SBCPD
<http://www.sbcpd.org>

Planta Daninha

Journal of The Brazilian Weed Science Society

ISSN 0100-8358 (print)
1806-9681 (online)

Research Article

# Efficacy of glyphosate applied using an electrostatic sprayer as affected by adjuvant and carrier volumes

Saulo F.B. Campos[a], João P.A.R. Cunha[a], Heli H.T. Assunção[a], Thales C. Alves[a], César H.S. Zandonadi[a], Ernane M. Lemes[a]*

[a] Universidade Federal de Uberlândia, Uberlândia-MG, Brasil.

## ARTICLE INFORMATION

**Received**: September 8, 2019
**Accepted**: May 28, 2020

**Keywords:**
spray adjuvant
spray drift
spray rate
glyphosate
physicochemical properties

***Corresponding author:**
<ernanefito@gmail.com>

**Cite this article:**
Campos SFB, Cunha JPAR, Assunção HHT, Alves TC, Zandonadi CHS, Lemes EM. Efficacy of glyphosate applied using an electrostatic sprayer as affected by adjuvant and carrier volumes. Planta Daninha. 2020;38:e020228417. https://doi.org/10.1590/S0100-83582020380100092

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

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

## HIGHLIGHTS

- The electrostatic system energized the droplets; however, it was not able to alter the spray deposition.
- The soybean lecithin + propionic acid adjuvant improved the effectiveness of weed control.
- The effectiveness of weed control, in general, was not influenced by the electrostatic spray system.

## ABSTRACT

**Background:** The use of electrostatic spray has the potential to optimize pesticide applications; however, further studies are required to verify its effectiveness.
**Objective:** The objective of this work was to evaluate the electrostatic application system for the chemical control of weeds with glyphosate and adjuvant in different carrier volumes.
**Methods:** The physicochemical properties of the spray solution, charge/mass relations, spray deposition on weeds, losses to the soil, effectiveness of weed control, and spray drift were evaluated. The field experiment was designed to have randomized blocks with four replications in a 2x2x2+2 factorial: the presence or not of electrostatic spray; with and without adjuvant (soybean lecithin + propionic acid); two carrier volumes (50 and 90 L $ha^{-1}$); a control without applications and a conventional spray rate (150 L $ha^{-1}$) for additional treatments. The study was performed in duplicate.
**Results:** The electrostatic system energized the droplets during the application of glyphosate and adjuvant; however, this did not influence the deposition on the weeds, the losses to the soil, and the drift. The adjuvant improved the effectiveness of weed control in various situations, changed the spray solution properties, and reduced the losses due to drift.
**Conclusions:** The adjuvant used proved to be an important tool in application technology. The effectiveness of weed control, in general, was not influenced by the electrostatic system.

## 1 INTRODUCTION

Glyphosate is one of the most commonly used herbicides for weed control in crop production, and it has demonstrated high effectiveness and a broad spectrum of action in both annual and perennial plant species since its inception. The activity and efficacy of glyphosate as a post-emergence herbicide can be affected by several factors, such as the environmental conditions during application, the

post-application period without precipitation, stage of weed development, the use of adjuvants, and water quality (Dan et al., 2009).

A common issue with herbicide applications is the occurrence of spray drift in neighboring areas. Yamashita et al. (2013), for example, observed that damage to the coffee crop is quite common and is caused by the drift of herbicides such as glyphosate. This effect can be minimized with the use of appropriate application technology involving sprayers and spray solution composition. To achieve better weed control, the spray solution must reach the target composition using the available technologies (Alves and Cunha, 2014; Tavares et al., 2014).

The highly effective phytosanitary treatment reduces the cost of crop production and lowers environmental impacts. Technologies such as electrostatic applications can improve the efficacy of phytosanitary products. The electrostatic system is advantageous as it deposits the spray solution in specific plant parts, whereas conventional spray methods use gravity and droplet inertia and are not efficient (Law, 2001). The electrostatic technology for applying phytosanitary products involves the electrical charging of spray droplets with negative or positive charges depending on the system used. The electrified cloud of droplets approaches the plant, which is an electrically neutral and grounded target, and induces a charge of opposite sign on the plant surface, thus increasing the attraction between the surface and the spray droplets (Chaim, 2006; Sasaki et al., 2015).

The main contributing factors to the movement of droplets toward the target are wind and gravitational pull. Coffee (1981) showed that droplets with diameters between 40 and 120 µm were predominantly coordinated by wind action. For droplets greater than 200 µm, the trajectory was determined based on the gravitational force. By adding one more force to this system, the electrostatic force, the possibility of droplets reaching the target could be increased. Law (2001) demonstrated that the electrostatic force exceeds the gravitational force by 51 times for droplets with 30 µm diameter, and 14 and 4 times for droplets with 100 and 300 µm diameters, respectively. Therefore, the droplet size is particularly important in this system.

Droplet courses directed via electrostatic induction increase the effectiveness of the application, reduce the application rates, and reduce losses of spray solution to air and soil (Maynagh et al., 2009; Sasaki et al., 2015). However, some studies did not find improvements in applications and efficacy with the electrostatic spray (Bayer et al., 2011; Magno Júnior et al., 2011). Chaim et al. (2002) observed that an increase in induction voltage increases the magnitude of the droplet charge to an extent where the voltage can damage the electrification of droplets and the quality of the application.

Therefore, the objective of the present study was to evaluate the use of electrostatic spray technology in the deposition, drift, and chemical control of weeds, with glyphosate as a function of adjuvant concentration and application rates.

## 2 Materials and Methods

### 2.1 Experimental area, treatments, and application

The field experiment was carried out at 842 m of altitude, in an area with flat topography and Aw type climate (humid, tropical with dry winter) (Beck et al., 2018). The experiment was conducted in duplicate during different periods of the year and in different areas (March and April/2018 in Test 1, June and July/2018 in Test 2). The experiment involved a randomized block design with 10 treatments and four repetitions in factorial 2x2x2+2; namely the absence and presence of electrostatic spray; absence and presence of adjuvant and two application rates (50 and 90 L $ha^{-1}$); an additional treatment using the conventional application (150 L $ha^{-1}$); and another additional treatment without herbicide application, totaling 40 plots of 30 $m^2$ (6 x 5 m). The experimental area did not have any crop for four months, and soybean was the previous crop. Test 1 was conducted during the rainy season and Test 2 during the dry period.

The applied herbicide consisted of the post-emergent herbicide glyphosate (ammonium salt of di-N-(phosphonomethyl) at a concentration of 445 g $L^{-1}$ of a.i. (370 g $L^{-1}$ acid equivalent), formulation soluble concentrate at a dose of 2 L $ha^{-1}$ of the commercial product (Roundup Original DI®) following the manufacturer's label. The adjuvant used was LI 700® (soy lecithin + propionic acid, 712 g $L^{-1}$), formulated as an emulsifiable concentrate, applied at a 0.5% proportion rate (5 mL $L^{-1}$). A dye-brilliant blue food coloring (internationally cataloged by the 'Food, Drug and Cosmetic' as FD&C Blue nº 1) was added to the spray solution. The dye dose was 300 g $ha^{-1}$, and the leaf spray deposition and losses to the soil were evaluated by absorbance using a spectrophotometer.

