Journal of the Brazilian Association of Agricultural Engineering
ISSN: 1809-4430 (on-line)

DISTRIBUTION PATTERN, SURFACE TENSION AND CONTACT ANGLE OF HERBICIDES ASSOCIATED TO ADJUVANTS ON SPRAYING AND CONTROL OF *Ipomoea hederifolia* UNDER RAINFALL INCIDENCE

Doi:http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v35n4p756-768/2015

RICARDO A. CALORE[1], MARCELO DA C. FERREIRA[2], NARA E. L. RODRIGUES[3], ALESSANDRA K. OTUKA[4]

ABSTRACT: Scarlet Morning Glory is considered to be an infesting weed that affects several crops and causes serious damage. The application of chemical herbicides, which is the primary control method, requires a broad knowledge of the various characteristics of the solution and application technology for a more efficient phytosanitary treatment. Therefore this study aimed to characterize the effect of rainfall incidence on the control of *Ipomoea hederifolia*, considering droplet size, surface tension, contact angle of droplets formed by herbicides liquid on vegetal and artificial surfaces, associated to adjuvants and the volumetric distribution profile of the spray jet. The addition of the adjuvants to the herbicide spraying liquid improved the application quality, as it influenced the angle formed by the spray by broadening the deposition band of the spray nozzle and thus the possible distance between the nozzles on spray boom and due the changes at droplet size, which contribute to a safety application. The rainfall occurrence affected negatively the weed control with the different spraying liquids and also the dry matter weight, suggesting that the phytosanitary product applied was washed off.

KEYWORDS: application technology, scarlet morning glory, glyphosate, paraquat.

PADRÃO DE DISTRIBUIÇÃO, TENSÃO SUPERFICIAL E ÂNGULO DE CONTATO DE CALDAS HERBICIDAS ASSOCIADAS A ADJUVANTES EM PULVERIZAÇÃO E CONTROLE DE *Ipomoea hederifolia* SOB INCIDÊNCIA DE CHUVA

RESUMO: A corda-de-viola é considerada uma planta daninha infestante de diversas culturas, causando importantes prejuízos. A aplicação de herbicidas químicos, principal método de controle, requer o conhecimento de diversas características da calda e da tecnologia de aplicação para tornar o tratamento fitossanitário mais eficiente. Diante disso, este trabalho teve como objetivo caracterizar o efeito da incidência de chuvas no controle de *Ipomoea hederifolia*, considerando o tamanho das gotas, a tensão superficial, o ângulo de contato de gotas formadas por caldas herbicidas em superfícies vegetais e artificiais, associados a adjuvantes e o perfil de distribuição volumétrica do jato pulverizado. A adição dos adjuvantes na calda herbicida melhorou a qualidade da aplicação, pois influenciou no ângulo formado pelo jato de pulverização, ampliando a faixa de deposição da ponta, e diminuiu as gotas suscetíveis à deriva divido às alterações no tamanho das gotas, o que contribui para uma aplicação de segurança. A incidência de chuva afetou negativamente o controle das plantas daninhas nas diferentes caldas e também o peso de massa seca, indicando uma lavagem dos produtos aplicados.

PALAVRAS-CHAVE: tecnologia de aplicação, corda-de-viola, glifosato, paraquat.

---

[1] Engº Agrônomo, Doutor, Departamento de Fitossanidade, Unesp, Campus de Jaboticabal, Jaboticabal-SP, Fone: (16) 3209-7299, ricardocalore@yahoo.com.br

[2] Engº Agrônomo, Prof. Adjunto, Departamento de Fitossanidade, UNESP, Campus de Jaboticabal, Jaboticabal – SP, mdacosta@fcav.unesp.br

[3] Engª Agrônoma, Doutora, Departamento de Fitossanidade, UNESP, Campus de Jaboticabal, Jaboticabal – SP, naraelr@hotmail.com

[4] Engª Agrônoma, Mestre, Departamento de Fitossanidade, UNESP, Campus de Jaboticabal, Jaboticabal – SP, naraelr@hotmail.com

Recebido pelo Conselho Editorial em: 11-3-2013
Aprovado pelo Conselho Editorial em: 22-12-2014

INTRODUTION

The genus *Ipomoea*, which is commonly known as Scarlet Morning Glory, is the most prominent in the Convolvulaceae family with over 600 species worldwide. *Ipomea hederifolia* is a plant native to the tropical and subtropical American continent and is considered to be an infesting weed of several crops, hampering the harvest and causing damage to sugar cane, maize and soybeans among other crops (KISSMANN & GROTH 1999).

Chemical control is the most commonly used weed management method, and knowledge of efficient herbicides, equipment and appropriate environmental conditions are required. Therefore, the proper application of the phytosanitary product should be performed at the right time, providing sufficient coverage of the target (FERREIRA et al. 2009) and depositing the required amount of active ingredient to safely eliminate or mitigate a particular problem while aiming to avoid economic and environmental damage (MATUO, 1990).

The spray nozzles are considered the main components of spraying because they have characteristics that ensure better safety and effectiveness in control of pests, diseases and weeds (VIANA et al. 2010). The correct application of plant protection product is possible when offers nozzles that provide uniform droplet distribution, uniform spectrum and appropriate size (CUNHA & SILVA, 2010).

The activity of the herbicide is often enhanced by adjuvants. The absorption of a herbicide can also be increased by adding one or more adjuvants (DAN et al. 2009; MARTINS et al., 2009, MACIEL et al. 2011), which can reduce the herbicide dose by more than 50% compared with that used without adjuvants (VARGAS & ROMAN 2006). However, there is still little scientific information on this subject, with difficulty to a secure selection or recommendation of adjuvants.

