agrochemicals

Article

Air Assistance and Electrostatic Spraying in Soybean Crops

Mariana Rodrigues Bueno [1], Guilherme Sousa Alves [2,*], Sérgio Macedo Silva [1], Tiago Seiji S. Hachiya [3], Hasle Thiago S. Guimarães [1], Gustavo Araújo Costa [1], Felipe Soares Gonçalves [1] and Mateus A. V. G. Oliveira [4]

1 Campus Unai, Agronomy Department, Federal University of Jequitinhonha and Mucuri Valleys (FUJMV), Unai 38610-000, Brazil; mariana.bueno@ufvjm.edu.br (M.R.B.); sergio.macedo@ufvjm.edu.br (S.M.S.); thiago.guimaraes@ufvjm.edu.br (H.T.S.G.); gustavo.araujo@ufvjm.edu.br (G.A.C.); felipe.goncalves@ufvjm.edu.br (F.S.G.)
2 Jacto Agricultural Machineries, Pompeia 17580-018, Brazil
3 Bela Vista Farm, Unai 38610-000, Brazil; tiago.hachiya@ufvjm.edu.br
4 Bayer CropScience, Unai 38610-069, Brazil; mateus.vitorino@bayer.com
* Correspondence: guilherme.alves@jacto.com.br

Abstract: This study aimed to evaluate the efficiency of air assistance associated with electrostatic spraying in terms of spray deposition and yield (Experiment 1), and the coverage and droplet density on soybean crops at different working speeds (Experiment 2). The treatments in Experiment 1 corresponded to combinations of electrostatic systems associated with air assistance at three airspeeds (21, 25, and 30 m·s^{-1}) plus a conventional treatment without electrostatic or air assistance. The treatments in Experiment 2 corresponded to three working speeds (3.3, 4.2, and 5.0 m·s^{-1}) with or without the use of an electrostatic system. All applications were performed with a self-propelled sprayer, delivering 75 L·ha^{-1} with ATR 2.0 nozzles. A blue tracer, detectable as absorbance with a spectrophotometer, was added to the spray solution to evaluate deposition. The results indicate that an air assistance at 21 m·s^{-1} plus electrostatic system increased the amount of spray deposited on the middle and top leaves of the plants in relation to the conventional system, with yield increments of up to 621 kg·ha^{-1}. The slowest working speed (3.3 m·s^{-1}) combined with air assistance and an electrostatic system provided the greatest spray deposition, droplet coverage, and density on the bottom leaves of soybean crops.

Keywords: spray deposition; coverage; droplet density; *Glycine max* L. Merril; yield

Citation: Bueno, M.R.; Sousa Alves, G.; Silva, S.M.; Hachiya, T.S.S.; Guimarães, H.T.S.; Costa, G.A.; Gonçalves, F.S.; Oliveira, M.A.V.G. Air Assistance and Electrostatic Spraying in Soybean Crops. *Agrochemicals* **2024**, 3, 107–117. https://doi.org/10.3390/agrochemicals3020009

Academic Editor: Árpád Ámbrus

Received: 15 December 2023
Revised: 4 February 2024
Accepted: 19 February 2024
Published: 24 March 2024

1. Introduction

Soybean (*Glycine max* L. Merril) is one of the most important crops grown in Brazil and around the world. Its importance is due to the significant flexibility in its uses, which include human and animal food, bioenergy such as biodiesel production, pharmacological purposes [1,2], and tire production for the automobile industry [3–5]. In 2022/2023 Brazil continued to rank highest worldwide in terms of production and exportation, with a record 156 million tons of soybean grain cultivated across 44 million hectares of land. These results were due to favorable weather conditions occurring in the strongest producing regions and the improved technology utilized by Brazilian farmers in recent years [6,7]. While these technologies aim to provide more meaningful results in terms of production and yield, adequate crop management is especially important and involves correct selection of pesticide and efficient application methods.

Multiple factors affect pesticide application, including the crop and its growth stage, equipment (machinery), and the environmental conditions during the application. A lack of technical knowledge regarding the product and the application technology can cause the indiscriminate use of these products, resulting in consequences such as crop injury and environmental contamination [8]. Different technologies have been developed to help farmers conduct more efficient applications, with lower losses and costs. Examples of these technologies include the use of air assistance [9], and the addition of an electrostatic charge to the sprayed droplets [10,11].

Air assistance in the spray boom consists of using a continuous air flow to assist in the distribution and deposition of spray in the crop canopy [12]. Once activated, the fans inflate a canvas tarp that distributes air evenly throughout the spray boom [13]. This system provides advantages such as uniformity of spray distribution, drift potential reduction, and improvements in spray deposition, especially on the lower leaves of crops [14,15]. The electrostatic system consists of adding electrical charges to the droplets, with the aim of assisting the movement of those droplets and their adhesion onto the leaves [11,16]. The effects of these technologies have been studied using different equipment such as backpack sprayers [11,17], agricultural aircraft [18], pneumatic sprayers [19], and hydraulic sprayers [20].

As an attempt to unify the two technologies, a self-propelled (EletroVortex®, Jacto, Pompeia, São Paulo State, Brazil) system was launched in 2019. The sprayer provides improvements to the conduction of droplets to the biological target and aims to increase efficiency by reducing the application rate and increasing the working speed without compromising the quality of the application. According to the manufacturer, the technology provides better pesticide spray deposition onto target, which increases pest and disease control [21,22]. In Brazil, these sprayers have been used in the application of insecticides and fungicides to row crops such as soybeans, corn, wheat, and cotton. However, little information is available in the literature that shows scientific results regarding this technology.