The applications were performed using a 12-m-long hydraulic boom sprayer (FM Copling®, JB80 400 BR12) with 24 nozzles, coupled to the hydraulic system of a tractor (Ursus®, model 4x2 2-85) of 62.5 kW. Only half of the boom was used for the applications. An electrostatic system SPE® (Electrostatic Spray System) was installed with this sprayer. The system produces an electric field of high voltage (6,950 V) at the base of the spray jet with hollow cone tips (SPE 1, SPE®) to electrically load the droplets. The charge was generated by the electric field produced by the induction rings connected to a high-voltage generator. The pressure used in the study was 250 kPa, and the speed of displacement was 3.3 km $h^{-1}$ for the application rate of 90 L $ha^{-1}$ and 6 km $h^{-1}$ for 50 L $ha^{-1}$. For the conventional application rate (150 L $ha^{-1}$) using flat-fan spray tips with air induction (AIXR 11002, Teejet®), the speed was 6.5 km $h^{-1}$ and the pressure was 300 kPa. According to the manufacturers, the SPE 1 tip, operating at 300 kPa, has a flow rate of 0.26 L $min^{-1}$ and a volume median diameter (VMD) of 125 µm, and the AIXR 11002 tip, working at 300 kPa, has a flow rate of 0.79 L $min^{-1}$ and a VMD of 332 µm.

Before herbicide application, the weeds in the area were estimated. The main weed species present in the region during the experiment were *Acanthospermum hispidum* DC. (bristly starbur), *Ageratum conyzoides* L. (billy goat weed), *Amaranthus deflexus* (perennial pigweed), *Commelina benghalensis* L. (wandering jew), *Raphanus raphanistrum* L. (wild radish), *Chamaesyce hirta* L. (garden spurg), *Alternanthera tenella* C. (sanguinarea), *Portulaca oleracea* L. (purslane), *Bidens pilosa* L. (blackjack), *Cyperus rotundus* L. (purple nutsedge), and *Cortaderia selloana* (S) A&G (pampas grass). The applications were performed when the weeds were in a late post-emergence state, with the application boom situated approximately 40 to 60 cm above the weed canopy in both experimental areas.

The environmental conditions at the time of application were monitored using a term-higro-digital anemometer (Kestrel®, model 4000). The air temperature was between 26.5 ºC and 29.0 ºC, relative humidity between 56.4% and 59.8%, and wind speed of up to 4.5 km $h^{-1}$ in Test 1 area. In Test 2 area, the air temperature ranged between 23.7 ºC and 28.2 ºC, relative humidity between 51 and 63%, and wind speed up to 11.3 km $h^{-1}$, thus avoiding the application in the total absence of wind.

## 2.2 Evaluation

*Physicochemical characteristics of the spray solutions*

The experimental design was set as a completely randomized design with four replications. Six treatments were elaborated: spray solution with glyphosate at a rate of 50 L $ha^{-1}$; spray solution with glyphosate at the rate of 50 L $ha^{-1}$ + adjuvant; spray solution with glyphosate at a rate of 90 L $ha^{-1}$; spray solution with glyphosate at the rate of 90 L $ha^{-1}$ + adjuvant; spray solution with glyphosate at the rate of 150 L $ha^{-1}$ (no electrostatic spray), and water. Evaluations were performed on solutions prepared in 0.5 L beakers at room temperature (25 ºC).

The surface tension, electrical conductivity, pH, dynamic viscosity, and density of all spray solutions applied with glyphosate were evaluated according to the methodology used by Cunha and Alves (2009) and Cunha et al. (2017).

The spray solution density was calculated by determining the mass of 0.1 L of the spray solution deposited into a volumetric flask on a scale (Uranus®, RU-420) with 0.1 mg precision. The pH and conductivity were measured directly from the spray solutions by using a portable pH meter and conductivity meter (Hanna®, HI98139). The equipment was previously calibrated with standard solutions, and automatic temperature compensation was disabled.

The dynamic viscosity was determined using a rotational viscometer (Quimis®, Q860M21) that electronically measures the torsion force and converts it into viscosity. The working principle of direct measurement of viscometer involves rotating the measuring cylinder (cylinder head) immersed in the sample to be analyzed and measuring the strength of the twist required to overcome the resistance of the rotation. The zero rotation (indicated by the viscosity range evaluated) and 60 rpm rotation were set for all evaluations.

The surface tension was determined with a tensiometer with a platinum ring (Kruss®, K6), using the method of Du Nouy (Dopierala and Prochaska, 2008). The test involves placing the ring attached to the edge of a flexible rod on the surface of the spray solution sample and measuring the tension with the ring. The ring is pressed until it breaks the surface tension of the corresponding solution. The tensiometer was calibrated with distilled water.

*Droplet electrification*

To evaluate the droplet electrification capacity, an experiment was carried out with five treatments (spray solution with glyphosate at a rate of 50 L $ha^{-1}$; spray solution with glyphosate at the rate of 50 L $ha^{-1}$ + adjuvant; spray solution with glyphosate at the rate of 90 L $ha^{-1}$; spray solution with glyphosate at the rate of 90 L $ha^{-1}$ + adjuvant; water). This experiment was set as a completely randomized design and had four replications. The influence of the spray solution on the functioning of the droplet electrification system was verified through an analysis of the charge/mass ratio (Q/M). The spray tip, pressure, and flow rate were the same as those in the field experiment, and the regulated voltage of the electrostatic system was 6.95 kV.

The system charge was determined by the Faraday cage method used by Chaim (1998) and Tavares et al. (2017). The output of the sprayer nozzle was maintained at 0.05 m from the cage opening. The galvanized steel (9.2 $mm^2$ screen, 1.2 mm wire) cage was 0.8 m round (diameter) and 0.6 m tall (length); thus, all the spray jets were captured during the treatment applications. The cage was isolated using a 1.7-m-long wooden rod (Figure 1).

Before the spray treatment applications, the sprayer was stabilized for 15 s and then sprayed for 2 min inside the cage. The density of each spray solution was determined by the relationship between the spray solution mass and volume. Thus, at each spraying inside the cage, the weight of the solution sprayed was determined. The electrical charge present on the atomized droplets was checked using a multimeter (Minipa®, model ET-2517A, 0 to 600 µA, accuracy: ±0.2%) connected to the cage. The multimeter was grounded by an iron rod buried 1 m below the ground level, similar to the methodology used by Maski and Durairaj (2010), and the electric current readings were noted in continuous current. The discharge of electricity contained in the droplet jet was determined to verify the charge/mass ratio (Q/M) using the relation between the electrical current and the mass of liquid sprayed (kg $s^{-1}$): $Q/M = i/m$ (Q/M is the mass/charge ratio (mC $kg^{-1}$), I is the electric current contained in the spray jet (mC $s^{-1}$), and *m* is the liquid flow (kg $s^{-1}$).