As for herbicides with local action, i.e., those with low translocation, such as paraquat, leaf coverage is a relevant factor. Thus, for these herbicides to become efficient, a uniform coverage of the parts treated is required, which can be achieved through the use of adjuvants (VARGAS & ROMAN 2006). As for herbicides with systemic action, i.e., such highly translocatable herbicides as glyphosate (GALLI, 2009), adjuvants can be used that enhance droplet retention on the leaf and foliar absorption, increasing the hydration of the cuticle and thus enhancing the herbicide diffusion (REDDY & SINGH 1992).

However, the occurrence of rainfall after herbicide application can determine the performance of weed control, depending on the herbicide mechanism of action, the time interval between the application and the occurrence and intensity of rainfall (BRYSON 1988).

Therefore this study aimed to characterize the effect of rainfall incidence on control of Scarlet Morning Glory, considering droplet size, surface tension, contact angle of herbicides associated to adjuvants and distribution of spraying profile in a patternator.

MATERIAL AND METHODS

For the evaluations, two combinations of herbicides and adjuvants and the effect of rainfall on the control of Scarlet Morning Glory were carried out, at the Department of Crop Protection of the University of the State of São Paulo -UNESP, Campus Jaboticabal-SP, Brazil, during November to December of 2011.

Two adjuvants, two herbicides, water (control), one spraying flow rate (70 L ha^{-1}), and one model of spray nozzle were used for treatments. The model was TT, with 0.15 gal min.$^{-1}$ flow, with a 110° angle and 186 kPa of pressure. The treatments (T) were as follows: T1: water (control); T2: glyphosate (Roundup Original® - 2.5 L/ha); T3: glyphosate + tributyl citrate + polydimethylsiloxane (Vertex premium®- 0.015 L in 100 L of water); T4: glyphosate + vegetable oil (VegetOil®- 0.2 L in 100 L of water); T5: paraquat (Gramoxone 200®- 1.5 L ha^{-1}); T6: paraquat + tributyl citrate + polydimethylsiloxane; T7: paraquat + vegetable oil.

Surface Tension and Contact Angle of the Leaves

Assessments of surface tension were performed using the same treatments (T1 to T7) described above. The leaves used in the assays were collected in the experimental fields. To ensure that the leaves exhibited no rugosity that could compromise the assays, the leaves of *I. hederifolia* were placed in a specific device for this purpose. The surface tension and contact angle assessments were performed using a OCA-15EC goniometer (DataPhysics, Germany), where the surface tension was determined using the pendant drop technique, and droplet spreading was assessed by measuring the contact angle of the droplet with the surface where it was deposited. The image of the liquid droplet, formed in a syringe to the optical thermostat, was captured using a CCD (charge-coupled device) camera, which analyzes the shape of the droplet by axisymmetric drop shape analysis (ADSA). An optical glass cuvette with water in the bottom was used to avoid droplet evaporation. Specific software, which uses an ideal position as the reference line in the image field, was used to identify the key point for starting to record images, even before the complete formation of the droplet. Surface tension was determined through digitization and analysis of the droplet profile using the Young-Laplace equation for fitting. The resulting data of surface tensions and contact angles were subjected to analysis of variance using the F test, and the means were compared using the Tukey test at 5% probability.

Droplet Size

A laser particle size analyzer (Mastersizer S Malvern Instruments Ltd.) was used to assess droplet size with the following technical parameters: He-Ne beam with 5 mW power at a wavelength of 310 mm and a range of droplet measurements from 0.5 to 900 µm. The device was connected to a computer that analyzed and stored the data using Mastersizer - S v.2.19 software. During the assessment, the spray of the nozzle was moved such that the formed stream transversally intercepted the laser, enabling the sampling of the entire range sprayed by the nozzle. The device has an optical unit that detects diffraction patterns of light when passing through a set of particles. The deviation that the rays suffer depends of the size of the particle. The smaller the particle, the greater is the degree of diffraction. The spraying (treatments T1 to T7) was activated by compressed air using a compressor, and constant pressure was maintained with the aid of a precision pressure regulator. Three spray nozzles of the same model (TT) were used with five readings per nozzle for a total of 15 replicates for each treatment. The following parameters were determined: volume of median diameter (VMD), uniformity (SPAN) and percentage of droplets smaller than 100 µm (%≤ 100). The resulting data were subjected to analysis of variance using an F test, and the means were compared using a Tukey test at 5% probability.

Volume Distribution

The assessment of the volumetric distribution profile was performed in a patternator consisting of a corrugated metal sheet forming 67 V-shaped channels, spaced at 2.5 cm from each other, totaling a width of 167.5 cm. In the lower part of the table, 100-mL test tubes were placed for collecting the sprayed solution with one tube per channel. The spray nozzle was positioned in the center of the table such that the stream was launched vertically at a height of 40 cm according to Food and Agriculture Organization of the United Nations (FAO 1998) recommendations. The volumetric distribution profile was assessed for the seven solutions (seven treatments: T1 to T7) using the model TT nozzle at a working pressure of 186 kPa. The spraying was performed until the test tubes of the central channels (which received the greatest amounts of solution) reached 90% of the maximum volume. Subsequently, the solution volume within each tube was recorded. The profile of volumetric distribution was determined based on the mean of volumes collected in two readings from three spray nozzles of the same model (TT) for a total of six replicates per solution. The resulting volumetric distribution profile was used to determine the spacing between spray nozzles to be used in a spraying boom using an electronic spreadsheet (Microsoft Excel®). The distribution uniformity (DU) throughout the range applied was assessed by the coefficient of variation (CV), which is acceptable for DU up to 10% (FAO 1998). The regression equation was established considering the relationship between the spray nozzle spacing and its respective CV to determine the distribution profile of the herbicide solution (treatments T1 to T7) and the spacing that falls within the 10% limit for the CV.

