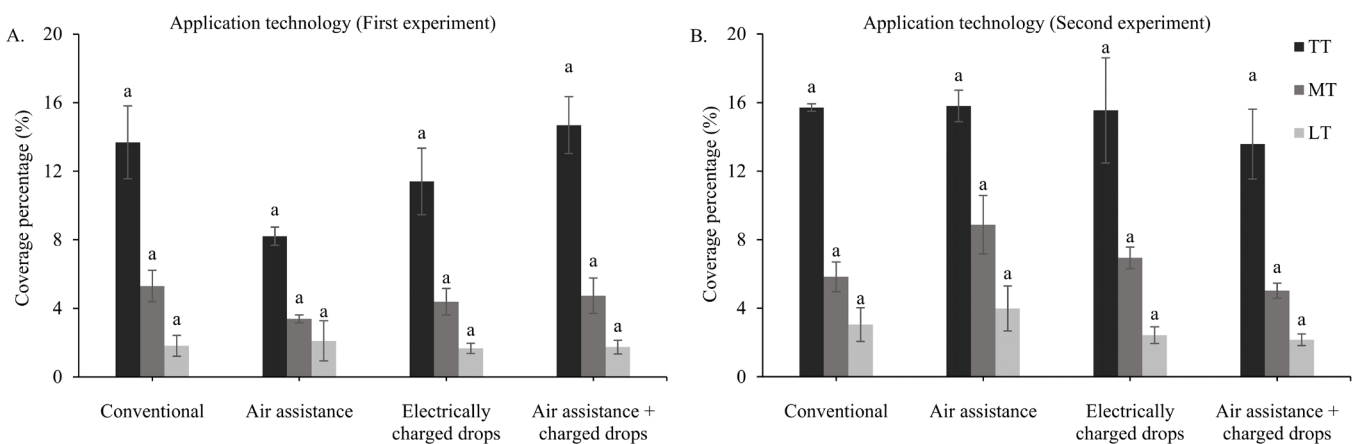
The results of analysis of the percentage of surface coverage on water-sensitive paper are shown in Figure 3A for the first experiment and 3B for the second experiment.

The coverage percentage did not show differences between application techniques for the evaluated plant thirds (top, middle, and lower) in both experiments. The conventional application showed 5.30% coverage in the middle third of plants, reaching 4.74% in the application with air-assistance and electrically charged droplets in the first experiment. In the



*Different lowercase letters indicate differences between treatments with in each evaluated third, represented by colors. Volumetric diameters (DV) vary between graphs. Means followed by different letters differ from each other by Tukey's test at a 5% probability. The mean values are shown with standard error bars indicating the standard error, $n = 200$. Coefficient of variation (%) - DV0.9 in top (T) - 5.38, DV0.9 in middle (M) - 6.09, DV0.9 in lower (L) - 5.06, DV0.5 in top (T) - 3.55, DV0.5 in middle (M) - 3.83, DV0.5 in lower (L) - 2.91, DV0.1 in top (T) - 2.29, DV0.1 in middle (M) - 5.34, DV0.1 in lower (L) - 2.98, for the first experiment. Coefficient of variation (%) - DV0.9 in top (T) - 2.91, DV0.9 in middle (M) - 4.05, DV0.9 in lower (L) - 2.22, DV0.5 in top (T) - 3.77, DV0.5 in middle (M) - 3.19, DV0.5 in lower (L) - 2.68, DV0.1 in top (T) - 3.69, DV0.1 in middle (M) - 2.86, DV0.1 in lower (L) - 3.99, for the second experiment

Figure 2. Droplet size analyzed using Gotas® software based on application technologies in the top, middle, and lower thirds. DV0.9 (A), DV0.5 (B), and DV0.1 (C) for the first experiment; and DV0.9 (D), DV0.5 (E), and DV0.1 (F) for the second experiment



*Different lowercase letters indicate differences between treatments with in each evaluated third, represented by colors. Means followed by different letters differ from each other by Tukey's test at a 5% probability. The mean values are shown with standard error bars indicating the standard error, $n = 200$. Coefficients of variation (%) - Top thirds (TT) - 14.22, Middle thirds (MT) - 14.41, Lower thirds (LT) - 14.89, for the first experiment. Coefficients of variation (%) - Top thirds (TT) - 5.21, Middle thirds (MT) - 12.24, Lower thirds (LT) - 17.20, for the second experiment

Figure 3. Surface coverage percentage based on application technologies in the top, middle, and lower thirds for the first (A) and second (B) experiments

second experiment, the coverage of the air-assisted application was 8.87%, reaching only 5.03% in the air-assisted application plus electrically charged droplets.

Considering the surface coverage required to control whiteflies, which predominantly inhabit the middle third of plants, the current coverage percentage falls below the

recommended threshold for effective insect control, which should average at least 15% (Hong et al., 2021).

The application efficiency requires adequate surface coverage and plant protection product deposition so that the target can be reached in the crop of interest. Fine droplets are more easily carried by wind and more subject to evaporation and, therefore, less safe from an environmental point of view (Hong et al., 2021). On the other hand, they provide higher target coverage, being indicated for fungicide and insecticide applications, especially contact ones, which require higher uniformity of plant protection products distribution for target control.