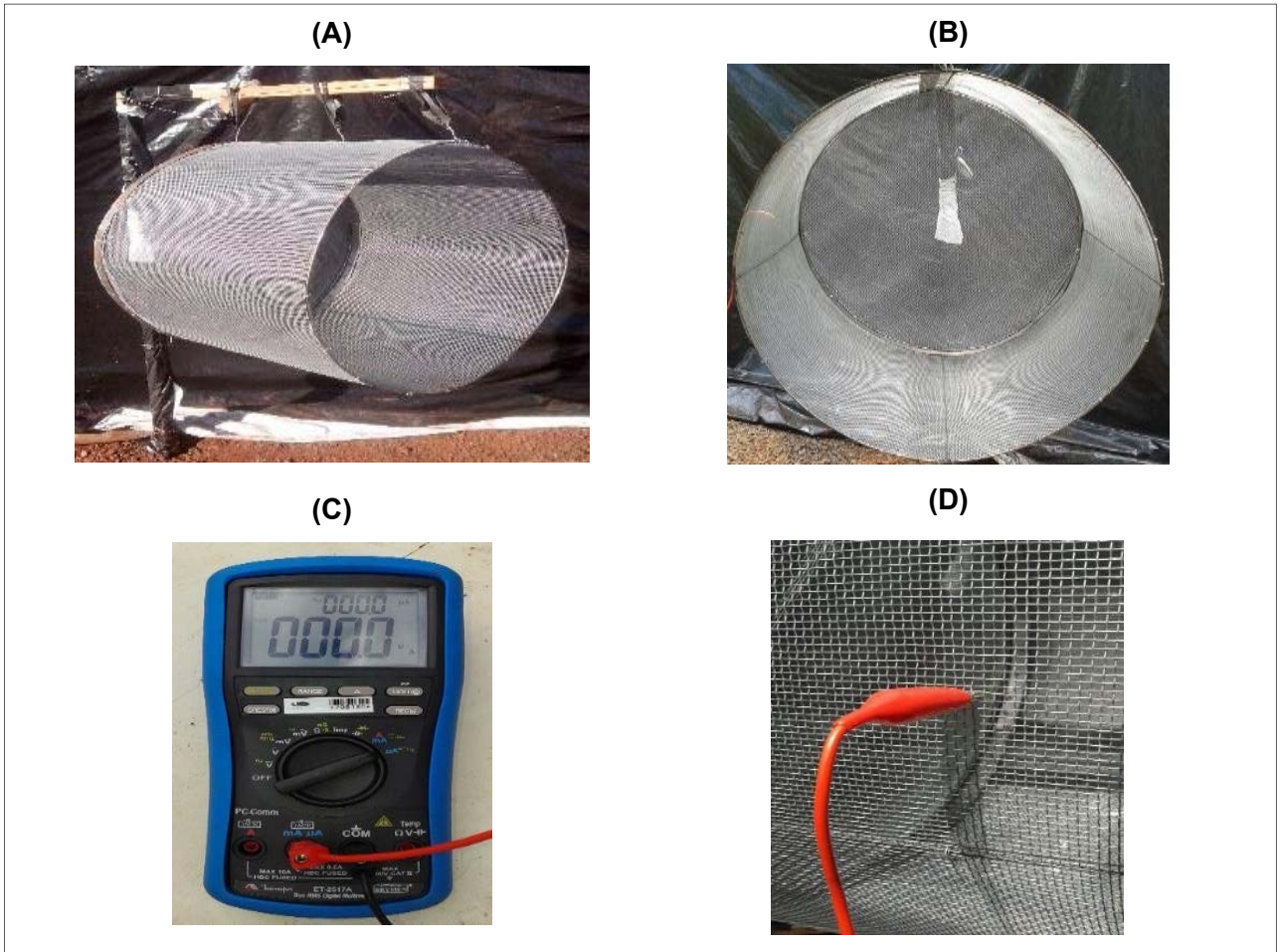


**Figure 1** - Faraday cage: (A) side view and (B) front view. (C) Multimeter used to measure current. (D) Connection of the multimeter to the Faraday cage.

The environmental conditions were monitored during the application of the treatments using a term-higro-digital anemometer (Kestrel®, model 4000), with a minimum temperature of 26.9 ºC and maximum of 30 ºC; the relative humidity of the air was between 65.0 and 66.4% and wind speed was up to 4.9 km $h^{-1}$.

*Spray deposition and losses to the soil*

The spray solution deposition on weed leaves and losses to soil were quantified by measuring the dye tracer added to the spray solution. The losses to the soil were determined using the random distribution of four Petri dishes (37.24 $cm^2$) placed on the soil of each plot. After the treatment application, weeds were cut close to the soil level, and then the Petri dishes were removed. The plant weeds collected were inside a metal frame (0.25 x 0.25 m) distributed randomly in each plot and packed in plastic bags.

The samples were washed in the lab by adding 300 mL of distilled water to weeds and 10 mL to the Petri dish. The bags were sealed, manually agitated for about 30 s, and packaged in thermal- and light-insulated containers to conserve the physicochemical characteristics of the samples. Subsequently, the dye tracer amount was determined by absorbance at 630 nm by using a spectrophotometer (Biospectro®, model SP-220). The dye tracer mass retained was determined by the initial concentration of the spray solution and the volume of dilution of the samples. To determine the marker mass (mg $g^{-1}$) on weeds, the total deposit found (mg) was divided by the respective weed dry mass. The plants were dried in an oven at 65 ºC for 72 h.

To determine the marker mass (µg $cm^{-2}$) lost to the soil, the total tracer deposit found in each Petri dish was divided by the area of the respective Petri dish.

*Weed control efficacy*

The analysis of the effectiveness of weed control was composed of five visual evaluations at 7, 14, 21, 28, and 35 days after herbicide application. The scale of visual assessment was developed by the Asociación Latinoamericana de Malezas (ALAM, 1974).

*Spray drift*

The determination of the spray drift from the electrostatic application was performed in a separate experiment in a 2x2 factorial scheme, i.e., with or without the electrostatic spray and with or without adjuvant, with 90 L $ha^{-1}$ application rate in a randomized block design with four replications. The equipment used and the spray conditions were similar to those previously reported. The application rate of 50 L $ha^{-1}$ was not assessed due to the absence of suitable weather conditions during drift evaluations.

The ratings of spray drift followed the methodology proposed by ISO 22866 (International Organization for Standardization, 2005), which recommends that the temperature must be between 5 and 35 ºC, the minimum wind speed should be 1 m $s^{-1}$, and the wind direction should be within the range of 90º ± 30º with the spray line of application. The spraying area was 24-m-wide and 50-m-long (1,200 $m^2$) and presented similar weed infestation.

The rhodamine B (purity ≥ 95%) (Sigma-Aldrich®) marker was added to the spray solution (200 mg $L^{-1}$) for later quantification by fluorimetry according to the methodology presented by Alves et al. (2014). Moreover, according to these authors, this marker shows little influence on the physical and chemical characteristics of the spray solution; it is low-cost and has sunlight stability for up to 60 min.

The area adjacent to the area sprayed had the soil exposed where the collector net samplers (vertical and horizontal) were positioned, always following the main wind direction. The climatic data were monitored using a meteorological station (Davis® Mobile, Vantage PRO2TM). It was installed next to the area of applications and connected in real-time to a digital console that provided data on air temperature, air humidity, and wind speed and direction at the time of application.

The vertical samplers were installed before the applications and consisted of PVC rods, which supported nylon wires (2 mm in diameter, 2 m in length). The collectors were positioned at 5, 10, and 15 m from the area of application, from the boundary of each experimental plot in the wind direction. Three collectors were placed at each position; they were installed such that each wire was positioned 30 cm above the soil level and spaced 5 m apart from each other in the same line.

The soil drift was determined using horizontal samplers. Before the spray applications, polyethylene plates (0.4 x 0.08 x 0.006 m) with filter paper were placed on soil in an area adjacent to the target area, perpendicular to the direction of the spray application and the prevailing wind direction. Three plates were placed every 5 m, at 5, 10, and 15 m from the edge of the sprayed area.

After the spray application, the nylon wires and papers on the soil on each line were collected, stored in plastic bags, properly identified, packaged separately in a thermal box, and sent to the laboratory where they were kept under refrigeration (5 ºC) in dark until the reading.

The deposits were extracted from each sample using a 100 mL aqueous solution containing 0.2% Tween 80® (Polysorbate 80) added to each plastic bag containing the sample. The samples were agitated for 15 min at 120 rpm in a suspended stirring table (Tecnal TE®, 240/1). After 10 min of waiting, the solution was transferred to plastic cups for a posterior reading of marker concentration (ηg $mL^{-1}$) using a fluorimeter (Thermo Scientific®, FM109515). All the extraction steps were carried out to protect the samples from light to prevent the degradation of rhodamine B.