The global demand for higher soybean yields, the constant attack of insects and diseases, and an inadequate number of sprayers being available have caused farmers to adopt faster working speeds to maintain operational capacity. It is essential that the quality of the application process be maintained at those speeds [23]. However, this increase in working speed influences the droplet transport time produced by the spray nozzle to the biological target and, consequently, can cause potential droplets to be lost to the environment and decrease the efficiency of the application [24]. It is necessary to better understand the behavior of droplets produced during spraying, especially at higher working speeds [25].

A study was conducted to evaluated droplet coverage in soybean crops with different spray nozzles at a 9.7 $m \cdot s^{-1}$ working speed using a self-propelled sprayer with a hydraulic boom and concluded that the working speed did not affect the percentage of droplet coverage in the lower and upper thirds of the plants [26]. In contrast, other authors concluded there was better spray deposition on soybean leaves when the slowest speed (2.8 $m \cdot s^{-1}$) was used [25].

Therefore, the objectives of this study were to: (1) evaluate the efficiency of air assistance associated with an electrostatic system on spray deposition and soybean yield; (2) evaluate the spray deposition, droplet coverage and density from applications with air assistance and an electrostatic system at different working speeds on soybeans crop.

2. Materials and Methods

2.1. Experiment 1

2.1.1. Location and Site Description

The field experiment was conducted in Bonfinópolis de Minas, Minas Gerais, Brazil (16°30′38″S, 46°17′08″W, 907 m of altitude). The climate of the region is classified as Aw (tropical climate with dry season, dry winter, and rainy summer season) according to Köppen–Geiger classification [27]. In the last five years, the average annual temperature and precipitation were 24 °C and 1230 mm, respectively [28]. The soil is classified as Red–Yellow Ultisol with 37% clay [29]. Applications were made on soybean cultivar RK5519 RR (KWS Seeds®, Patos de Minas, Minas Gerais, Brazil) during the 2021/2022 season. Plant population was 480,000 plants per hectare at 60 cm row spacing, planted on

October 13, 2021. All crop maintenance including pesticide applications followed farmer's recommendation.

Laboratorial analyses were carried out at the Weed Science Laboratory belonging to the Institute of Agricultural Sciences of the Federal University of Jequitinhonha and Mucuri Valleys (FUJMV) located in Unai, Minas Gerais State, Brazil.

2.1.2. Experimental Design and Treatments

A spray deposition experiment was conducted in a randomized complete block design (RCBD) with 4 treatments and 10 replications. The treatments consisted of three airspeeds for the air assistance (level #3: 21 $m \cdot s^{-1}$, level #4: 25 $m \cdot s^{-1}$, and level #5: 30 $m \cdot s^{-1}$) with the electrostatic system, and a fourth treatment which was a conventional application with no air assistance and no electrostatic system. For the soybean yield determination, an RCBD with the same four treatments were evaluated with three replications. All four fungicide applications during the season followed the same treatment configuration and equipment calibration.

The experimental plots were 32 m wide, equivalent to one pass of the sprayer using the entire boom width, by 200 m length. For evaluation purposes, the wheel track region, 2 m in each boom extremity, the 10 m at the beginning, and the 10 m at the end of the plot were not considered for the deposition and yield data collection.

2.1.3. Application Equipment

Applications were performed using a self-propelled sprayer (Uniport 3030 EletroVortex®, Jacto, Pompeia, São Paulo State, Brazil) with 93 ATR 2.0 hollow cone nozzles (ALBUZ®, Évreux, France) spaced by 0.35 m across a 32 m boom length (Figure 1a). Carrier volume, working speed, working pressure, and boom height above crop canopy were 75 $L \cdot ha^{-1}$, 4.44 $m \cdot s^{-1}$, 450 kPa, and 0.50 m, respectively. Nozzles were mounted in nozzle body caps with electrodes (Figure 1b) which operated at 5 kV. When transported through the electrostatic system, droplets receive a positive charge from the electrodes surrounding each nozzle.

(**a**) (**b**)

Figure 1. Self-prolled sprayer (**a**) and eletrostatic nozzle body (**b**) used in applications.

2.1.4. Environmental Conditions

The applications were performed between 8 and 10 a.m., and the meteorological data were monitored using a digital thermo-hygro-anemometer (Kestrel® 3000, Boothwyn, PA, USA). During the application, average air temperature, relative humidity, and wind speed were 25 °C (± 1), 77% (± 2), and 4.6 $m \cdot s^{-1}$, respectively.

2.1.5. Spray Deposition

The evaluation of spray deposition on soybean leaves occurred when the crops were in the R5/R6 reproductive stage [30]. Products and their respective rates used were: Approach Prima (pyraclostrobin + cyproconazole, Corteva Agriscience, Barueri, Brazil) at 0.3 $L \cdot ha^{-1}$, Fighter (vegetable oil adjuvant, De Sangosse, Ibiporã, Brazil) at 0.15% $v\ v^{-1}$, and TA 35 (lauril ether sodium adjuvant, Inquima, Cambé, Brazil) at 0.15% $v\ v^{-1}$.