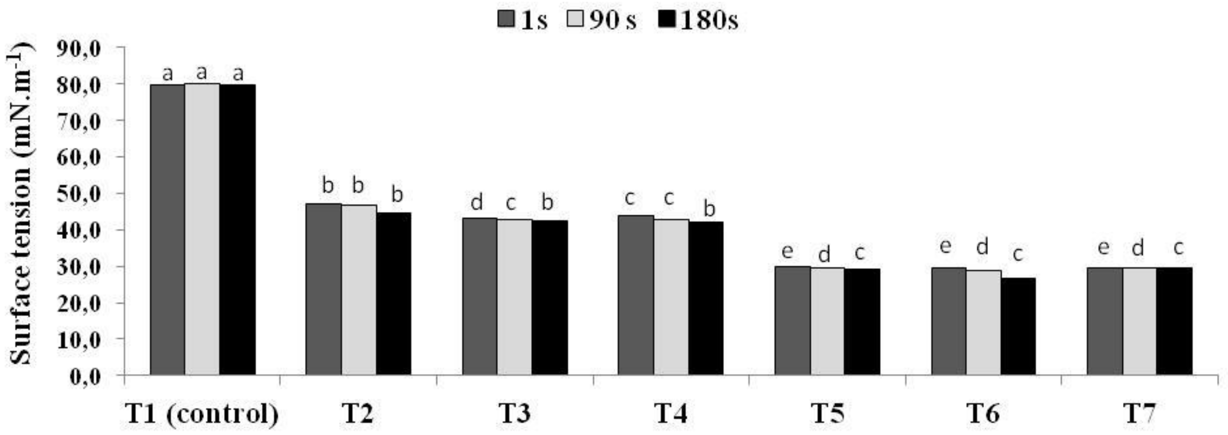
Effect of Rainfall on the Control of *Ipomoea hederifolia* Using Different Spraying liquids

Seeds of *I. hederifolia* were sowed in 5-L pots with two parts soil and one part of bovine manure. After emergence, the plants where thinned, maintaining four plants per pot. The experimental design was completely random in a 6 (herbicide solutions) x 2 (with or without rainfall) + 1 (control, not sprayed) factorial scheme, totaling 14 treatments with three replicates. Treatment application was performed after emergence of the weed using a CO^2 pressurized backpack sprayer at a constant working pressure of 186 kPa. The spraying boom consisted of two TT nozzles with a flow rate of 0.57 L $min.^{-1}$ and an angle of 110°, with the nozzles being spaced 50 cm from each other. Fifty minutes after spraying, the pots were placed in a greenhouse to simulate 20 mm of rainfall over 7.5 minutes. The simulator consisted of six FL10 model nozzles with a working pressure of 186 kPa, spaced at 0.25 m, circularly arranged and fixed to a support at a height of 2.3 m. For qualitative analysis, the effects of applying the solutions with or without simulated rain were assessed using a scoring system, where a score of 1 was given when 0% to 9% of visible damage was recorded, and a score of 10 was given for 90% to 100% visible damage at 0, 4, 8 and 16 days after spraying. For quantitative analysis, the plants were sieved and rinsed to remove any remaining soil, and the roots were retained to determine the dry matter of shoots and roots. The resulting plant material was placed in paper bags and stored for 72 hours in a convection oven at 38°C for drying until they maintained a constant weight. The data were subjected to analysis of variance using an F test, and the means were compared using the Tukey test at 5% probability.

RESULTS AND DISCUSSION

Surface Tension and Contact Angle on the Leaves of *Ipomoea hederifolia*

All of the solutions exhibited a surface tension significantly lower than the water (control) at 1, 90 and 180 seconds. The solutions with paraquat (with or without adjuvants) exhibited the lowest values for surface tension without significant differences among them at tree times evaluated (Figure 1). These results imply that a greater spreading factor on the surface due to lower surface tension resulted in a greater spreading of the droplets and therefore enabled reduction of the solution volume (MATUO et al. 1989). The solution with glyphosate has a diminution the reduction in surface tension when vegetable oil and mixture tributyl citrate + polydimethylsiloxane were added, except at 180 seconds (Figure 1).



T1: water (control); T2: glyphosate; T3: glyphosate + tributyl citrate + polydimethylsiloxane; T4: glyphosate + vegetable oil; T5: paraquat; T6: paraquat + tributyl citrate + polydimethylsiloxane; T7: paraquat + vegetable oil.

FIGURE 1. Values of surface tension of water (control), herbicides and adjuvants used for the control of *Ipomoea hederifolia* in three times evaluated by the pedant drop method. Jaboticabal, SP, 2011.

With a greater spreading factor, can occur a reduction of the maximum quantity of liquid retained by the leaves, as showed in the research of ANDRADE et al. (2010), where was observed that the addition of oil, either mineral or vegetable, to an acaricide in the spraying solution reduced the maximum quantity of liquid retained by the leaves of citrus plants, which suggested the possibility of reducing the amount of solution needed for good coverage of the plant. MACIEL et al. (2010) also reported that mineral oil proved effective in reducing the surface tension for tank mixing with glyphosate formulations and with chlorimuron-ethyl.

As for the contact angle, the treatment and time factors were significant. All solutions resulted in lower values compared with the water (control), except for the glyphosate + tributyl citrate + polydimethylsiloxane treatment on the standard surface (glass) and the glyphosate treatment on the *I. hederifolia* leaf.

TABLE 1. Values of contact angle formed by droplets of aqueous solution containing herbicides and adjuvants on standard surface (glass) and leaf of *Ipomoea hederifolia* at two moments of evaluation and their interactions. Jaboticabal, SP, 2011.