The fluorimeter reading, the surface area of the collector ($cm^2$), the marker concentration in the spray solution, and the application rate were used to calculate the amount of marker deposit sprayed per unit area. The luminescence data extracted from the papers were converted to the percentage of drift at each distance correlating the deposit to the amount applied in the field, using the equations presented by ISO (2005).

### 2.3 Statistical analysis

The data were analyzed to check normality of distribution of residues and homogeneity of variances of the treatments. After confirming the presuppositions, the F test of the analysis of variance was performed, when significant results were obtained, multiple comparisons of means were performed using the Tukey test ($p$<0.05). Comparisons with the additional treatments were performed using Dunnett's test ($p$<0.05). The statistical software Systat®, SPSS®, and Sisvar® were used.

## 3 Results and Discussion

The physicochemical properties of the spray solution and the charge/mass ratio differed for all variables (Table 1); all spray solutions were affected by the adjuvant. Cunha and Alves (2009) evaluated the effect of the addition of different doses of adjuvants on the physicochemical properties of spray solutions and verified the changes in these properties. The authors concluded that the characteristics of the spray solution were not similar, even for products with the same use indication. Thus, the results observed with the adjuvant (soybean lecithin + propionic acid) in this study may differ for other adjuvants. The solution pH, surface tension, and viscosity properties were more susceptible to the addition of the adjuvant.

The presence of glyphosate in the spray solutions had minor effect on pH; however, with the addition of the adjuvant, there was a greater reduction in pH. This result is linked to the presence of propionic acid in the composition of the adjuvant. Changes in pH may interfere with the biological effectiveness of phytosanitary spray solution, as demonstrated by Cunha and Alves (2009). The pH reduction (acidification) reduces the alkaline hydrolysis of sensitive products present in the spray solution. Herbicides such as glyphosate can be optimized by decreasing the pH of water to approximately 4 (Cunha et al., 2017).

The adjuvant slightly increased the density and dynamic viscosity of the spray solution; glyphosate reduced the spray solution density compared to water. Maski and Durairaj (2010) studied the influence of dynamic viscosity, density, electrical conductivity, and dielectric constant of spray solutions, as well as the efficiency of electric charge induction by an electrostatic spray. The authors concluded that the highest electrical conductivities and charge loads were observed in spray solutions that included adjuvants. In

**Table 1** - Physical and chemical properties and charge/mass ratio of the spray solution used in field tests

| Spray solution | pH | Density (g $cm^{-3}$) | Viscosity (mPa $s^{-1}$) | Surface tension (mN $m^{-1}$) | Electrical conductivity (µS $cm^{-1}$) | Charge/mass (mC $kg^{-1}$) |
|---|---|---|---|---|---|---|
| Gly 50 | 6.58 C | 0.995 D | 1.00 BC | 36.50 B | 18525 A | 13.83 B |
| Gly 50 Adj | 5.43 D | 1.021 B | 1.05 A | 30.50 C | 17034 B | 12.91 C |
| Gly 90 | 6.73 B | 0.992 E | 0.98 C | 35.60 B | 11242 C | 15.33 A |
| Gly 90 Adj | 4.98 E | 1.015 C | 1.02 B | 31.50 C | 10151 D | 10.66 D |
| Gly 150 | 6.65 BC | 0.993 E | 0.96 D | 35.60 B | 7312 E | - |
| Water | 6.85 A | 1.024 A | 0.99 C | 71.63 A | 16 F | 0.00 E |
| CV (%) | 0.85 | 0.09 | 1.03 | 1.19 | 0.01 | 0.93 |
| Fc | 905* | 1,104* | 33* | 4,261* | 8,091.421* | 15,468* |

Averages followed by similar letters in columns do not differ by the Tukey test (p<0.05); Fc: value of the F test; CV (%): coefficient of variation. *: significant at 5% probability. Gly 50: spray solution with glyphosate at a rate of 50 L $ha^{-1}$; Gly 50 Adj: spray solution with glyphosate at a rate of 50 L $ha^{-1}$ + adjuvant; Gly 90: spray solution with glyphosate at a rate of 90 L $ha^{-1}$; Gly 90 Adj: spray solution with glyphosate at a rate of 90 L $ha^{-1}$ + adjuvant; Gly 150: spray solution with glyphosate at a rate of 150 L $ha^{-1}$ (no electrostatic spray).

the present study, the use of an adjuvant led to a reduction in the electrical charge on the droplets as compared with the spray solution without adjuvant, which is possibly due to the decrease in conductivity, as observed in the mass/charge ratio.

The electrical conductivity increased in all spray solutions compared to water. Spray solutions without adjuvant and with glyphosate exhibited higher conductivities.

The surface tension for all spray solutions reduced compared to water, demonstrating that the glyphosate formulation has surfactant action. This reduction intensified with the presence of the adjuvant. Adjuvant with surfactant characteristics decreases the surface tension of the spray solution and improves the spread, retention, and adhesiveness on the leaf surface and, consequently, the coverage of the spray solution (Cunha and Alves, 2009; Cunha et al., 2017).

The charge/mass ratio is an important variable for understanding the ability of electrostatic equipment to energize the droplets. The largest mass/charge ratios were found in the spray solutions with glyphosate. The addition of the adjuvant did not improve this parameter. This possibly occurred because the herbicide formulation already possessed a high capacity to increase the electrical conductivity of the spray solution.

A significant difference in leaf deposition was detected in Test 1 for different application rates. We observed superior deposition at 90 L ha$^{-1}$ regardless of the electrostatic application and the use of adjuvant in spray solution (Table 2). When comparing the treatments with the additional (150 L ha$^{-1}$), all treatments were found to be similar except the 90 L ha$^{-1}$ rate of application, without adjuvant and electrostatic treatment, which presented higher spray deposition. No difference between the treatments was observed for the variable loss of spray solution to the soil, and all the treatments were similar to the conventional treatment (150 L ha$^{-1}$).

In Test 2 (Table 3), there was a significant improvement in the deposition on plants with the addition of the adjuvant to the spray solution independent of the electrostatic spray technology. This could be a result of a change in the physicochemical properties of the spray solution by the adjuvant, in particular, the reduction of surface tension, which improved the deposition on targets.

The electrostatic factor did not influence the deposition for either of the application rates of 50 or 90 L ha$^{-1}$. It is noteworthy that the droplet size in the treatments with and without electrostatic system was the same (VMD close to 125 µm according to the manufacturer) since the spray tips were similar, and this may have contributed to the results. The use of very fine and fine droplets is one of the main characteristics of systems energizing the droplets, which facilitates an increase in the target coverage. According to Chaim (2006), the production of fine droplets improves the induction of electrical forces of sufficient magnitude to control their movement, including against the force of gravity.