A blue tracer dye (Duas Rodas Industrial®, Jaraguá do Sul, Santa Catarina, Brazil), was added to the spray solution at 400 $g{\cdot}ha^{-1}$ to be quantified by spectrophotometry in the laboratory. After the application and for each replication, 10 soybean plants were randomly selected, and 3 leaves in each position (bottom, middle, and top) were collected from each plant. Leaves were separated and grouped by position and placed in plastic bags, stored away from sunlight and heat until being processed afterwards.

In the laboratory, 50 mL of distilled water were added to each plastic bag, which was closed and shaken for 30 s, and the extracted solution was placed in Falcon tubes for absorbance reading in the spectrophotometer (FEMTO®, 700 plus, São Paulo, São Paulo, Brazil) at 630 nm wavelength [31]. Equation (1) was generated by serial dilution of the applied spray solution:

$$y = 0.0161\ x + 0.0036 \qquad \left(R^2\ 0.99\right) \tag{1}$$

where y is the tracer concentration ($mg{\cdot}L^{-1}$) and x is absorbance. By knowing the tracer concentration and the volume of distilled water added to plastic bag, the amount of tracer (ɳg) on leaves was calculated.

Additionally, the leaf area was measured by Petiole Limited® 0.5.1 [32], a software installed in a Samsung Galaxy Note 10 plus (Samsung, ® Samsung Digital City, Suwon, Republic of Korea). With the amount of tracer and leaf area, data were converted into ɳg·cm^{-2}.

2.1.6. Soybean Yield

Harvesting occurred on January 24, 2022 using a combine harvester (CR 8.90 Twin Rotor®, New Holland, Curitiba, Paraná, Brazil) with a 13.7 m draper head (MacDon®, Winnipeg, MB, Canada). The harvest speed was 1.7 $m{\cdot}s^{-1}$. Two passes of the combine were made in each plot and then grains were transferred to a truck (Mercedes-Benz®, Model Atego 2430, São Bernardo City, São Paulo, Brazil) which was weighed with a large-size scale (Capital Scales®, BC Controller 3.0, São Bernardo do Campo, São Paulo, Brazil) located approximately 500 m from the area. As the distance between the area and the scale was short, the amount of fuel consumption was considered irrelevant. The grain moisture was determined by a moisture meter (Agrosystem®, GAC 2100, Ribeirão Preto, São Paulo State, Brazil), and the final yield was corrected to 13% moisture according to Equation (2).

$$\text{Yield}\left(\text{kg}{\cdot}\text{ha}^{-1}\right) = \text{Sample wet weight} \times \frac{(100 - \text{Sample moisture})}{(100 - 13)} \tag{2}$$

2.2. Experiment 2

2.2.1. Location and Site Description

The field experiment was conducted in Unaí, Minas Gerais, Brazil (16°10′10″ S, 46°22′18″ W, 929 m of altitude). The climate of the region is classified as Aw, the same as the area in Experiment 1. The soil is classified as dystrofic Red Latosol (Oxisol) with 43% clay [29]. Applications were made on soybean cultivar CZ 37B43 IPRO (Credenz—BASF®, Leverkusen, Germany) during the 2022/2023 season. Plant population was 320,000 plants per hectare at 50 cm row spacing, planted on 3 November 2022. All crop maintenance including pesticide applications followed farmer's recommendation.

Laboratorial analyses were carried out at the Weed Science Laboratory belonging to the Institute of Agricultural Sciences of the FUJMV located in Unai, Minas Gerais State, Brazil.

2.2.2. Experimental Design and Treatments

The experiment was conducted in a RCBD with a 2 × 3 split plot scheme and eight replications. The treatments corresponded to three working speeds (3.3, 4.2, and 5.0 $m{\cdot}s^{-1}$)

(sub-plot) with or without air assistance plus electrostatic system, (main plot). Plots were 16 m wide (equivalent to one pass of the sprayer using half-boom width) by 150 m length. For evaluation purposes, 2 m in each boom extremity, 10 m at the beginning, and 10 m at the end of the plot were not considered.

Applications were performed with a self-propelled sprayer similar to the one used in Experiment 1. Hollow cone ATR 2.0 nozzles (ALBUZ®, Évreux, France) were used to deliver 75 L·ha^{-1} carrier volume. Boom height above crop canopy was set at 0.50 m. At 3.3, 4.2, and 5.0 m·s^{-1} working speeds, the pressures were 250, 400, and 570 kPa, respectively.

Applications were performed between 9 and 11 am and meteorological data were monitored using a digital thermo-hygro-anemometer (Kestrel® 3000, Boothwyn, PA, USA). The average air temperature, relative humidity, and wind speed were 27 °C (±1), 75% (±2), and 3.3 m·s^{-1}, respectively.

2.2.3. Spray Deposition, Droplet Coverage and Density

The evaluation of spray deposition on soybean leaves was conducted when the crop was in the R7.1 reproductive stage [30]. Similar methodology [31] to that previously described in Experiment 1 was used in Experiment 2, including solution composition, blue dye tracer, product rate, and extraction. After application, 10 soybean plants were randomly selected, and in each plant, three leaves in each position (bottom and middle) were collected. Leaves were separated and grouped by position and placed in plastic bags, stored away from sunlight and heat until being processed afterwards in laboratory.

In addition, before application, kromekote cards (10 × 7 cm) (Masterprint, Maringá, Paraná, Brazil) were positioned horizontally at the same positions where soybean leaves were collected (30 and 80 cm above soil level). Cards were attached to paper holders specifically designed for that purpose. After the application, cards were collected, grouped by position, and placed in plastic bags, stored away from sunlight and heat until being processed afterwards in laboratory. In the laboratory, the cards were scanned (Epson®, Epson Perfection v19, Suwa, Japan) at 600 dpi resolution and analyzed by AccuStain 0.35 (AccuStain Software®, Urbana, IL, USA).