	Values of contact angle (in degrees)	
Treatment (T)	Glass	Leaf
Water (control)	21.35 b	65.73 a
Glyphosate	26.73 a	54.56 ab
Glyphosate+tributyl citrate + polydimethylsiloxane	19.93 bc	43.91 bc
Glyphosate+ vegetable oil	24.45 a	42.36 bcd
Paraquat	17.64 cd	32.39 cd
Paraquat+tributyl citrate + polydimethylsiloxane	15.73 de	25.66 d
Paraquat+ vegetable oil	14.33 e	26.90 d
F (T)	57.15**	14.55**
Time (Te)		
5 seconds	24.62 a	50.07 a
60 seconds	15.42 b	33.24 b
F (Te)	43.53**	32.95**
F (TxTe)	7.67**	0.69^{NS}
C.V.(%)	8.46	26.34

Means followed by the same letter in the same column do not differ from one another by the Tukey test. ^{NS} Not significant; ** P <0.01.

The lowest contact angle values were observed for the paraquat treatment, regardless of the adjuvant addition. A significant difference was observed for the paraquat + vegetable oil treatment, which was the lowest value obtained among the treatments compared with the water (control) (Table 1).

It is known in the technical-scientific field that the contact angle may vary according to the surfaces, as reported MONQUERO et al. (2005), where observed that the amount of wax per unit of leaf area was greater in *I. hederifolia* (38.5 µg cm^{-2}) compared with the other weeds studied. The same author reported that *I. hederifolia* has a rough leaf surface, glandular trichomes and paracytic stomata. This differences between the leave´s surface can influence at spreading and consequently on contact angle.

TABLE 2. Breakdown of the interaction of treatments compared with time for the assessment on glass surface (standard) for contact angles of droplets of aqueous solutions containing herbicides and adjuvants. Jaboticabal, SP, 2011.

	Values of contact angle ϴ		
Treatment	5 sec.	60 sec.	F (T)
Water (control)	24.96 bcA	17.73 bB	36.66**
Glyphosate	28.56 abA	24.86 aB	9.55**
Glyphosate + tributyl citrate + polydimethylsiloxane	24.10 cdA	15.75 bB	48.63**
Glyphosate + vegetable oil	30.90 aA	18.00 bB	116.06**
Paraquat	24.33 cA	10.95 cB	124.76**
Paraquat + tributyl citrate + polydimethylsiloxane	20.45 deA	11.00 cB	62.28**
Paraquat+vegetable oil	19.03 eA	09.63 cB	61.63**
F (C)	24.24**	40.58**	-

Means followed by the same upper case letter in the same row and lower case letter in the same column do not differ from one another by the Tukey test. ** P <0.01.

The effect of adjuvants on the physicochemical characteristics of aqueous solutions may depend on their chemical composition and formulation (CUNHA & ALVES 2009). These authors observed that changes in dosage influenced the physicochemical characteristics of the adjuvants assessed in different ways. The pH, surface tension and viscosity were the proprieties most sensitive to the addition of adjuvants to the tested solutions. The surface tension and viscosity can inferred directly from spray formation process, the droplet size and spreading factor on the surface.

Droplet Size

The addition of adjuvants to herbicides increased the size of the droplets (VMD) produced by TT11001 nozzle. The lowest value was obtained in the glyphosate treatment, while treatments glyphosate + vegetable oil and paraquat + tributyl citrate + polydimethylsiloxane had the highest value although without difference with the water (control) (Table 3). BARBOSA et al. (2011) reported that the use of adjuvants, including vegetable oils gave an increase to the volumetric diameter of droplets relative to the absence of adjuvants at spraying liquids, as occurred in this study. There are no defined conclusions about why it happens, especially for models of hydraulic energy. There is an hypothesis about the viscosity of the liquid, applied only to rotary nozzles, explained by the formula of WALTON & PREWETT (1949), in which the density is an important factor in the formation of droplets by centrifugal energy, describing a mathematical model that the lower density the larger the diameter of the droplets.

Observing the uniformity (SPAN), the TT110 spray nozzle have shown higher values when tributyl citrate + polydimethylsiloxane and vegetable oil adjuvants were added to the herbicide paraquat. All treatments differed of water (control), obtaining the lowest values of SPAN (Table 3). As near to zero the SPAN is, more uniform is the droplet size distribution.

The values and percentages of the droplets smaller than 100 μm (%vol. ≤ 100 μm) ranged between 10.35% and 11.45% for the treatments applied. The glyphosate treatment exhibited significantly higher percentages of droplets smaller than 100 μm than others treatments. When the adjuvants tributyl citrate + polydimethylsiloxane and vegetable oil were added to the herbicide glyphosate, this percentage decreased significantly, this can contribute to a safety application due to decrease of droplets susceptible to drift (Table 3).

These factors are important when choosing a spray nozzle, once that droplets with sizes between 50 and 100 μm, which are classified as very fine, can lead to greater drift; however, they provide a better distribution in the crop canopy; a good coverage may result in better control, depending on the mode of action of the product and the target. At the same time, the use of fine droplets, which influences the cover resulting in larger losses by evaporation and dragging in unfavorable environmental conditions (Matthews, 2000), making the application less secure.

Consequently, the drift of non-selective herbicides in plantations of sensitive crops can result in intoxications and damage to these crops (ANTUNIASSI 2009), affecting negatively the productive characteristics and reduce the crop yield (RIGOLI et al. 2008; WAGNER JÚNIOR et al., 2008, CARVALHO et al. 2013).

According to VIANA et al. (2010), the most important parameters in determining the population drops are the VMD, the uniformity (SPAN) and percentages of the droplets smaller than 100 µm (%vol. ≤ 100 µm). Together it defines the potential of spray drift, homogeneity and the droplet size produced by the spraying nozzles.