The decrease in the application rate caused no significant difference in the coverage of weeds, indicating that reducing the volume of water used per unit area is technically viable. Lower rates of application provide a greater operational capacity of

**Table 2** - Spray solution deposition applied on weeds and losses to the soil for different application rates, use of an adjuvant, and the technology of electrostatic application (Test 1)

| Application rate (L ha$^{-1}$) | Adjuvant | Deposition (mg g$^{-1}$) | | | Loss to the soil (µg cm$^{-2}$) | | |
|---|---|---|---|---|---|---|---|
| | | Electrostatic | | Average | Electrostatic | | Average |
| | | With | Without | | With | Without | |
| 50 | With | 0.88 | 1.30 | 0.98 B | 1,785.75 | 1,873.78 | 1,722.65 |
| | Without | 0.86 | 0.87 | | 1,716.57 | 1,514.48 | |
| 90 | With | 1.25 | 1.41 | 1.46 A | 1,579.37 | 1,571.94 | 1,693.87 |
| | Without | 1.43 | 1.75 $^{+}$ | | 2,091.75 | 1,530.25 | |
| 150 | | 0.83 | | | 1,984.34 | | |
| CV (%) | | 36.30 | | | 63.45 | | |
| Fc | | $F_{ExRxA}$=0.84$^{ns}$; $F_{ExR}$=0.00$^{ns}$; $F_{ExA}$=0.17$^{ns}$; $F_{RxA}$=2.38$^{ns}$; $F_{E}$=2.16$^{ns}$; $F_{R}$=9.47**; $F_{A}$=0.01$^{ns}$; $D_{unnett}$=3.18* | | | $F_{ExRxA}$=0.03$^{ns}$; $F_{ExR}$=0.08$^{ns}$; $F_{ExA}$=0.30$^{ns}$; $F_{RxA}$=0.34$^{ns}$; $F_{E}$=0.19$^{ns}$; $F_{R}$=0.00$^{ns}$; $F_{A}$=0.00$^{ns}$; $D_{unnett}$=0.29$^{ns}$ | | |

Averages followed by similar letters in columns do not differ by the Tukey test ($p$<0.05); Fc: value of the F test; CV (%): coefficient of variation. * significant at 5% probability; ** significant at 1% probability; $^{ns}$ not significant; $^{+}$: average diverging from the conventional treatment (150 L ha$^{-1}$) by Dunnett's test ($p$<0.05). $F_{ExRxA}$: interaction among electrostatic, application rate, and adjuvant; $F_{ExR}$: interaction between electrostatic and application rate; $F_{ExA}$: interaction between electrostatic and adjuvant; $F_{RxA}$: interaction between application rate and adjuvant; $F_{E}$: electrostatic; $F_{R}$: rate of application; $F_{A}$: adjuvant; $F_{Dunnett}$: interaction between factorial and conventional treatment (150 L ha$^{-1}$).

**Table 3** - Spray solution deposition applied on weeds and losses to the soil for different application rates, use of an adjuvant, and the technology of electrostatic application (Test 2)

| Application rate (L ha$^{-1}$) | Electrostatic | Deposition (mg g$^{-1}$) | | Loss to the soil (µg cm$^{-2}$) | |
|---|---|---|---|---|---|
| | | With adjuv. | Without adjuv. | With adjuv. | Without adjuv. |
| 50 | With | 0.45 | 0.30 | 3,104.03 $^{+}$ | 2,522.15 $^{+}$ |
| | Without | 0.43 | 0.33 | 2,141.24 $^{+}$ | 2,686.36 $^{+}$ |
| | Average | 0.44 a | 0.32 b | 2,622.63 | 2,604.25 |
| 90 | With | 0.60 $^{+}$ | 0.32 | 2,972.18 $^{+}$ | 1,312.37 $^{+}$ |
| | Without | 0.52 | 0.22 | 2,079.20 $^{+}$ | 2,370.85 $^{+}$ |
| | Average | 0.50 a | 0.29 b | 2,525.75 | 1,841.61 |
| 150 | | 0.34 | | 6,171.87 | |
| CV (%) | | 30.88 | | 44.99 | |
| Fc | | $F_{ExRxA}$=0.16$^{ns}$; $F_{ExR}$=1.26$^{ns}$; $F_{ExA}$=0.06$^{ns}$; $F_{RxA}$=3.83$^{ns}$; $F_{E}$=0.96$^{ns}$; $F_{R}$=0.80$^{ns}$; $F_{A}$=22.58**; $F_{Dunnett}$=0.69$^{*}$ | | $F_{ExRxA}$=0.29$^{ns}$; $F_{ExR}$=0.39$^{ns}$; $F_{ExA}$=4.06$^{ns}$; $F_{RxA}$=0.76$^{ns}$; $F_{E}$=0.17$^{ns}$; $F_{R}$=1.26$^{ns}$; $F_{A}$=0.84$^{ns}$; $F_{Dunnett}$=39.25** | |

Averages followed by similar letters in rows do not differ by the Tukey test ($p$<0.05); Fc: value of the F test; CV (%): coefficient of variation. * significant at 5% probability; ** significant at 1% probability; $^{ns}$: not significant; $^{+}$ average diverging from the conventional treatment (150 L ha$^{-1}$) by Dunnett's test ($p$<0.05). $F_{ExRxA}$: interaction among electrostatic, application rate, and adjuvant; $F_{ExR}$: interaction between electrostatic and application rate; $F_{ExA}$: interaction between electrostatic and adjuvant; $F_{RxA}$: interaction between application rate and adjuvant; $F_{E}$: electrostatic; $F_{R}$: rate of application; $F_{A}$: adjuvant; $F_{Dunnett}$: interaction between factorial and conventional treatment (150 L ha$^{-1}$).

spraying equipment, which tends to reduce costs and increase the use periods in favorable climatic conditions during application. The comparison of the spray deposition among the conventional treatment (150 L ha$^{-1}$) and the other treatments indicated that the 90 L ha$^{-1}$ rate of application with electrostatic spray technology and adjuvant presented superior deposition.

Weeds are exposed to spraying for a short period; moreover, factors such as fluctuations and boom height, wind, droplet size, and stage of plant development render the deposit values to be highly variable, reducing the scope of comparison among treatments.

There was no significant difference among the treatments for spray solution losses to the soil, regardless of the use of electrostatic spray technology or adjuvant. The losses to the soil with the hollow cone tip, compared to the conventional treatment, indicated that low rates of application reduced the losses, regardless of the presence of adjuvant and droplet electrification. All treatments were different and presented reduced losses with low rates of application, probably as a function of the droplet spectra produced by the tips evaluated; coarse droplets tend to increase the losses to the soil after colliding with the target. Similar responses were presented by Matuo et al. (2004). Cunha et al. (2003) evaluated the strategies for drift control and observed that the tips that produce coarse droplets allow drift reduction. However, coarse droplets are not suitable for electrostatic systems, given the difficulty in energizing them.

In Tables 4 and 5, we present the effectiveness of weed control based on a visual grading scale. Seven days after the first application, no significant differences were observed among the treatments and the conventional treatment (150 L ha$^{-1}$). After 14 days, the treatment with 90 L ha$^{-1}$ rate of application presented superior efficiency with the use of an adjuvant, regardless of the use of the electrostatic spray technology. The plants showed abnormal growth of branches and stem and bending of leaves, decreasing the surface area exposed to light.

In Test 1, after 21, 28, and 35 days of application (Table 4), the 90 L ha$^{-1}$ rate of application showed greater efficiency with the use of an adjuvant compared to the rest, regardless of the use of electrostatic spray technology. Only the treatment with a 90 L ha$^{-1}$ rate of application without adjuvant, regardless of the use of electrostatic spray technology, was inferior than the conventional treatment (150 L ha$^{-1}$).

In Test 2 (Table 5), seven days after the application, the interaction between factors (rate of application and electrostatic application) indicated great weed control at 90 L ha$^{-1}$ rate with the electrostatic spray. The comparisons with the conventional treatment (150 L ha$^{-1}$) showed that treatment with 50 L ha$^{-1}$ rate of application without adjuvant presented low values of control effectiveness; at 90 L ha$^{-1}$ rate, only the treatment without electrostatic spray technology and adjuvant differed.