The application of electrically charged droplets and air assistance can reduce evaporation losses and drift, as charged droplets allow mutual attraction between finer droplets and the plant, including on the abaxial leaf surface, the main site of housing of the whitefly (Zhou et al., 2024). Water-sensitive paper evaluations revealed that although the droplet size was different for some thirds of the plants in the second experiment, they did not result in differences in surface coverage for the evaluated thirds.

Electrically charged droplets are more strongly attracted to the top third of plants, a region that is more exposed to the external environment of the crop canopy. Therefore, droplets need to be conducted inside the canopy (Magno Júnior et al., 2011; Hong et al., 2021). Similarly, to that reported in this study, the average percentages of coverage in citrus cultivation between applications with and without electrically charged droplets did not show differences, and the top third presented the highest coverage (Magno Júnior et al., 2011).

The functionality of using air-assistance depends on the stage of crop development and the wind speed produced by the sprayer. The evaluation of surface coverage was carried out at the reproductive stage (R1) of soybean, a period in which the crop reaches its maximum development and leaf area index (Santos et al., 2019).

Therefore, the non-difference between treatments can be attributed to interception imposed by vegetation cover, resulting from the presence and development of leaflets and crop densification. The fan air speed of 8.06 m s^{-1} improved surface coverage of the middle and lower thirds of soybean plants (Prado et al., 2010), different from what was observed in this study, an air-assistance speed of 6 m s^{-1} did not result in an increase in coverage, since the weather conditions during the application of the treatments were within the recommended range for spraying, they likely did not impact the coverage results.

The results of plant protection products deposition in the first experiment show differences between application techniques only in the middle and lower abaxial thirds (Figure 4A, B, and C). The deposition in the abaxial middle third with conventional spraying had the lowest value ($0.04 \mu\text{g cm}^{-2}$), differing from applications with air-assistance ($0.09 \mu\text{g cm}^{-2}$), electrically charged droplets ($0.12 \mu\text{g cm}^{-2}$), and air-assistance plus electrically charged droplets ($0.09 \mu\text{g cm}^{-2}$). As well as in the abaxial middle third, deposition in the abaxial lower third with conventional spraying had the lowest value ($0.05 \mu\text{g cm}^{-2}$), differing from applications with air-assistance ($0.08 \mu\text{g cm}^{-2}$), electrically charged droplets ($0.16 \mu\text{g cm}^{-2}$), and air-assistance plus electrically charged droplets ($0.11 \mu\text{g cm}^{-2}$).

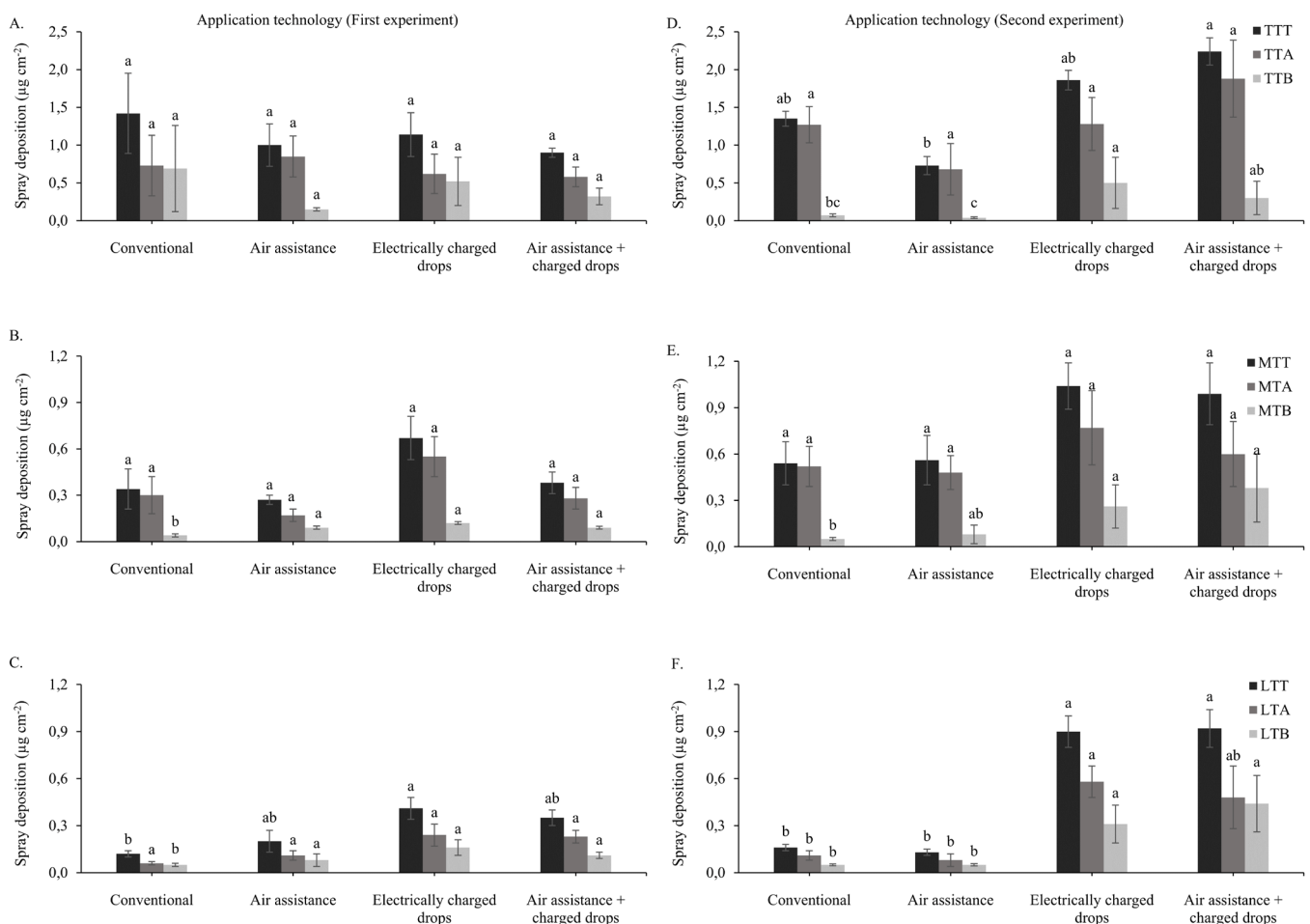
In the second experiment, differences were found in the abaxial top, abaxial middle, total lower, adaxial lower, and abaxial lower thirds (Figure 4D, E, and F). Spraying with charged droplets in the abaxial top third was $0.50 \mu\text{g cm}^{-2}$, not different from spraying with air assistance plus electrically charged droplets ($0.30 \mu\text{g cm}^{-2}$). In addition, air-assisted spraying had the lowest value ($0.04 \mu\text{g cm}^{-2}$), not different from the conventional application ($0.07 \mu\text{g cm}^{-2}$).