TABLE 3. Droplet diameters when 50% of the total sprayed volume exhibited diameters smaller than the indicated diameter (VMD), uniformity (SPAN) and percentage of droplets smaller than 100 µm (%≤ 100). Jaboticabal, SP, 2011.

Treatments	VMD(µm)	SPAN	%≤100
Water (control)	226.99 a	1.81 a	11.45 bc
Glyphosate	181.37 d	1.66 bc	15.21 a
Glyphosate + tributyl citrate + polydimethylsiloxane	210.46 bc	1.71 b	11.88 b
Glyphosate + vegetable oil	226.68 a	1.65 c	10.40 c
Paraquat	203.14 c	1.39 e	11.07 bc
Paraquat + tributyl citrate + polydimethylsiloxane	222.71 a	1.53 d	10.35 c
Paraquat + vegetable oil	217.80 ab	1.55 d	10.97 bc
CV(%)	3.70	3.19	10.26

Means followed by the same letter in the same column do not differ from one another by the Tukey test ($P<0.05$).

Volumetric Distribution

As for the distribution profile on the patternator, the TT 11001 spray nozzle has a distribution pattern that decreases from the center to the edges (Figure 2). Such nozzle types with discontinuous distributions can be used in spray bars, where an overlap between nozzles occurs.

The coefficients of determination greater than 0.96 in all cases indicate that the spray of nozzle exhibits symmetric distribution between the left and right sides of the sprayed for both pressures evaluated (Figure 2). Despite the similarity between the depositions profiles measured on the patternator, the addition of adjuvants to the herbicide solution influenced the angles formed by the jet spray, extending the depositing range of the nozzle and, consequently, the possible distance between the nozzles in the bar. This result implies that the addition of adjuvants to the herbicide solutions may lead to improved quality of application, compared of the same conditions without adjuvants, due the lowers CVs value and consequently a better phytosanitary distribution on the target.

It was observed that the working spacing for the TT 11001 nozzle spraying only water at 186 kPa should be in the range of 45-70 cm, featuring CVs of 4.9% and 9.9%, respectively. The safest working spacing is 55 cm because it has the lowest CV (2.4%). For glyphosate, the safest working spacing is in the 45-60 cm range with CVs of 4.2% and 8.9%, respectively; the ideal spacings are 47.5 cm and 50 cm, which feature the lowest CV (3.1%). For paraquat, the limit of working spacing between nozzles on the spraying bar ranges from 50-67.5 cm with CVs of 9.6% and 9.2%, respectively; the spacing 57.5 cm features the lowest CV (4.7%) (Figure 3).

The spacing was suggested according to the CV based on the individual distribution profile of the nozzles on the deposition table with overlapping jets (Figure 3). These values are acceptable because they are below the level of 10% variation in the profile, leaving a safety margin for application (FAO 1998).

With the addition of vegetable oil and tributyl citrate + polydimethylsiloxane adjuvants to the herbicide paraquat, a conspicuous change in the distribution profile is observed due to changes in the physicochemical characteristics of the solution as the surface tension. For all the spacings assessed, the maximum CV remained between 8.3% and 8.7% for paraquat + vegetable oil and tributyl citrate + polydimethylsiloxane, respectively, still maintaining a safety margin for the spacing recommended by the manufacturers. The spacing that provides the greatest working safety margin is 62.5 cm with a CV of 3.9% for both adjuvants added to paraquat (Figure 3).