2.3. Statistical Analyses

Spray deposition, soybean yield, droplet coverage and density data were submitted to assumption tests (Shapiro–Wilk for normality of residues and Levene for homogeneity of variances) at 0.05 significance. Then, data were submitted to analysis of variance (ANOVA) using the Snedecor F's test and when significant, the means were compared to each other using Tukey's test at 0.05 significance. All tests were performed using the SPSS version 28.0 Statistical Program [33].

3. Results

3.1. Experiment 1

3.1.1. Spray Deposition

Applications with air assistance (level #3) and electrostatic charging increased tracer deposition on the middle and top soybean leaves by 96% and 32%, respectively, in comparison to conventional spraying (Figure 2). Greater airspeeds did not result in a better deposition on either the bottom, middle, or top leaves. On the bottom leaves, a lower amount of tracer deposition was observed for airspeed level #5 in relation to airspeed levels #3 and #4. However, those depositions did not differ from the conventional application.

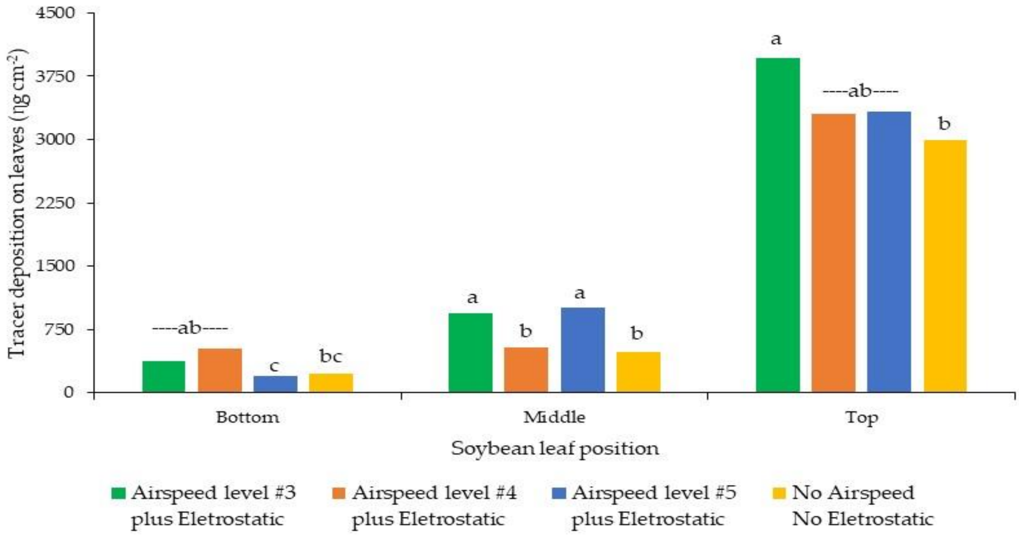

Figure 2. Spray deposition on bottom, middle, and top leaves of soybeans provided by air assistance (level #3: 21 m·s^{-1}, level #4: 25 m·s^{-1}, level #5: 30 m·s^{-1}) associated with electrostatic charging. Bars with similar letters within leaf position do not differ using Tukey's test at α = 0.05.

3.1.2. Soybean Yield

Soybean areas with conventional system application yielded 386, 562, and 621 kg·ha^{-1} less in comparison to areas which received applications through electrostatic charging and air assistance at airspeed levels #3, #4, and #5, respectively (Figure 3). Applications using airspeed level #5 resulted in a 15% higher grain yield than the conventional system. No yield difference was observed between airspeeds ranging from 4385 to 4620 kg·ha^{-1}, even considering that a lower deposition on bottom leaves was obtained using airspeed level #5.

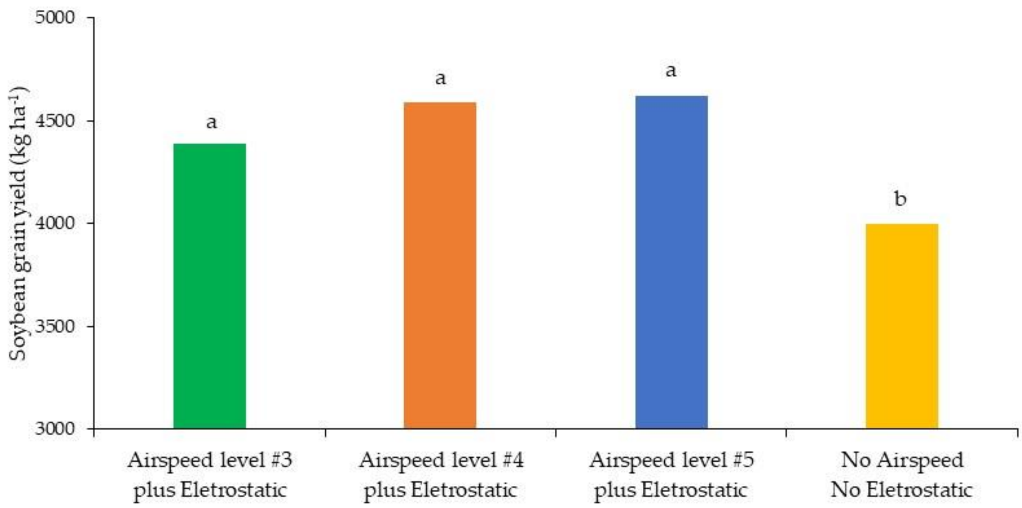

Figure 3. Soybean grain yield provided by air assistance (level #3: 21 m·s^{-1}, level #4: 25 m·s^{-1}, level #5: 30 m·s^{-1}) associated with electrostatic charging. Bars with similar letters do not differ using Tukey's test at α = 0.05.