Still, in the second experiment, the largest plant protection product depositions in the abaxial middle third were 0.38 and $0.26 \mu\text{g cm}^{-2}$ in applications with air assistance plus charged droplets and electrically charged droplets, respectively. They did not differ from the application with air-assistance ($0.08 \mu\text{g cm}^{-2}$) but were different from the conventional application ($0.02 \mu\text{g cm}^{-2}$) (Figure 4E). Applications in the total lower third with charged droplets ($0.90 \mu\text{g cm}^{-2}$) and air-assistance plus charged droplets ($0.92 \mu\text{g cm}^{-2}$) showed the highest values, differing from the conventional application ($0.12 \mu\text{g cm}^{-2}$) and air-assistance ($0.10 \mu\text{g cm}^{-2}$). The plant protection products deposition in the lower adaxial third was higher with application with charged droplets ($0.58 \mu\text{g cm}^{-2}$), not different from the application with charged droplets plus air-assistance ($0.44 \mu\text{g cm}^{-2}$). In the abaxial lower third, applications with charged droplets ($0.31 \mu\text{g cm}^{-2}$) and air-assistance plus charged droplets ($0.48 \mu\text{g cm}^{-2}$) showed the highest values, differing from the conventional application ($0.01 \mu\text{g cm}^{-2}$) and air-assistance ($0.01 \mu\text{g cm}^{-2}$) (Figure 4F).

Similarly, to this experiment, the deposition analyzed in mature cotton (*Gossypium hirsutum* L.) between the top and lower thirds of the plants and between the adaxial and abaxial surfaces showed differences in the evaluation with the conventional application, air assistance, and electrically charged droplets (Sumner et al., 2000), technologies utilizing charged droplets and charged droplets combined with air assistance demonstrated greater efficiency. These results can be explained by the architecture of soybean, which present high leafiness and densification in the reproductive period, causing the droplets to be gradually deposited from the top to the lower third, that is, higher deposition in the top third and lower in the lower third (Santos et al., 2019; Hong et al., 2021).

Applications with air-assisted speeds of 10 and 15 m s^{-1} did not increase the deposition on leaves compared to conventional spraying. These results were observed without the use of wind in a wind tunnel and the use of artificial cotton and fine droplets ($88 \mu\text{m}$) (Bayat & Bozdogan, 2005). The reason for this could be the high turbulence generated by these air-assistance speeds, causing droplets to drift (Bayat & Bozdogan, 2005).

The differences found in the top, middle, and lower thirds for plant protection product deposition were not found in the evaluation of surface coverage. This difference probably occurred due to the deposition of droplets smaller than $80 \mu\text{m}$, as there is difficulty in reading droplets of this size by software in the coverage analysis (Salyani et al., 2013). Therefore, the determination of which application technique provides the best plant protection product penetration in the middle and lower thirds of the plants should consider the deposition and not only the surface coverage.



*Different lowercase letters indicate differences between treatments with in each evaluated third, represented by colors. Means followed by different letters differ by Tukey's test at a 5% probability. The mean values are shown with standard error bars indicating the standard error, $n = 200$. Coefficients of variation (%) - Top third total (TTT) - 16.79, Top third adaxial (TTA) - 16.57, Top third abaxial (TTB) - 21.41, Middle third total (MTT) - 8.01, Middle third adaxial (MTA) - 8.25, Middle third abaxial (MTB) - 0.98, Lower third total (LTT) - 4.96, Lower third adaxial (LTA) - 4.34, Lower third abaxial (LTB) - 2.48, for the first experiment. Coefficients of variation (%): Top third total (TTT) - 13.59, Top third adaxial (TTA) - 13.61, Top third abaxial (TTB) - 4.44, Middle third total (MTT) - 11.34, Middle third adaxial (MTA) - 9.80, Middle third abaxial (MTB) - 4.38, Lower third total (LTT) - 4.32, Lower third adaxial (LTA) - 4.90, Lower third abaxial (LTB) - 2.83, for the second experiment

Figure 4. Deposition of plant protection products based on application technologies in the total top, top adaxial, top abaxial, total middle, middle adaxial, middle abaxial, total lower, lower adaxial, and lower abaxial thirds for the first (A, B, C) and second experiments (D, E, F)

Furthermore, differences and variations in values, even if not significant, indicate the potential of using charged droplets and air-assistance associated with charged droplets, which can increase the plant protection products deposition, especially in the abaxial leaf surfaces of the thirds. Thus, fans that provide higher wind speed and tips that form finer droplets are recommended for this purpose compared to those used in this study.