After 14 days of the application, there was no significant difference between the treatments. Only the 90 L ha$^{-1}$ rate of application without electrostatic and adjuvant differed from the conventional treatment (150 L ha$^{-1}$). After 21 days of the application, the 90 L ha$^{-1}$ rate of application

**Table 4** - Efficacy of weed control (%) for different application rates, use of an adjuvant, and the technology of electrostatic application (Test 1)

| Application rate (L ha$^{-1}$) | Adjuvant | 7 days | | | 14 days[(1)] | | | 21 days[(1)] | | | 28 days[(1)] | | | 35 days[(1)] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Electrostatic | | | Electrostatic | | | Electrostatic | | | Electrostatic | | | Electrostatic | | |
| | | With | Without | Average | With | Without | Average | With | Without | Average | With | Without | Average | With | Without | Average |
| 50 | With | 2.50 | 2.50 | 2.50 | 33.75Ψ$^{+}$ | 43.75Ψ | 38.75 Ab | 80.00Ψ | 83.75Ψ | 81.87 Aa | 88.75Ψ | 90.00Ψ | 89.37 Ab | 78.75Ψ | 78.75Ψ | 78.75 Aa |
| | Without | 2.50 | 2.50 | 2.50 | 42.50Ψ | 45.00Ψ | 43.75 Aa | 68.75Ψ | 71.25Ψ | 70.00 Aa | 91.25Ψ | 90.00Ψ | 90.62 Aa | 80.00Ψ | 82.50Ψ | 81.25 Aa |
| 90 | With | 2.50 | 0.00 | 1.25 | 62.50Ψ | 57.50Ψ | 60.00 Aa | 91.25Ψ | 93.25Ψ | 92.25 Aa | 96.25Ψ | 98.75Ψ | 97.50 Aa | 87.50Ψ | 91.25Ψ | 89.37 Aa |
| | Without | 2.50 | 2.50 | 2.50 | 30.00Ψ$^{+}$ | 31.25Ψ$^{+}$ | 30.62 Ba | 66.25Ψ$^{+}$ | 52.50Ψ$^{+}$ | 59.37 Bb | 57.50Ψ$^{+}$ | 57.50Ψ$^{+}$ | 57.50 Bb | 37.50Ψ$^{+}$ | 47.50Ψ$^{+}$ | 42.50 Bb |
| 150 | | | 3.75 | | | 60.00 | | | 92.00 | | | 97.50 | | | 90.00 | |
| Control | | | 0 | | | 0 | | | 0 | | | 0 | | | 0 | |
| CV (%) | | | 125.94 | | | 32.15 | | | 16.97 | | | 18.91 | | | 23.50 | |
| Fc | | $F_{ExRxA}$=0.41$^{ns}$; $F_{ExR}$=0.41$^{ns}$; $F_{ExA}$=0.41$^{ns}$; $F_{RxA}$=0.41$^{ns}$; $F_E$=0.41$^{ns}$; $F_R$=0.41$^{ns}$; $F_A$=0.41$^{ns}$; $F_{Dunnett}$=0.09$^{ns}$ | | | $F_{ExRxA}$=0.48$^{ns}$; $F_{ExR}$=0.68$^{ns}$; $F_{ExA}$=0.00$^{ns}$; $F_{RxA}$=12.20**; $F_E$=0.19$^{ns}$; $F_R$=0.68$^{ns}$; $F_A$=0.13*; $F_{Dunnett}$=6.92* | | | $F_{ExRxA}$=0.63$^{ns}$; $F_{ExR}$=0.97$^{ns}$; $F_{ExA}$=0.87$^{ns}$; $F_{RxA}$=5.32*; $F_E$=0.09$^{ns}$; $F_R$=0.00$^{ns}$; $F_A$=24.18**; $F_{Dunnett}$=40.59** | | | $F_{ExRxA}$=0.00$^{ns}$; $F_{ExR}$=0.01$^{ns}$; $F_{ExA}$=0.05$^{ns}$; $F_{RxA}$=13.56**; $F_E$=0.01$^{ns}$; $F_R$=4.98*; $F_A$=11.97**;$F_{Dunnett}$=37.02** | | | $F_{ExRxA}$=0.02$^{ns}$; $F_{ExR}$=0.21$^{ns}$; $F_{ExA}$=0.13$^{ns}$; $F_{RxA}$=16.58**; $F_E$=0.44$^{ns}$; $F_R$=5.38*; $F_A$=13.39**; $F_{Dunnett}$=21.02** | |

Fc: value of the F test; CV (%): coefficient of variation. $^{+}$ Ψ: averages that differ from the conventional treatment (150 L ha$^{-1}$) and control (no application), respectively, by the Dunnett test ($p$<0,05). * significant at 5% probability; ** significant at 1% probability; $^{ns}$ not significant. $F_{ExRxA}$: interaction among electrostatic, application rate, and adjuvant; $F_{ExR}$: interaction between electrostatic and application rate; $F_{ExA}$: interaction between electrostatic and adjuvant; $F_{RxA}$: interaction between application rate and adjuvant; $F_E$: electrostatic; $F_R$: rate of application; $F_A$: adjuvant; $F_{Dunnett}$: interaction between factorial and conventional treatment (150 L ha$^{-1}$). [(1)] Averages followed by similar capital letters in columns do not differ by the Tukey test ($p$<0.05) in comparison to the adjuvant within the application rate. Averages followed by similar lowercase letters in columns do not differ by the Tukey test ($p$<0.05) in the comparison of the application rate within the adjuvant.

**Table 5** - Efficacy of weed control (%) for different application rates, use of an adjuvant, and the technology of electrostatic application (Test 2)