3.2. Experiment 2

3.2.1. Spray Deposition

A significant interaction between air assistance and working speed was observed for the bottom (F = 4.748, ρ = 0.017) and middle (F = 6.116, ρ = 0.006) leaves. For air assistance plus electrostatic application, the slowest working speed resulted in the greatest tracer deposition on soybean leaves, which corresponded to 1.39- and 2.36-fold greater depositions on the bottom and middle leaves, respectively, in relation to the fastest speed (Table 1). In contrast, no difference between speeds was observed for the conventional application. At the 5.0 m·s^{-1} working speed, both application methods provided a similar tracer deposition to leaves, whereas at 3.3 m·s^{-1}, air assistance plus electrostatic increased tracer deposits by 52% for the bottom leaves and 125% for the middle leaves in comparison to conventional application.

Table 1. Spray deposition on bottom and middle leaves of soybean crops including air assistance plus electrostatic charging and conventional applications at three working speeds.

Application Method	Working Speed (m·s^{-1})					
	3.3		4.2		5.0	
	Tracer deposition on bottom leaves (ηg·cm^{-2})					
Air assistance plus Eletrostatic	120	bB	82	aA	86	aA
Conventional	79	aA	87	aA	76	aA
	Tracer deposition on middle leaves (ηg·cm^{-2})					
Air assistance plus Eletrostatic	870	cB	636	bB	368	aA
Conventional	386	aA	354	aA	340	aA

Means followed by same letter, lower case in row and upper case in column within leaf position, do not differ using Tukey's test at α = 0.05.

3.2.2. Droplet Coverage and Density

On the bottom cards, a significant interaction between air assistance and working speed was observed for droplet coverage (F = 5.276, ρ = 0.017) and density (F = 8.063, ρ = 0.004). However, on the middle cards no interaction between factors was observed for droplet coverage (F = 0.154, ρ = 0.859) and density (F = 0.569, ρ = 0.577).

Similarly, as noticed for spray deposition, the conventional application provided similar results for the bottom cards across working speeds, ranging from 0.3% to 0.5% coverage and 4 to 5 drops·cm^{-2} (Table 2). For the air assistance plus electrostatic application, an increase by two percentage points in coverage and by nine drops·cm^{-2} in density was obtained at 3.3 m·s^{-1} in relation to a 5.0 m·s^{-1} working speed when evaluating bottom cards. At the 4.2 and 5.0 m·s^{-1} speeds, both application methods resulted in similar droplet coverage and density on the bottom cards, whereas at 3.3 m·s^{-1}, the conventional application produced lower results, 5.4-fold for coverage and 3-fold for density, in comparison to the air assistance plus electrostatic method.

Table 2. Droplet coverage and density on bottom cards provided by air assistance plus electrostatic charging and conventional applications at three working speeds.

Application Method	Working Speed (m·s^{-1})					
	3.3		4.2		5.0	
	Droplet coverage (%)					
Air assistance plus Eletrostatic	2.7	bB	0.8	aA	0.7	aA
Conventional	0.5	aA	0.3	aA	0.4	aA
	Droplet density (drops·cm^{-2})					
Air assistance plus Eletrostatic	15	bB	6	aA	6	aA
Conventional	5	aA	5	aA	4	aA

Means followed by same letter, lower case in row and upper case in column, do not differ using Tukey's test at α = 0.05.

Working speed did not affect droplet coverage and density on the middle cards (Table 3). On average, 17.1% coverage and 113 drops·cm^{-2} were obtained across working speed regardless of application method. Comparing methods, air assistance plus electrostatic resulted in 79% and 25% more droplet coverage and density, respectively, in relation to the conventional application regardless of working speed. The highest coverage achieved was 21.9% and the greatest density observed was 125 drops·cm^{-2} on the middle cards.

Table 3. Droplet coverage and density on middle cards provided by air assistance plus electrostatic charging and conventional applications at three working speeds.

Application Method	Working Speed (m·s^{-1})						Average	
	3.3		4.2		5.0			
Droplet coverage (%)								
Air assistance plus Eletrostatic	20.6		21.2		24.1		21.9	B
Conventional	12.3		11.7		12.5		12.2	A
Average	16.5	a	16.5	a	18.3	a		
Droplet density (drops·cm^{-2})								
Air assistance plus Eletrostatic	119		129		128		125	B
Conventional	80		103		119		101	A
Average	100	a	116	a	123	a		

Means followed by same letter do not differ using Tukey's test at α = 0.05.

4. Discussion

4.1. Experiment 1

4.1.1. Spray Deposition

In general, air assistance at level #5 plus an electrostatic system provided low deposition on the bottom soybean leaves in relation to the middle and top positions (Figure 2). It is possible that the excessive airspeed caused the opposite effect, with the loss of spray reaching the ground or the rebound of drops, especially in the top position. This in turn could direct these drops upwards making them more prone to drift. However, a study evaluated a similar application method during fungicide application on a cotton crop using a spray volume of 60 L ha^{-1} and observed better spray deposition when using air assistance at level #5 plus an electrostatic system in comparison to a conventional application system [9].