The evolution of the whitefly nymph population is shown in Table 2 for the first experiment and Table 3 for the second

experiment. The repeated-measures analysis of the number of whitefly nymphs per leaflet showed that the interaction between treatment and day was significant ($p < 0.001$) for both experiments. The previous evaluation (1 before) showed no difference between treatments, indicating that the infestation was uniform before applications in both experiments.

In the first experiment, the control population started reducing from 3 DAFA, but this reduction was only significant after 21 DAFA (Table 2). The population in treatments with conventional application and air-assistance significantly

Table 2. Number of *Bemisia tabaci* nymphs per soybean leaflet over time for each application technology in the first experiment

Treatments	Days after the first application (DAFA)					
	1 Before ¹	3	7	14	21	28
Untreated	8.7 ± 2.02 Aa*	9.4 ± 1.14 Aa*	8.9 ± 2.03 Aa*	7.7 ± 1.37 Aa*	5.6 ± 0.75 Aa*	3.1 ± 0.28 Ab*
Conventional	9.6 ± 0.72 Aa	7.4 ± 0.85 ABab	6.3 ± 0.83 ABb	3.4 ± 0.56 Bc	2.5 ± 0.32 Bcd	1.4 ± 0.15 Ad
Air-assisted	9.7 ± 1.05 Aa	7.1 ± 0.58 ABab	6.0 ± 0.58 Bbc	4.5 ± 0.54 Bcd	2.6 ± 0.19 Bde	1.6 ± 0.28 Ae
Electrically charged droplets	8.8 ± 0.99 Aa	6.2 ± 0.97 Bb	5.6 ± 0.72 Bbc	4.0 ± 0.54 Bcd	2.9 ± 0.62 Bd	1.7 ± 0.45 Ae
Air-assisted + charged droplets	8.1 ± 1.12 Aa	5.5 ± 0.75 Bb	4.4 ± 0.49 Bbc	3.2 ± 0.51 Bc	2.3 ± 0.14 Bc	1.2 ± 0.15 Ad
CV (%)	6.85	9.20	8.82	11.73	9.31	8.61

*Means followed by different uppercase letters, corresponding to the different applications in the columns, and different lowercase letters, corresponding to the days in the rows, differ according to Tukey's test at a 5% probability. The standard error follows means, $n = 200$. C.V. - Coefficient of variation; 1Before - One day before the first application

Table 3. Number of *Bemisia tabaci* nymphs per soybean leaflet over time for each application technology in the second experiment

Treatments	Days after the first application (DAFA)					
	1 Before ¹	3	7	14	21	28
Untreated	11.5 ± 1.58 Aab*	13.7 ± 1.11 Aa*	13.0 ± 0.40 Aab*	11.2 ± 0.45 Aab*	9.4 ± 0.57 Ab*	6.2 ± 0.16 Ac*
Conventional	10.0 ± 1.75 Aa	10.5 ± 1.53 Ba	9.5 ± 1.12 Bab	7.2 ± 1.16 Bb	5.6 ± 0.48 Bbc	3.6 ± 0.08 Bc
Air-assisted	11.1 ± 0.95 Aa	10.6 ± 1.18 Ba	10.1 ± 0.77 ABa	6.7 ± 0.49 Bb	5.5 ± 0.68 Bbc	3.4 ± 0.22 Bc
Electrically charged droplets	11.7 ± 1.33 Aa	10.3 ± 1.08 Ba	10.5 ± 0.85 ABa	6.6 ± 0.42 Bb	5.4 ± 0.46 Bbc	3.3 ± 0.33 Bc
Air-assisted + charged droplets	12.0 ± 2.38 Aa	10.4 ± 1.85 Ba	9.6 ± 1.20 Ba	6.3 ± 0.83 Bb	5.3 ± 0.75 Bc	3.3 ± 0.36 Bc
CV (%)	6.17	5.95	8.38	5.61	9.31	4.73

*Means followed by different uppercase letters, corresponding to the different applications in the columns, and different lowercase letters, corresponding to the days in the rows, differ according to Tukey's test at a 5% probability. The standard error follows means, n = 200. C.V. - Coefficient of variation; 1 Before - One day before the first application

reduced with first application only from 7 DAFA onwards, and population between 3 and 7 DAFA did not differ from each other. The population reduced significantly after the evaluation at 7 DAFA, and only evaluation between 14 and 21 DAFA was not different. Applications with electrically charged droplets and with air-assistance plus charged droplets reduced the nymph population significantly in the first evaluation (3 DAFA) after the first application, while the population between 3 and 7 DAFA showed no differences. After the second application and 7 DAFA, the populations significantly reduced for these treatments, and only the evaluation between 14 and 21 DAFA showed no difference.