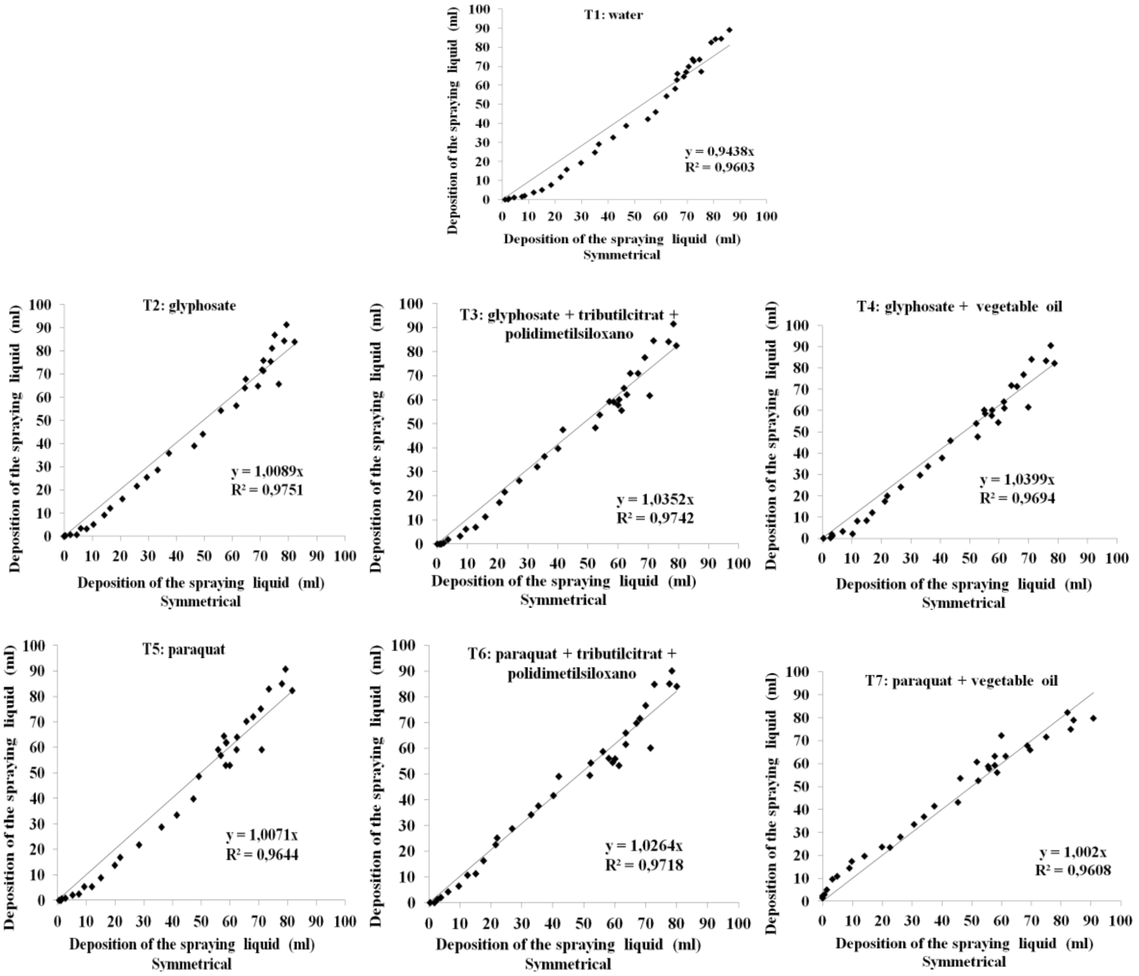


FIGURE 2. Linear regression equations and coefficients of determination for the symmetry of solution deposition profile provided by the TT 110001 flat spray nozzle. Jaboticabal, SP, 2011.

The distribution profile of the solution with glyphosate is also altered when adjuvants are added. When vegetable oil is added, the safe working range is between 45 cm and 72.5 cm with CVs of 8% and 9.6%, respectively; the lowest CV is for a spacing of 60 cm between nozzles (3.9%). With the addition of tributyl citrate + polydimethylsiloxane, the safe working range is between 45 cm and 70 cm with CVs of 8.5% and 9.2%, respectively; the lowest CV is for 57.5 cm (3.8%), which is the safest working spacing (Figure 3). As occurred in this research, VOLPE et al. (2012) also reported that the use of adjuvants in the spraying liquid tested contributed to the production of more homogeneous droplets, resulting in more uniform spraying distribution, besides the gain of 10 cm away from the spacing relative to the spray nozzles without adjuvant.

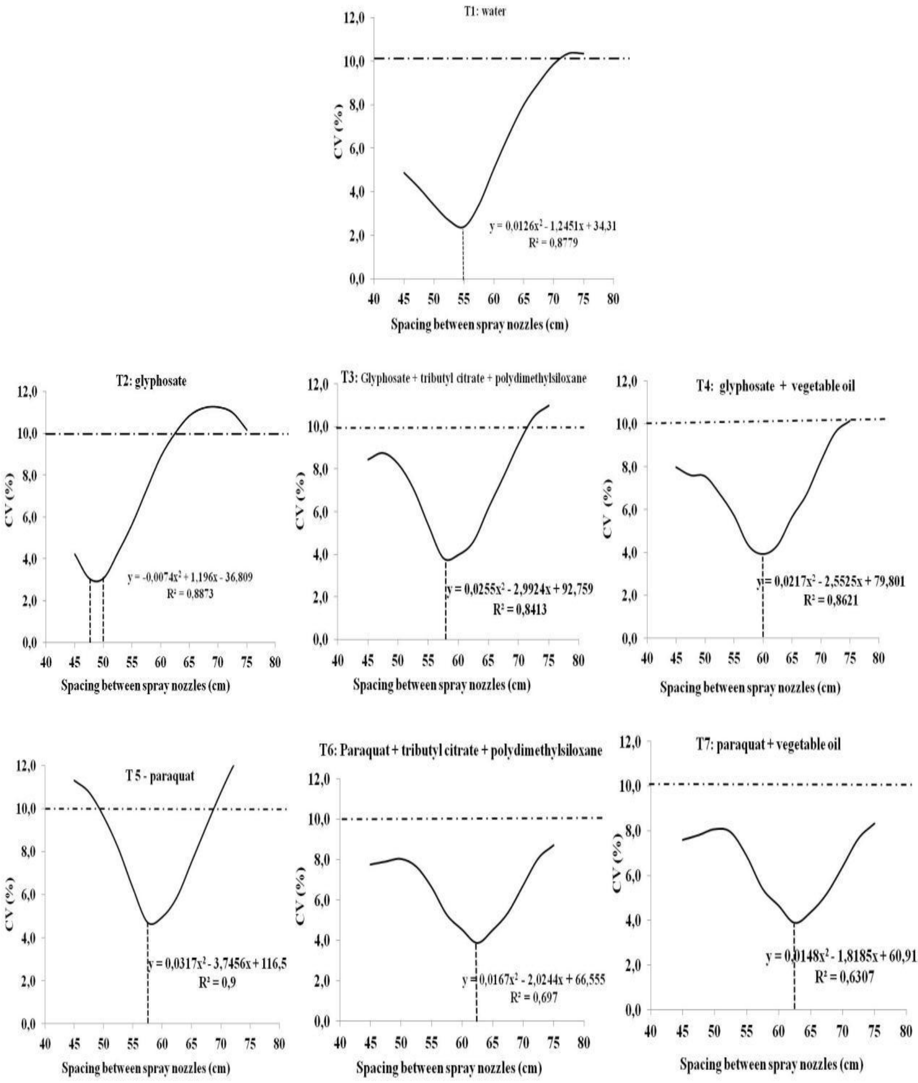


FIGURE 3. Smoothened curve and coefficient of variation in percentage (CV%) of the solution deposition profile provided by the TT 110001 flat spray nozzle. Jaboticabal, SP, 2011.