In another study, the authors also obtained significant increases in fungicide deposition and control of *Phakopsora pachyrhizi* Sydow and Sydow (causal agent of Asian Soybean Rust) using an air assistance plus electrostatic charge application, especially on the bottom leaves [34]. Researchers evaluated the use of a motorized knapsack sprayer with air assistance (airspeed of 6 m·s^{-1}) and droplet electrification (7 kV) on soybean crop using 56 L ha^{-1} [17]. The authors observed that the system allowed for an increase in spray deposits on bottom leaves, which does not corroborate the results found in this study. Moreover, the authors suggested that the faster airspeed can significantly increase spray deposition on bottom leaves.

The use of air assistance helps with opening the crop canopy, which facilitates droplet deposition on lower plant positions and reduces spray drift [13,18,35]. Electrifying fine droplets less than 80 µm can also improve spray deposition and uniformity and reduce losses due to evaporation and drift [11,36,37]. The association of air assistance with electrostatic droplet charging may demonstrate a feasible alternative which can increase the application efficiency [13]. However, more research must be conducted to better understand the behavior of these two systems used simultaneously on other crops, phenological stages, and carrier volumes.

4.1.2. Soybean Yield

Fungicide applications to control Asian Soybean Rust with the air assistance sprayer resulted in increases of up to 17% in grain soybean yield in relation to the conventional sprayer [38]. Unlike the observations made by other authors [38] and those in this study, other research has shown that applications with air assistance plus electrostatic charge used to control silverleaf whitefly (*Bemisia tabaci* Genn.) on soybeans did not provide yield increase in comparison to the conventional system [17]. It is important to mention that the yield data from this study could not be replicated in multiple seasons due to unfavorable weather events. Therefore, additional research should be conducted to confirm these one-season yield results.

4.2. Experiment 2

4.2.1. Spray Deposition

One study evaluated spray deposition on soybean crops using a conventional self-propelled sprayer at 80 and 150 $L \cdot ha^{-1}$ carrier volumes and working speeds of 2.8, 4.2, and 5.6 $m \cdot s^{-1}$ [25]. The authors found that the speeds did not influence the spray deposition on the top and bottom leaves, which corroborates the results of this study considering no air assistance and no electrostatic system. The authors also concluded that an 80 $L \cdot ha^{-1}$ carrier volume, which is very close to that used in this study, with the two slowest speeds, led to a greater spray deposition. It is worth mentioning that the authors used air inclusion nozzles with a pattern of coarse and very coarse droplets.

In another study, after evaluating the spray deposition on cotton leaves using a conventional self-propelled sprayer with working speeds ranging from 4.7 to 7.2 $m \cdot s^{-1}$, it was concluded that working speed did not influence the deposition of sprayed droplets [39]. The authors also tested a conventional self-propelled sprayer at 120 $L \cdot ha^{-1}$ carrier volume and concluded that the spray deposition on the top cotton leaves at the flowering stage was slightly higher using the lowest working speed (3.3 $m \cdot s^{-1}$) for both cone and flat-fan nozzles, while for the bottom leaves, there was no difference across nozzles and speeds (4.2, 5.0, and 7.0 $m \cdot s^{-1}$) [23], corroborating the results of this study.

It is important to mention that no research was found in literature which shows the effect of working speed on spray deposition on soybean or other crops using boom sprayers equipped simultaneously with air assistance and electrostatic droplet charging. Future studies should be conducted to better understand how much the electrostatic droplet charging affects spray deposition when associated with air assistance applications.

4.2.2. Droplet Coverage and Density

Another study evaluated droplet coverage on soybean crops with different spray nozzles at 4.2 and 9.7 $m \cdot s^{-1}$ working speeds through a conventional self-propelled sprayer [26]. The authors also concluded that the speed did not affect the percentage of coverage on the bottom and top leaves. Based on the results shown in this study, it is possible to suggest that, in cases of white mold (*Sclerotinia sclerotiorum* Lib.), Asian Soybean Rust, and other diseases that first establish in the middle and bottom sections of plants, slower working speeds (3.3 $m \cdot s^{-1}$) are an alternative method which can achieve greater droplet coverage and density, especially using air assistance and an electrostatic system. Consequently, this might improve control effectiveness, increase the interval between applications, and even reduce the number of fungicide applications.

5. Conclusions

The use of air assistance (level #3) plus an electrostatic system increased the spray deposit on the middle and top soybean leaves in relation to the conventional system.

Soybean yield increments of up to 621 kg·ha^{-1} were observed when air assistance plus an electrostatic system was used in comparison to conventional application.

The lower working speed (3.3 m·s^{-1}) combined with the air assistance and electrostatic system provided the greatest spray deposition and droplet coverage and density on the bottom soybean leaves.

The air assistance plus electrostatic system provided greater droplet coverage and density on the middle soybean leaves regardless of working speed.