In the second experiment, the number of nymphs per leaves in the control of the previous evaluation to evaluate 3 DAFA increased significantly, reduced subtly until 21 DAFA, and then considerably reduced until 28 DAFA (Table 3). The behavior of the conventional, air-assisted, charged droplet and air-assisted + charged droplet applications were like the corresponding treatments of the first experiment. The comparison between treatments for each day evaluated in the first experiment showed that the control did not differ from conventional and air-assisted applications at 3 DAFA but differed from charged droplets and charged droplets plus air assistance. Furthermore, conventional application and air-assistance did not differ from charged droplets and air-assistance plus charged droplets, as observed in the evaluation carried out at 7 DAFA.

In the second experiment, the evaluation of 3 DAFA showed that the conventional and air-assisted treatments did not differ from the control and neither from the charged droplets and charged droplets plus air-assistance, but these last two treatments differed from the control. In the evaluation carried out at 7 DAFA, the control did not differ from air-assistance and charged droplet, being different from the conventional application and charged droplets plus air-assistance, while these last two showed no differences compared to the conventional application and charged droplets plus air-assistance.

Comparisons between treatments for each evaluated day were similar in some cases in both experiments. The experiments had similar behavior in the evaluations at 14 and 21 DAFA, with the treated plots being different compared to the control. In the last evaluation (28 DAFA), the treatments did not differ from each other, including the control. The air assistance showed no differences compared to the control treatments, and air assistance showed no differences compared to the control treatments at 3 DAFA. On the other hand, charged droplets and charged droplets plus air assistance

were different from the control but not different from the conventional application and air assistance. Moreover, the treatments differed from the control at 7 DAFA. However, the treatments air-assistance and charged droplets were not different from the control in the second experiment at DAFA, with no difference between treated plots.

The number of whitefly nymphs between 3 and 21 DAFA was lower for electrically charged droplets with air assistance, indicating that, although not significantly different from other treatments, this application demonstrates faster effectiveness.

The insect cycle (egg to adult) lasted approximately 22.3 days in the tomato (*Solanum lycopersicum* L.) crop under conditions of 65% relative humidity and a temperature of 25 °C (Aregbesola et al., 2020). A similar result found in the present study, in which a natural whitefly reduction was observed in soybean from the first evaluation until the last counting day (28 DAFA).

For assessments between 3 and 7 DAFA and between 14 and 21 DAFA, not significantly, populations were subtly reduced. These results may be due to the hatching of eggs, which, before this process, were found in the upper abaxial third of the leaves, and with the development of the crop, when they hatched, they went to the abaxial middle third, with the whitefly eggs at a temperature of 24 °C can hatch for 7 days, corresponding to the soybean growth period, so depending on environmental conditions this time may vary (Yang et al., 2010; Schwartz & Singhi, 2013).

Rainfall occurrence can affect the quantity and action of the products deposited on the leaves through dilution, redistribution, and physical removal from the plant surface (Adil et al., 2023), directly influencing the effectiveness of the application of plant protection products (Venugopal et al., 2021; Ayilara et al., 2023). Decaro et al. (2016) evaluated the effect of artificial rainfall after application of products and found that 10 mm at time intervals of 1, 6, 12, and 24 hours after application were sufficient to reduce the amount of deposited plant protection products compared to the control (no rainfall). These studies possibly explain the non-significant occurrence of nymph reduction between evaluations at 3 and 7 DAFA in the second experiment since a 10 mm rainfall was observed 45 min after application.

The product used in this study has pyriproxyfen as an active ingredient, with the characteristic of not being a shock insecticide, as its action in the reduction and control of eggs and nymphs occurs throughout plant development (Fernandes et al., 2017). Nymph evaluations for each time between

treatments showed that the values for the treated plots were only different from the control after 14 DAFA. Sparks & Nauen (2015) reported that this product causes disturbances in the hormonal balance. That is, it would affect the longevity of this insect in young forms, in addition to affecting effects on the cycle such as fecundity causing various disorders during reproduction.

Considering insect control, the reduced rate of control may be related to several factors, including low insect infestation, equipment adjustment and calibration, and even plant protection products. From this, it can be inferred that more sustainable measures can be taken for phytosanitary treatments, including crop monitoring, sprayer adjustments, and the choice of more effective pest control products (Adil, et al 2023).

Yield results are shown in Figures 5A and B for the first and second experiments, respectively. Soybean yield showed no difference between application techniques and the control, with values ranging from 3900 to 5200 kg ha⁻¹.

In general, the yield of the second experiment was lower than that of the first experiment. The application with air-assistance plus electrically charged droplets led to a yield of 4936 kg ha⁻¹ for the first experiment and 4092 kg ha⁻¹ in the second experiment, which means an approximate reduction of 850 kg ha⁻¹. A similar reduction was observed for the other treatments, possibly due to the climate more favorable for its development, since the first experiment was sown 15 days before the second experiment (Webster, et al 2022).