| Application rate (L ha$^{-1}$) | Adjuvant | 7 days[(1)] | | | 14 days | | | 21 days[(2)] | | | 28 days | | | 35 days[(2)] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Electrostatic | | | Electrostatic | | | Electrostatic | | | Electrostatic | | | Electrostatic | | |
| | | With | Without | Average | With | Without | Average | With | Without | Average | With | Without | Average | With | Without | Average |
| 50 | With | 57.50Ψ | 60.00Ψ | 58.75 a | 68.75Ψ | 68.75Ψ | 68.75 | 83.75Ψ | 83.75Ψ | 83.75 Aa | 82.50Ψ | 81.25Ψ | 81.88 | 81.25Ψ | 82.00Ψ | 81.62 Aa |
| | Without | 45.00Ψ$^{+}$ | 45.00Ψ$^{+}$ | 45.00 a | 71.25Ψ | 66.25Ψ | 68.75 | 86.25Ψ | 85.00Ψ | 85.62 Aa | 89.25Ψ | 85.00Ψ | 87.13 | 83.75Ψ | 84.50Ψ | 84.12 Aa |
| | Average | 51.25 Aa | 52.50 Aa | | | | | | | | | | | | | |
| 90 | With | 53.75Ψ | 51.25Ψ | 52.50 a | 72.50Ψ | 71.25Ψ | 71.88 | 87.50Ψ | 87.50Ψ | 87.50 Aa | 88.75Ψ | 83.00Ψ | 85.88 | 81.25Ψ | 82.00Ψ | 81.62 Aa |
| | Without | 50.00Ψ | 35.00Ψ$^{+}$ | 42.50 a | 72.50Ψ | 50.00Ψ$^{+}$ | 61.25 | 86.00Ψ | 72.50Ψ$^{+}$ | 79.25 Bb | 90.00Ψ | 81.25Ψ | 85.63 | 77.00Ψ | 66.25Ψ$^{+}$ | 71.62 Bb |
| | Average | 51.87 Aa | 43.12 Bb | | | | | | | | | | | | | |
| 150 | | | 63.75 | | | 75.00 | | | 89.25 | | | 88.00 | | | 87.50 | |
| Control | | | 0 | | | 0 | | | 0 | | | 0 | | | 0 | |
| CV (%) | | | 12.59 | | | 15.33 | | | 5.99 | | | 8.18 | | | 9.97 | |
| Fc | | $F_{ExRxA}$=1.27$^{ns}$; $F_{ExR}$=5.11*; $F_{ExA}$=2.87$^{ns}$; $F_{RxA}$=0.71$^{ns}$; $F_E$=2.87$^{ns}$; $F_R$= 3.91$^{ns}$; $F_A$=28.82**; $F_{Dunnett}$=33.64** | | | $F_{ExRxA}$=1.22$^{ns}$; $F_{ExR}$=1.63$^{ns}$; $F_{ExA}$=3.20$^{ns}$; $F_{RxA}$=2.19$^{ns}$; $F_E$=3.84$^{ns}$; $F_R$= 0.35$^{ns}$; $F_A$=2.09$^{ns}$; $F_{Dunnett}$= 49.54** | | | $F_{ExRxA}$=2.95$^{ns}$; $F_{ExR}$=2.95$^{ns}$; $F_{ExA}$=4.29$^{ns}$; $F_{RxA}$=8.08**; $F_E$=4.29$^{ns}$; $F_R$= 0.54$^{ns}$; $F_A$=3.20$^{ns}$; $F_{Dunnett}$= 297.51** | | | $F_{ExRxA}$=0.00$^{ns}$; $F_{ExR}$=0.83$^{ns}$; $F_{ExA}$=0.37$^{ns}$; $F_{RxA}$=1.25$^{ns}$; $F_E$=4.12$^{ns}$; $F_R$= 0.26$^{ns}$; $F_A$=1.03$^{ns}$; $F_{Dunnett}$=213.66** | | | $F_{ExRxA}$=1.04$^{ns}$; $F_{ExR}$=1.04$^{ns}$; $F_{ExA}$=1.04$^{ns}$; $F_{RxA}$=4.94*; $F_E$=0.57$^{ns}$; $F_R$= 4.94*; $F_A$=1.78$^{ns}$; $F_{Dunnett}$=130.34** | |

Fc: value of the F test; CV (%): coefficient of variation. +, Ψ: averages that differ from the conventional treatment (150 L ha$^{-1}$) and control (no application), respectively, by the Dunnett test ($p$<0,05). * significant at 5% probability; ** significant at 1% probability; $^{ns}$ not significant. $F_{ExRxA}$: interaction among electrostatic, application rate, and adjuvant; $F_{ExR}$: interaction between electrostatic and application rate; $F_{ExA}$: interaction between electrostatic and adjuvant; $F_{RxA}$: interaction between application rate and adjuvant; $F_E$: electrostatic; $F_R$: rate of application; $F_A$: adjuvant; $F_{Dunnett}$: interaction between factorial and conventional treatment (150 L ha$^{-1}$). [(1)] Averages followed by similar capital letters in columns do not differ by the Tukey test ($p$<0.05) in comparison to the rate of application within the electrostatic factor. Averages followed by similar lowercase letters in rows do not differ by the Tukey test ($p$<0.05) in the comparison of the electrostatic factor within the rate of application. Averages followed by similar italic lowercase letters in columns do not differ by the Tukey test ($p$<0.05) in the comparison of the adjuvant factor levels (average with or without the adjuvant). [(2)] Averages followed by similar capital letters in columns do not differ by the Tukey test ($p$<0.05) in comparison to the adjuvant within the rate of application. Averages followed by similar lowercase letters in columns do not differ by the Tukey test ($p$<0.05) in the comparison of the rate of application within the adjuvant.

presented high efficacy when using adjuvant, regardless of the use of electrostatic spray technology. Only the 90 L ha$^{-1}$ rate of application without electrostatic and without adjuvant differed from the conventional treatment (150 L ha$^{-1}$). On the 28th day after application, no significant differences among treatments or conventional treatment (150 L ha$^{-1}$) were observed.

After 35 days of the application, the 90 L ha$^{-1}$ rate of application presented great efficacy when the adjuvant was used, regardless of the use of electrostatic spray technology. Without the use of an adjuvant, the 50 L ha$^{-1}$ rate of application promoted greater control than the 90 L ha$^{-1}$ rate of application. When comparing the treatments with the conventional (150 L ha$^{-1}$) rate, only the 90 L ha$^{-1}$ rate of application without electrostatic and adjuvant was inferior.

In all the applications in both the tests, treatments with herbicide application differed from the control, i.e., treatment without application.

According to Furness and Pinczewski (1985), the comparison of the performance of spray systems should include the evaluation of biological effectiveness.

**Table 6** - Spray drift (% of the application rate) of herbicide with adjuvant added to the spray solution using electrostatic spray technology at different distances using nylon and paper horizontal collectors

| Distance | Nylon collector (Vertical) | | | | Paper collector (Horizontal) | | | |
|---|---|---|---|---|---|---|---|---|
| | Adjuvant | | Electrostatic | | Adjuvant | | Electrostatic | |
| | With | Without | With | Without | With | Without | With | Without |
| 5 m | 21.52 b | 23.72 a | 22.58 | 22.67 | 2.88 b | 3.44 a | 3.00 | 3.32 |
| CV (%) | 13.03 | | | | 17.80 | | | |
| Fc | $F_{ExA}$=0.02$^{ns}$; $F_E$=0.00$^{ns}$; $F_A$=5.01* | | | | $F_{ExA}$=0.16$^{ns}$; $F_E$=3.03$^{ns}$; $F_A$=8.73** | | | |
| 10 m | 19.68 b | 22.74 a | 21.07 | 21.35 | 2.57 b | 2.87 a | 2.71 | 2.73 |
| CV (%) | 12.67 | | | | 7.99 | | | |
| Fc | $F_{ExA}$=0.04$^{ns}$; $F_E$=0.09$^{ns}$; $F_A$=11.62** | | | | $F_{ExA}$=0.00$^{ns}$; $F_E$=0.11$^{ns}$; $F_A$=17.05** | | | |
| 15 m | 18.96 | 19.60 | 18.89 | 19.67 | 2.54 b | 2.65 a | 2.59 | 2.60 |
| CV (%) | 6.56 | | | | 4.79 | | | |
| Fc | $F_{ExA}$=1.40$^{ns}$; $F_E$=3.39 $^{ns}$; $F_A$=2.33$^{ns}$ | | | | $F_{ExA}$=0.16$^{ns}$; $F_E$=0.00$^{ns}$; $F_A$=7.30** | | | |

Averages followed by similar letters in rows do not differ by the Tukey test ($p$<0.05); Fc: value of the F test; CV (%): coefficient of variation. * significant at 5% probability; ** significant at 1% probability; $^{ns}$ not significant. $F_{ExA}$: interaction between electrostatic and adjuvant; $F_E$: electrostatic; $F_A$ adjuvant.

However, variations in operating conditions of the equipment may not be sufficient to detect significant control differences, since the active ingredient can be in excess concentrations in commercial formulations, as quoted by Raetano and Matuo (1999).

Regarding the spray drift (Table 6), no interaction between the use of adjuvant and electrostatic spray technology was observed. The nylon wire collector, at 5 and 10 m from the sprayed area, indicated that the adjuvant reduced the spray solution drift, regardless of the technology of electrostatic application. At 15 m from the spray area, there was no difference between the treatments.