Author Contributions: Conceptualization, G.S.A. and M.R.B.; methodology, G.S.A. and M.R.B.; validation, G.S.A. and M.R.B.; formal analysis, G.S.A.; investigation, G.S.A., M.R.B. and S.M.S.; resources, G.S.A. and M.R.B.; data curation, G.S.A., M.R.B., S.M.S., T.S.S.H., H.T.S.G., G.A.C., F.S.G. and M.A.V.G.O.; writing—original draft preparation, M.R.B. and S.M.S.; writing—review and editing, G.S.A.; visualization, G.S.A.; data curation, G.S.A., M.R.B., S.M.S., T.S.S.H., H.T.S.G., G.A.C., F.S.G. and M.A.V.G.O.; supervision, G.S.A., M.R.B. and S.M.S.; project administration, G.S.A.; funding acquisition, G.S.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors would like to thank the Jacto Agricultural Machineries, the FUJMV Unai Campus, and farmers Fábio Ribamar and Massaru Hachiya for their support in carrying out this study, and Kasey Schroeder for contributing with English review.

Conflicts of Interest: Jacto Agricultural Machineries only provided materials to conduct this study. No funding was granted. The company had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results, but their researcher did.

References

1. Aprosoja Brasil. Available online: https://aprosojabrasil.com.br/a-soja/ (accessed on 16 August 2023).
2. Conab. A Produtividade da Soja: Análise e Perspectivas. Available online: https://www.conab.gov.br/uploads/arquivos/17_08_02_14_27_28_10_compendio_de_estudos_conab__a_produtividade_da_soja_-_analise_e_perspectivas_-_volume_10_2017.pdf (accessed on 16 August 2023).
3. Espósito, L.H.; Marzocca, A.J. Silica-filled S-SBR with epoxidized soybean oil: Influence of the mixing process on rheological and mechanical properties of the compound. *J. Appl. Polym. Sci.* **2020**, *137*, 48504. [CrossRef]
4. Li, J.; Isayev, A.I.; Ren, X.; Soucek, M.D. Toward replacement of petroleum oils by modified soybean oils in elastomers. *Rubber. Chem. Technol.* **2016**, *89*, 608–630. [CrossRef]
5. Lovison, V.M.H.; Freitas, M.A.; Forte, M.M.C. Chemically modified soybean oils as plasticizers for silica-filled e-SBR/Br compounds for tire tread applications. *J. Elastomers. Plast.* **2021**, *53*, 806–824. [CrossRef]
6. Conab. Acompanhamento da Safra Brasileira de Grãos—Safra 2022/23. Available online: https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos (accessed on 16 August 2023).
7. USDA. Oilseeds: World Markets and Trade. Available online: https://apps.fas.usda.gov/psdonline/circulars/oilseeds.pdf (accessed on 16 August 2023).
8. Bueno, M.R.; Cunha, J.P.A.R.; Santana, D.G. Assessment of spray drift from pesticide applications in soybean crops. *Biosyst. Eng.* **2017**, *154*, 35–45. [CrossRef]
9. Antuniassi, U.R.; Mertens, T.B.; Carvalho, F.K.; Mota, A.A.B.; Chechetto, R.G.; Silva, D.P.; Madeira, R.G. Assistência de ar em conjunto com a transferência de carga elétrica na deposição de fungicidas na cultura do algodão. *Rev. Plantio Direto* **2021**, *31*, 18–22.
10. Salcedo, R.; Llop, J.; Campos, J.; Costas, M.; Gallart, M.; Ortega, P.; Gil, E. Evaluation of leaf deposit quality between electrostatic and conventional multi-row sprayers in a trellised vineyard. *Crop Prot.* **2019**, *127*, 104964. [CrossRef]
11. Tavares, R.M.; Cunha, J.P.; Alves, T.C.; Bueno, M.R.; Silva, S.M.; Zandonadi, C.H. Electrostatic spraying in the chemical control of *Triozoida limbata* (Enderlein) (Hemiptera: Triozidae) in guava trees (*Psidium guajava* L.). *Pest Manag. Sci.* **2016**, *73*, 1148–1153. [CrossRef]
12. Matthews, G.A.; Bateman, R.; Miller, P. Air-assisted sprayers. In *Pesticide Application Methods*, 4th ed.; Matthews, G.A., Bateman, R., Miller, P., Eds.; Wiley Blackwell: Hoboken, NJ, USA, 2014; pp. 215–244.