The highest occurrence of *B. tabaci* for the cultivar P98R31 occurred at the soybean reproductive stage R3 and in the treatment without insecticide application, and the whitefly infestation naturally decreased from R3 to R6 even where there was no phytosanitary treatment (Vieira et al., 2013). The highest number of nymphs for the cultivar used in this study was found between the R1 and R2 stages, and the insect infestation naturally decreased between R4 and R5. Furthermore, soybean plants did not present symptoms of stem necrosis or sooty mold in this work, which are commonly associated with whitefly infestations due to direct feeding damage and the deposition of honeydew that promotes fungal growth (Saleem et al., 2021).

The study of soybean yield as a function of different times of whitefly control indicates that the use of insecticides to control is avoided when the number of nymphs per leaflet is less than 40 for the cultivar P98R31 (Vieira et al., 2013). The non-occurrence of yield differences in this study between treatments may be associated with low whitefly infestation in the crop, as there was a similarity in yield between the untreated control and treatment with the application when the plants reached 40 nymphs per leaflet. Natural population reduction and meteorological factors may also be associated with a lack of significance between treatments (Vieira et al., 2013).

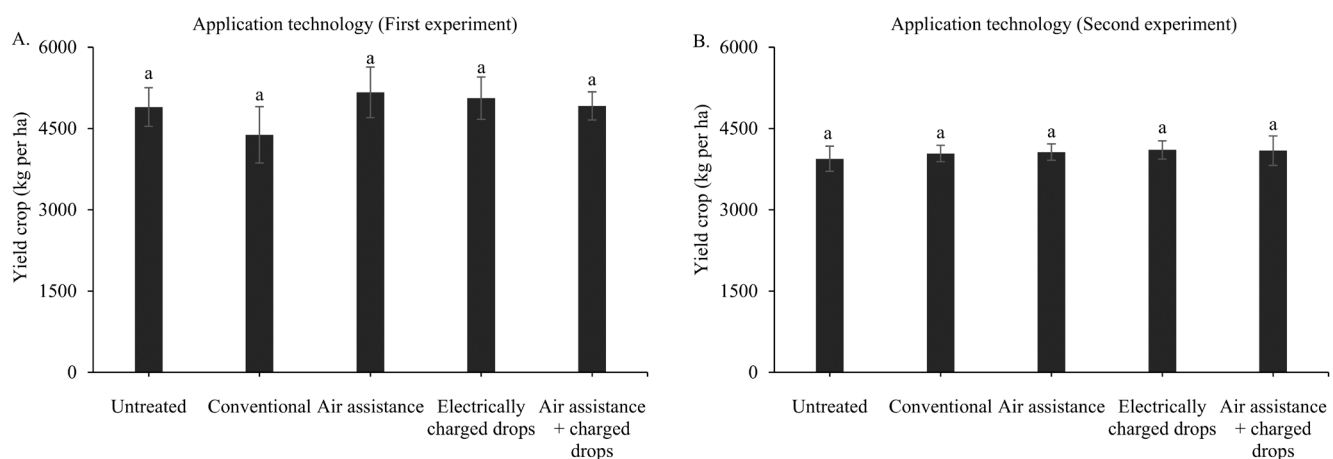
Furthermore, the presence of white mold (*Sclerotinia sclerotiorum*) was observed in the experiments, mainly in the second experiment, which was sown 15 days after the first experiment. The fungus that causes white mold can cause losses of up to 100% in some crops, in Brazil, there are reports that this fungus has reduced soybean yield by up to 30% (Webster et al., 2022; Adil et al., 2023).

Yield reduction in the second experiment may be due to the higher presence of white mold compared to the first experiment. In the period between the beginning of flowering and the end of pod formation, the temperature was close to 23 °C and relative humidity 80%, so the pathogen is favored in mild temperatures (18 to 23 °C) and high humidity, conditions that favor the vulnerability of soybean to infection by *S. sclerotiorum* (Fontes et al., 2023).

Comprehensive crop monitoring, combined with proper management and consideration of meteorological conditions, can optimize application timing, and reduce unnecessary treatments, preventing yield losses from phytosanitary issues (Adil et al., 2023).

CONCLUSIONS

1. Spraying performed with air assistance in association with electrically charged droplets under the sprayer settings used in productive crop applications did not change soybean yield and whitefly control compared to the conventional application.



*Lowercase letters compare differences between treatments. Means followed by different letters differ from each other by Tukey's test at a 5% probability. The mean values are shown with standard error bars indicating the standard error, n = 200. Coefficients of variation (%): A = 5.80, for the first experiment and B = 4.00 for the second experiment

Figure 5. Soybean yields based on application technologies used for *Bemisia tabaci* control for the first (A) and second (B) experiments

2. As there was no significant positive impact in whitefly control, the use of air assistance and charged droplets can be dispensed in some situations, reducing production costs without compromising efficacy.

3. Strategies such as using smaller droplets, increasing air-assisted wind speeds, testing under higher whitefly infestations, and employing artificial insect infestations could enhance the evaluation of treatments for insect control.