Effect of Rainfall on the Control of *Ipomoea hederifolia* with Different Spraying Liquids

As for the weed control, the F test applied to the mean scores given in the visual assessments revealed a significant interaction between solutions (treatments) with or without rain at 4, 8 and 16 days after the herbicide application (Table 4). At 0 and 4 days, the paraquat treatment already exhibited a phytotoxic effect on the Scarlet Morning Glory, while glyphosate started to demonstrate weed control 8 days after application. At 8 and 16 days, we noted that plants that had received solution with paraquat started to sprout again, increasing their dry matter and decreasing the control scores, while glyphosate in the same period was acting on the metabolism of the weeds in the pots (Table 4).

This outcome can be explained by the herbicides' modes of action; paraquat has a fast action because it is a contact herbicide and requires several days to promote necrosis; and glyphosate is an herbicide with systemic action with slow absorption (BRYSON 1988), requiring more days to promote necrosis.

In addition, the cuticle of *I. hederifolia* has a significant amount of wax per leaf unit (38.5 µg cm^{-2}) (MONQUERO et al. 2005) and thus exhibits apolar properties and acts as a barrier to herbicide penetration. Epicuticular wax composition of species can influence the efficiency of absorption of the herbicide solution (RIZZARDI et al. 2008). Consequently, a longer application period is required for amounts of herbicide sufficient to penetrate and translocate throughout the plant.

It was observed that the rain, exception of day 0, negatively affected weed control for the different solutions and also the dry matter weight, suggesting that the applied phytosanitary product was washed off (Table 4).

Regarding dry matter, the treatments with paraquat, regardless of adjuvant addition, exhibited lower values compared with glyphosate treatment, which were more effective in weed control for the 16 days assessed (Table 5). Over a longer evaluation period, dry matter might gradually increase and the control score might decrease for the paraquat treatment because the plants were sprouting again.

Under simulated rain, the paraquat and paraquat + tributyl citrate + polydimethylsiloxane treatments exhibited the lowest dry matter values followed by the paraquat + vegetable oil and glyphosate treatments. The control treatment yielded the greatest dry matter value and did not differ from the solution with glyphosate + tributyl citrate + polydimethylsiloxane and glyphosate + vegetable oil.

TABLE 4. Control scores and dry matter of *Ipomoea hederifolia* with or without rainfall with herbicides solutions combined with adjuvants. Jaboticabal, SP, 2011.

Treatments	Days after application				Dry matter (g)
	0 days	4 days	8 days	16 days	
Control	1.00 d	1.00 c	1.00 c	1.00 d	10.23 a
Glyphosate	1.00 d	1.00 c	3.00 abc	6.00 a	4.32 bc
Glyphosate + tributyl citrate + polydimethylsiloxane)	1.00 d	1.00 c	4.67 a	4.83 b	6.60 b
Glyphosate + vegetable oil	1.00 d	1.00 c	2.50 bc	5.67 a	6.52 b
Paraquat	6.33 b	7.33 a	3.50 ab	1.83 c	4.39 bc
Paraquat + tributyl citrate + polydimethylsiloxane)	7.67 a	7.67 a	4.50 ab	1.50 cd	3.54 c
Paraquat + vegetable oil	5.67 c	6.50 b	4.33 ab	1.00 d	5.18 bc
F (T)	577.33**	922.78**	7.95**	216.89**	15.72**
Rain (R)					
With rain	3.29 a	3.48 b	2.71 b	1.29 b	7.88 a
Without rain	3.48 a	4.24 a	4.00 a	4.95 a	3.78 b
F (C)	4.00^{NS}	208.33**	13.25**	988.17**	91.41**
F (TxC)	1.67 ^{NS}	49.67**	7.27**	183.56**	5.08 **
C.V.(%)	9.13	7.34	34.08	12.12	-

Means followed by the same letter in the same column do not differ from one another by the Tukey test.
^{NS} Not significant; ** P <0.01.

The addition of these adjuvants to glyphosate under rainfall resulted in less control of *I. hederifolia* due to the greater values of dry matter, which did not occur with paraquat. The aforementioned adjuvants may have contributed to the spreading effect when added to glyphosate, which notably reduces the retention after rainfall (Table 5).

Glyphosate is easily affected by the occurrence of rain after application due to its relatively slow absorption (BRYSON 1988). Glyphosate has the best control when the interval between application and rainfall occurrence is higher (SILVA et al. 2011, SOUZA et al. 2011). Therefore, the time interval between application and the occurrence of rain and the amount and intensity of the rain, dosage and concentration of herbicides used influenced the effectiveness of the weed control (BRYSON 1988).

The dry matter after 20 mm of rainfall was higher for all treatments, thus reducing the power of weed control, except for the only paraquat treatment, which demonstrated no difference in dry matter with or without simulated rain (Table 5).

TABLE 5. Breakdown of interactions for dry matter (g) of *Ipomoea hederifolia* after application of herbicide solutions with or without rain, Jaboticabal, SP, 2011.

Treatment	With rain	Without rain	F (T)
Water (control)	10.73 aA	9.71 aA	0.82 ^{NS}
Glyphosate	6.87bcdA	1.78 bB	20.17**
Glyphosate + tributyl citrate + polydimethylsiloxane	10.14abcA	3.07 bB	38.46**
Glyphosate + vegetable oil	10.34 abA	2.70bB	45.59**
Paraquat	5.32dA	3.47 bA	2.74 ^{NS}
Paraquat + tributyl citrate + polydimethylsiloxane	5.10 dA	1.98 bB	7.61**
Paraquat + vegetable oil	6.63 cdA	3.73bB	6.59*
F (C)	9.35**	11.47**	-

Means followed by the same upper case letter in the same row and lower case letter in the same column do not differ from one another by the Tukey test. ^{NS} Not significant; *P <0.05; ** P <0.01.