13. Silva, D.P. Interação Eletrostática—Assistência de ar na Deposição da Pulverização e Viabilidade de Fungos Entomopatogênicos. Master's Thesis, São Paulo University State Júlio de Mesquita Filho, Botucatu, Brazil, 2019.
14. Raetano, C.G.; Bauer, F.C. Deposição e perdas da calda em feijoeiro em aplicação com assistência de ar na barra pulverizadora. *Bragantia* **2004**, *63*, 309–315. [CrossRef]
15. Raetano, C.G. Assistência de ar em pulverizadores de barra. *Biológico* **2022**, *64*, 221–225.
16. Assunção, H.H.T.; Silva, S.M.; Alves, G.S.; Zandonadi, C.H.S.; Cunha, J.P.A.R. Electrostatic spraying effect on spray deposition and powdery mildew control in soybean. *Eng. Agri.* **2019**, *39*, 721–728. [CrossRef]
17. Pelegrini, G.; Souza, A.M.; Ferreira, P.H.U.; Monteiro, G.G.; Ferreira, M.C. Air-assisted spraying and electrically charged droplets for *Bemisia tabaci* control in soybeans. *Pest Manag. Sci.* **2022**, *78*, 4618–4627. [CrossRef] [PubMed]
18. Martin, D.E.; Latheef, M.A. Aerial electrostatic spray deposition and canopy penetration in cotton. *J. Electrost.* **2017**, *90*, 38–44. [CrossRef]
19. Pascuzzi, S.; Cerruto, E. Spray deposition in "tendone" vineyards when using a pneumatic electrostatic sprayer. *Crop Prot.* **2014**, *68*, 1–11. [CrossRef]
20. Souza, D.M.; Raetano, C.G.; Moreira, C.A.F.; Bueno, R.C.O.F.; Carvalho, M.M. Effects of news sowing arrangements and air assistance on fungicide spray distribution on soybean crop. *Acta Sci. Agron.* **2019**, *41*, e42700. [CrossRef]
21. Jacto. Uniport 3030 EletroVortex: A Pulverização em Outro Nível. Available online: https://jacto.com/brasil/products/pulverizadores-automotrizes/uniport-3030-eletrovortex (accessed on 18 August 2023).
22. Jacto. Uniport 3030 EletroVortex. *Rev. Cultivar. Máquinas* **2020**, *206*, 20–27.
23. Cavalieri, J.D.; Raetano, C.G.; Madureira, R.P.; Moreira, L.L.Q. Spraying systems and traveling speed in the deposit and spectrum of droplets in cotton plant. *Eng. Agríc.* **2015**, *35*, 1042–1052. [CrossRef]
24. Liu, Q.; Cooper, S.E.; Qi, L.; Fu, Z. Experimental study of droplet transport time between nozzles and target. *Biosyst. Eng.* **2006**, *95*, 151–157. [CrossRef]
25. Cunha, J.A.P.; Victor, A.P.; Sales, C.G.R. Spray deposition on soybean crop using different travel speeds and application rates. *Eng. Agric.* **2018**, *38*, 82–87. [CrossRef]
26. Zaidan, S.E.; Gadanha, C.D., Jr.; Gandolfo, M.A.; Pontelli, C.O.; Mosquini, W.W. Performance of spray nozzles in land applications with high speed. *Eng. Agric.* **2012**, *32*, 1126–1132. [CrossRef]
27. Peel, M.C.; Finlayson, B.L.; Mcmahon, T.A. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.* **2007**, *11*, 1633–1644. [CrossRef]
28. INMET. Tempo: Estação Unai (A542). Available online: https://tempo.inmet.gov.br/ (accessed on 20 August 2023).
29. Santos, H.G.; Jacomine, P.K.T.; Anjos, L.H.C.; Oliveira, V.A.; Lumbreras, J.F.; Coelho, M.R.; Almeida, J.A.; Filho, J.C.A.; Oliveira, J.B.; Cunha, T.J.F. *Sistema Brasileiro de Classificação de Solos*; Embrapa: Brasília, Brazil, 2018; 356p.
30. Farias, J.B.; Nepomuceno, A.L.; Neumaier, N. *Ecofisiologia da Soja*; Embrapa Soja: Londrina, Brazil, 2007; 9p.
31. Palladini, L.A.; Raetano, C.G.; Velini, E.D. Choice of tracers for the evaluation of spray deposits. *Sci. Agric.* **2005**, *62*, 440–445. [CrossRef]
32. Seleznov, A.; Kuzmenko, M. PetiolePRO. 2013. Available online: https://www.petiolepro.com/leaf-area-meter-petiole-pro/ (accessed on 12 March 2023).
33. IBM Corp. *IBM SPSS Statistics for Windows, version 28.0*; IBM Corp: New York, NY, USA, 2021.
34. Oliveira, M.A.P.; Antuniassi, U.R.; Velini, E.D.; Siduri, F.V.; Oliveira, R.B.; Pontelli, C.O.; Beltramello, L.G.F.; Zaidan, S.E. Desempenho de um sistema eletrostático com assistência de ar na deposição de calda e no controle da deriva em aplicações de fungicidas. In *International Symposium on Application Technology, Proceedings of International Symposium on Application Technology, Cuiabá, Brazil, 12–14 September 2011*; FEPAF: Botucatu, Brazil, 2011.
35. Gupta, P.; Sirohi, N.P.S.; Mishra, I.M. Air flow characteristics of an air-assisted sprayer through horizontal crop canopy. *Int. J. Agric. Biol. Eng.* **2012**, *5*, 1–6. [CrossRef]
36. Appah, S.; Wang, P.; Ou, M.; Gong, C.; Jia, W. Review of electrostatic system parameters, charged droplets characteristics and substrate impact behavior from pesticides spraying. *Int. J. Agric. Biol. Eng.* **2019**, *12*, 1–9. [CrossRef]
37. Chaim, A.; Wadt, L.G.R. *Pulverização Eletrostática: A Revolução na Aplicação de Agrotóxicos*; Embrapa Meio Ambiente: Jaguariúna, Brazil, 2015; 7p.
38. Prado, E.P.; Raetano, C.G.; Aguiar Junior, H.O.; Dalpogetto, M.H.F.A.; Christovam, R.S.; Gimenes, M.J.; Araújo, D. Velocidade do ar em barra de pulverização na deposição da calda fungicida, severidade da ferrugem asiática e produtividade da soja. *Summa Phytopathol.* **2010**, *36*, 45–50. [CrossRef]
39. Peres, A.J.A.; Raetano, C.G.; Baio, F.H.R.; Neves, D.C.; Cavalieri, J.D. Pulverização em taxa variada na cultura do algodão. *Energ. Na Agric.* **2020**, *35*, 18–28. [CrossRef]