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LITERATURE CITED

- Adil, M.; Abbas, G.; Khan, R. N.; Abbas, F. Impact of climate change on environmental fate and ecological effects of pesticides. In: Bandh, S.A. (eds.). *Strategizing agricultural management for climate change mitigation and adaptation*. Cham: Springer. 2023. Cap.15, p.247-263. https://doi.org/10.1007/978-3-031-32789-6_15
- Aregbesola, O. Z.; Legg, J. P.; Lund, O. S.; Sigsgaard, L.; Sporleder, M.; Carhuapoma, P.; Rapisarda, C. Life history and temperature-dependence of cassava-colonising populations of *Bemisia tabaci*. *Journal of Pest Science*, v.93, p.1225-1241, 2020. <https://doi.org/10.1007/s10340-020-01249-z>
- Ayilara, M. S.; Adeleke, B. S.; Akinola, S. A.; Fayose, C. A.; Adeyemi, U. T.; Gbadegesin, L. A.; Omole, R. K.; Johnson, R. M.; Uthman, Q. O.; Babalola, O. O. Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. *Frontiers Microbiology*, v.14, e1040901, 2023. <https://doi.org/10.3389/fmicb.2023.1040901>
- Bayat, A.; Bozdogan, N. Y. An air-assisted spinning disc nozzle and its performance on spray deposition and reduction of drift potential. *Crop Protection*, v.24, p.951-960, 2005. <https://doi.org/10.1016/j.cropro.2005.01.015>
- Bortolotto, O. C.; Pomari-Fernandes, A.; Bueno, R. C. O. F.; Bueno, A. F.; Kruz, Y. K. S.; Queiroz, A. P.; Sanzovo, A.; Ferreira, R. B. The use of soybean integrated pest management in Brazil: a review. *Agronomy Science and Biotechnology*, v.1, p.25-32, 2015. <https://doi.org/10.33158/ASB.2015v1i1p25>
- Chaim, A.; Camargo, J. N.; Pessoa, M. C. P. Y. Uso do programa computacional Gotas para avaliação da deposição de pulverização aérea sob diferentes condições climáticas. Jaguariúna: Embrapa Meio Ambiente, 2006. Available on: < <https://www.infoteca.cnptia.embrapa.br/infotec/doc/15921/1/boletim39.pdf> >. Accessed on: Mar. 2023.
- CONAB – Companhia Nacional de Abastecimento. Acompanhamento de Safra de Grãos – Safra 2023/24. Acompanhamento da Safra Brasileira, 12º levantamento, p.74-87, 2024.
- Dai, S.; Ou, M.; Du, W.; Yang X.; Dong, X.; Jiang, L.; Zhang, T.; Ding, S.; Jia, W. Effects of sprayer speed, spray distance, and nozzle arrangement angle on low-flow air-assisted spray deposition. *Frontiers in Plant Science* v.14, e1184244, 2023. <https://doi.org/10.3389/fpls.2023.1184244>
- Decaro, R. A.; Decaro Júnior, S. T.; Ferreira, M. D. C. Deposit of pesticides without and with adjuvants on citrus seedlings following different intervals of artificial rain. *Ciência Rural*, v.46, p.13-19, 2016. <http://dx.doi.org/10.1590/0103-8478cr20150064>
- Dimov, K.; Matev, A.; Meranzova, R.; Hristova, N. Influence of the irrigation method on the soybean productivity. *Scientific Papers. Series A. Agronomy*, v.63, p.255-262, 2020.
- Fernandes, W. C.; Oliveira, R. C. M.; Pastori, P. L.; Pereira, F. P.; Godoy, M. S. Avaliação de inseticidas para o controle de tripes *Frankliniella* spp. em roseira. *Revista Agropecuária Técnica*, v.1, p.34-40, 2017. <https://doi.org/10.25066/agrotec.v38i1.32326>
- Fontes, B. A.; Rodrigues, F. C. T.; Picanço, B. B. M.; Silva, L. C.; Silva, B. N.; Einhardt, A. M.; Rodrigues, F. A. Nickel potentiates soybean resistance against *Sclerotinia sclerotiorum* infection. *Tropical Plant Pathology*, v.49, p.193-208, 2023. <https://doi.org/10.1007/s40858-023-00620-6>
- Gennadius, P. Disease of tobacco plantations in Trikonía: the aleurodid of tobacco. *Ellenike Georgia*, v.5, p.1-3, 1889.
- Hong, S. W.; Park, J.; Jeong, H.; Lee, S.; Choi, L.; Zhao, L.; Zhu, H. Fluid dynamic approaches for prediction of spray drift from ground pesticide applications: A Review. *Agronomy*, v.11, e1182, 2021. <https://doi.org/10.3390/agronomy11061182>
- Li, L. L.; Zhang, R. R.; Chen, L. P.; Yi, T. C.; Xu, G.; Xue, D. X.; Tang, Q.; Hewitt, A. J.; An, Y. Development of sensor system for real-time measurement of droplet deposition of agricultural sprayers. *International Journal of Agricultural and Biological Engineering*, v.14, p.19-26, 2021. <https://doi.org/10.25165/ijabe.20211405.5528>
- Lima, A. C. S.; Lara, F. M. Resistência de genótipos de soja à mosca Branca *Bemisia tabaci* (Genn.) biótipo B (Hemiptera: Aleyrodidae). *Neotropical Entomology*, v.33, p.071-075, 2004. <https://doi.org/10.1590/S1519-566X2004000100013>
- Magno Júnior, R. G.; Teixeira, M. M.; Vieira, L. B.; Ferreira, L. R.; Alvarenga, C. B. Desenvolvimento de um dispositivo eletrônico para atração de gotas da aplicação eletrostática em plantas cítricas. *Bioscience Journal*, v.27, p.798-804, 2011. <https://doi.org/10.14393/BJ-v27n5a2011-11647>