The drift responses using the horizontal collectors were similar to the vertical collectors. There was less drift at 5 and 10 m distances when the spray solution was applied with the adjuvant. For 15 m of distance from the sprayed area, the spray drift was similar among the treatments. Studies such as those conducted by Godinho Júnior et al. (2018) demonstrate the potential of soy lecithin + propionic acid in the reduction of losses by drift.

The intensive use of glyphosate to control weeds resulted in multiple opportunities for the occurrence of spray drift (Johnson et al., 2006; Ghisi and Cestari, 2013). Glyphosate toxicity has also been reported for many crops, which demonstrates the need for a technique to reduce spray drift.

## 4 Conclusions

The electrostatic system could energize the droplets during the application of a spray solution containing glyphosate and adjuvant; however, the droplet electrification did not influence the spray solution deposition, losses to the soil, or drift. The weed control, in general, was also not affected by the electrostatic system. However, the adjuvant soy lecithin + propionic acid changed all the physicochemical properties of the spray solution, thus improving the efficiency of the application and reducing the losses caused by the drift. The findings of this study highlight the use of an adjuvant as an important tool in the technology for application of weed control.

## 5 Contributions

Conceptualization, formal analysis, investigation, methodology, project administration, all authors; writing - original draft, SFBC; writing - review & editing, EML and JPARC; funding acquisition, JPARC.

## 6 Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES) – Finance Code 001 and Fundação de Amparo à Pesquisa do Estado de Minas Gerais – Brazil (Fapemig) - Finance Code PPM-00124-18. To CNPq for the Research Fellowship of João Paulo Arantes Rodrigues da Cunha/N.Proc. 304353/2017-5 CNPq.

## 7 References

Alves GS, Cunha JPAR. Field data and prediction models of pesticide spray drift on coffee crop. Pesq Agropec Bras. 2014;49(8):622-9.

Alves GS, Cunha JPAR, Palladini LA. Seleção de traçadores para estudos de eficiência das aplicações de produtos fitossanitários. Planta Daninha 2014;32(4):861-70.

Asociación Latinoamericana de Malezas – ALAM. Recomendaciones sobre unificación de los sistemas de evaluación en ensayos de control de malezas. ALAM. 1974;1(1):35-8.

Bayer T, Costa IFD, Lenz G, Zemolin C, Marques LN, Stefanelo MS. Equipamentos de pulverização aérea e taxas de aplicação de fungicida na cultura do arroz irrigado. Rev Bras Eng Agríc Ambient. 2011;15(2):192-8.

Beck HE, Zimmermann NE, Mcvicar TR, Vergopolan N, Berg A, Wood EF. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data 2018;1:1-12.

Chaim A. Aperfeiçoamento de bico de pulverização eletrostática para geração de gotas com alto nível de carga. Pesq Agropec Bras. 1998;33(4):463-70.

Chaim A, Pessoa MCPY, Ferracini VL. Eficiência de deposição de agrotóxicos obtida com bocal eletrostático para pulverizador costal motorizado. Pesq Agropec Bras. 2002;37(4):497-501.

Chaim A. Pulverização eletrostática: principais processos utilizados para eletrificação de gotas. Jaguariúna: Embrapa Meio Ambiente; 2006.

Coffee RA. Electrodynamic crop spraying. Outlook Agr. 1981;10(7):350-6.

Cunha JPAR, Alves GS. Características físico-químicas de soluções aquosas com adjuvantes de uso agrícola. Interciência 2009;34(9):655-9.

Cunha JPAR, Teixeira MM, Coury JR, Ferreira LR. Avaliação de estratégias para a redução da deriva de agrotóxicos em pulverizações hidráulicas. Planta Daninha 2003;21(2):325-332.

Cunha JPAR, Alves GS, Marques RS. Tensão superficial, potencial hidrogeniônico e condutividade elétrica de caldas de produtos fitossanitários e adjuvantes. Rev Ciênc Agron. 2017;48(2):261-70.

Dan HA, Dan LGM, Barroso AL, Souza CH. Efeito do pH da calda de pulverização na dessecação de braquiária brizanta com o herbicida glyphosate. Global Sci Tech. 2009;2(1):1-6.

Dopierala K, Prochaska K. The effect of molecular structure on the surface properties of selected quaternary ammonium salts. J Colloid Interf Sci. 2008;321(1):220-6.

Furness GO, Pinczewski WV. A comparison of the spray distribution obtained from sprayers with converging and diverging airjets with low volume air assisted spraying on citrus and grapevines. J Agric Eng Res. 1985;32(4):291-310.

Ghisi NC, Cestari MM. Genotoxic effects of the herbicide Roundup® in the fish *Corydoras paleatus* (Jenyns 1842) after short-term, environmentally low concentration exposure. Environ Monit Assess. 2013;185(4):3201-7.

Godinho Júnior JD, Ruas RAA, Reis MR, Carvalho Filho AC, Faria VR. Reduction in the spray drift of 2,4-D in tomato using hydraulic nozzles with air induction and LI-700 adjuvant. Pesq Agropec Trop. 2018;48(2):134-9.

ISO. Equipment for crop protection - Methods for field measurement of spray drift. ISO/FDIS 22866. Geneva: ISO; 2005.

Johnson AK, Roeth FW, Martin AR, Klein RN. Glyphosate spray drift management with drift reducing nozzles and adjuvants. Weed Technol. 2006;20(4):893-7.

Law SE. Agricultural electrostatic spray application: a review of significant research and development during the 20th century. J Electrostat. 2001;51:25-42.

Magno Júnior RG, Teixeira MM, Vieira LB, Ferreira LR, Alvarenga CB. Desenvolvimento de um dispositivo eletrônico para atração de gotas da aplicação eletrostática em plantas cítricas. Biosci J. 2011;27(5):798-804.

Maski D, Durairaj D. Effects of charging voltage, application speed, target height and orientation upon charged spray deposition on leaf abaxial and adaxial surfaces. Crop Prot. 2010;29(2):134-41.

Matuo T, Pio LC, Ramos HH. Curso de proteção de plantas. Mod. 2. Tecnologia de aplicação de defensivos agrícolas e equipamentos e técnicas de aplicação. Brasília: ABEAS; 2004.

Maynagh BM, Ghobadian B, Jahannama MR, Hashjin TT. Effect of electrostatic induction parameters on droplets charging for agricultural application. J Agr Sci Tech. 2009;11(3):249-57.

Raetano CG, Matuo T. Efeito da pulverização com turboatomizadores em diferentes condições operacionais no controle de ácaros em citros. An Soc Entomol Bras. 1999;28(1):131-40.

Sasaki RS, Teixeira MM, Santiago H, Madureira RP, Maciel CFS, Fernandes HC. Adjuvantes nas propriedades físicas da calda, espectro e eficiência de eletrificação das gotas utilizando a pulverização eletrostática. Ciênc Rural 2015;45(2):274-9.

Tavares RM, Cunha JPAR, Alves TC, Alves GS, Silva ER. Estudo de um sistema de eletrificação de gotas em pulverizador costal pneumático pelo método de gaiola de Faraday. Rev Ceres 2017;64(5):476-85.

Tavares RM, Cunha JPAR, Naves MG, Bueno MR, Alves GS. Deposição de calda em plantas de soja empregando pulverizador com barra convencional e barra auxiliar. Rev Agrotec. 2014;5(1):87-104.

Yamashita O, Orsi JVN, Resende DD, Mendonça FS, Ribeiro Campos O, Massaroto JA, et al. Deriva simulada de herbicidas em mudas de *Coffea canephora*. Sci Agrar Paran. 2013;12(2):148-56.