- Mahmood, M. A.; Ahmed, N.; Hussain, S.; Muntaha, S. T.; Amin, I.; Mansoor, S. Dominance of Asia II 1 species of *Bemisia tabaci* in Pakistan and beyond. *Scientific Reports*, v.12, e01528, 2022. <https://doi.org/10.1038/s41598-022-05612-1>
- Martin, D. E.; Latheef, M. A. Aerial electrostatic spray deposition and canopy penetration in cotton. *Journal of Electrostatics*, v.90, p.38-44, 2017. <http://dx.doi.org/10.1016/j.elstat.2017.08.005>
- Oliveira, M. L.; Machado-Neto, J. G. Use of manganese as tracer in the determination of respiratory exposure and relative importance of exposure routes in the safety of pesticide applicators in citrus orchards. *Bulletin of Environmental Contamination and Toxicology*, v.70, p.415-421, 2003. <https://doi.org/10.1007/s00128-003-0002-8>
- Prado, E. P.; Raetano, C. G.; Aguiar Júnior, H. O.; Pogetto, M. H. F. A. D.; Christovam, R. S.; Gimenes, M. J.; Araújo, D. Effect of the air speed in sleeve boom on pesticide spray deposition, severity and soybean crop yield. *Summa Phytopathologica*, v.36 p.45-50, 2010. <https://doi.org/10.1590/S0103-90162010000100029>
- R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2023. Available on: < <https://www.r-project.org/> >. Accessed on: Jun. 2023.
- Saleem, M.; Hasan, M.; Sagheer, M.; Atiq, M. Determination of insecticide resistance in *Bemisia tabaci* (Hemiptera: Aleyrodidae) populations from Punjab, Pakistan. *International Journal of Tropical Insect Science*, v.41, p.1799-1808, 2021. <http://doi.org/10.1007/s42690-020-00340-6>
- Salyani, M.; Zhu, H.; Sweeb, R. D.; Pai, N. Assessment of spray distribution with water-sensitive paper. *Agricultural Engineering International*, v.15, p.101-111, 2013. <https://doi.org/10.3965/j.ijabe.20160903.2310>
- Santos, E. R.; Spehar, C. R.; Pereira, P. R.; Capone, A.; Barros, H. B. Parâmetros genéticos e avaliação agrônômica em progênies F2 de soja no Distrito Federal, Brasil. *Revista Brasileira de Ciências Agrárias*, v.14, p.1-8, 2019. <https://doi.org/10.5039/agraria.v14i1a5625>
- Schwartz, H. F.; Singh, S. P. Breeding common bean for resistance to white mold: A review. *Crop Science*, v.53, p.1832-1844, 2013. <https://doi.org/10.2135/cropsci2013.02.0081>
- Sparks, T. C.; Nauen, R. IRAC: Mode of action classification and insecticide resistance management. *Pesticide Biochemistry and Physiology*, v.121, p.122-128, 2015. <https://doi.org/10.1016/j.pestbp.2014.11.014>
- Sumner, H. R.; Herzog, G. A.; Sumner, P. E.; Bader, M.; Mullinix, B. G. Chemical application equipment for improved deposition in cotton. *The Journal of Cotton Science*, v.4, p.19-27, 2000. <https://doi.org/10.3965/j.ijabe.20160904.1938>
- Venugopal, D.; Karunamoorthy, P.; Beerappa, R.; Sharma, D.; Aambikapathy, M.; Rajasekar, K.; Gaikwad, A.; Kondhalkar, S. Evaluation of work place pesticide concentration and health complaints among women workers in tea plantation, Southern India. *Journal Exposure Science & Environmental Epidemiology*, v.31, p.560-570, 2021. <https://doi.org/10.1038/s41370-020-00284-3>
- Vieira, S. S.; Bueno, R. C. O. F.; Bueno, A. F.; Boff, M. I. C.; Gobbi, A. L. Different timing of whitefly control and soybean yield. *Ciência Rural*, v.43 p.247-253, 2013. <https://doi.org/10.1590/S0103-84782013000200009>
- Webster, R. W.; Roth, M. G.; Mueller, B. D.; Mueller, D. S.; Chilvers, M. I.; Willbur, J. F.; Mourtzinis, S.; Conley, S. P.; Smith, D. L. Integration of row spacing, seeding rates, and fungicide applications for control of *Sclerotinia* stem rot in *Glycine max*. *Plant Disease*, v.106, p.1183-1191, 2022. <https://doi.org/10.1094/PDIS-09-21-1931-RE>
- Yang, N. W.; Li, A. L.; Wan, F. H.; Liu, W. X.; Johnson, D. Effects of plant essential oils on immature and adult sweet potato whitefly, *Bemisia tabaci* biotype B. *Crop Protection*, v.29, p.1200-1207, 2010. <https://doi.org/10.1016/j.cropro.2010.06.019>
- Zhou, H.; Ou, M.; Dong, X.; Zhou, W.; Dai, S.; Jia, W. Spraying performance and deposition characteristics of an improved air-assisted nozzle with induction charging. *Frontiers in Plant Science*, v.15, e1309088, 2024. <https://doi.org/10.3389/fpls.2024.1309088>