CONCLUSIONS

The addition of the adjuvants to the herbicide spraying liquid improved the application quality, as it influenced the angle formed by the spray by broadening the deposition band of the spray nozzle and thus the possible distance between the nozzles on spray boom and due the changes at droplet size, which contribute to a safety.

The rainfall occurrence affected negatively the weed control with the different spraying liquids and also the dry matter weight, suggesting that the phytosanitary product applied was washed off.

REFERENCES

ANTUNIASSI, U.R. Conceitos básicos da tecnologia de aplicação de defensivos na cultura da soja.

Rondonópolis: Fundação de Apoio à Pesquisa Agropecuária de Mato Grosso, v. 13, 2009, p. 299-316. (Boletim de Pesquisa de Soja)

ANDRADE, D.J.; FERREIRA, M.C.; SANTOS, N.C. Efeito da adição de óleos ao acaricida cyhexatin sobre o ácaro *Brevipalpus phoenicis*e na retenção de calda por folhas de citros. **Revista Brasileira de Fruticultura**, Jaboticabal, v. 32, n. 4, p. 1055-1063, 2010.

BARBOSA, B.F.F.; FERREIRA, M.C.; SILVA, J.L.; CAVICHIOLU, F.A. Controle de *Ipomoea nil* utilizando ponta centrífuga de pulverização em volumes de aplicação com e sem adjuvante. **Revista Brasileira de Herbicidas**, Londrina, v.10, n.3, p. 277-290, 2011.

BRYSON, C. T. Effects of rainfall on foliar herbicides applied to seedling johnsongrass. **Weed Technology**, Champaign, v. 2, p. 153-158, 1988.

CARVALHO, F.P.; LEMOS, V.T.; FERREIRA, E.A.; SANTOS, J.B.; SILVA, S.S. Atividade fotossintética de café após a aplicação de subdoses de glifosato. **Acta Scientiarum: Agronomy,** Maringá, v 35, n. 1, março de 2013. Disponível em <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1807-86212013000100013&lng=en&nrm=iso>. Acesso em: 05 mar. 2013.

CUNHA, J.P.A.R.; SILVA, R.A.M. Uniformidade de distribuição volumétrica de pontas de pulverização em função da pressão de trabalho e altura da barra. **Bioscience Journal**, Uberlândia, v.26, n.1, p.52-58, 2010.

CUNHA, J. P. A. R.; ALVES, G. S. Características físico-químicas de soluções aquosas com adjuvantes de uso agrícola. **Interciência**, Caracas, v. 34, n. 9, p. 655-659, 2009.

DAN, H. A.; DAN L. G. M.; BARROSO, A. L. L.; SOUZA, C. H. Effect of pH of the spraying at drying of the *Braquiaria brizanta* with glyphosate. **Global Science and Technology**, Rio Verde, v. 2, p. 1-6, 2009.

FERREIRA, M.C.; OLIVEIRA, J.R.G.D.; PIETRO, I.R.P.S.D. Distribuição da calda herbicida por pontas de pulverização agrícola utilizadas em áreas de reflorestamento com eucalipto. **Engenharia Agrícola**, Jaboticabal, v. 29, n. 2, p. 267-276, 2009.

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS **Agricultural pesticide sprays.** Rome, 1998. v. 2. p. 62.

GALLI, A. J. B, The glyphosate molecule and Brazilian agriculture In: VELINI et al. **Glyphosate**. Botucatu: FEPAF, 2009. 496 p.

KISSMANN, K. G.; GROTH, D. **Plantas infestantes e nocivas**. São Paulo: BASF Brasileira, 1999. Tomo II, 798 p.

MACIEL, C.D.G.; POLETINE, J.P.; OLIVEIRA NETO, N.G.; JUSTINIANO, W. Eficiência de paraquat e msma isolados e associados a adjuvantes no manejo de plantas daninhas. **Global Science and Technology**, Rio Verde, v. 4, n. 1, p.70 – 81, 2011.

MACIEL, C.D.G; GUERRA, N.; OLIVEIRA NETO, A.M.; POLETINE, J.P.; BASTOS, S.L.W.; DIAS, N.M.S. Tensão superficial estática de misturas em tanque de glyphosate + chlorimuron-ethyl isoladas ou associadas com adjuvantes. **Planta Daninha,** Viçosa, MG, v.28, n.3, p.673-685, 2010.

MARTINS, D.; CARBONARI, C. A.; TERRA, M. A.; MARCHI, S. R. Action of adjuvants on the absorption and translocation of glyphosate in *Eichhornia crassipes*. **Planta Daninha**, Viçosa, MG, v. 27, p. 155-163, 2009.

MATTHEWS, G.A. **Pesticide application methods**. London: Longman, 2000. 448 p.

MATUO, T.; NAKAMURA, S.H.; ALMEIDA, A. Efeito de alguns adjuvantes da pulverização nas propriedades físicas do líquido. **Summa Phytopathology**, Botucatu, v.15, p.163-173, 1989.

MATUO, T. **Técnicas de aplicação de defensivos agrícolas.** Jaboticabal: FUNEP, 1990. 140 p.

MONQUERO, P.A.; CURY, J.C.; CHRISTOFFOLETI, P.J. Controle pelo glyphosate e caracterização geral da superfície foliar de *Commelina benghalensis*, *Ipomoea hederifolia*, *Richardia brasiliensis* e *Galinsoga parviflora*. **Planta Daninha**, Viçosa, MG, v. 23, n. 1, p. 123-132, 2005.

REDDY, N. K.; SINGH, M. Organosilicone adjuvants effects on glyphosate efficacy and rainfastness.**Weed Technology**, Champaign, v. 6, n. 3, p. 361-365, 1992.

RIGOLI, R. P.; FONTANA, L. C.; FIGUEREDO, S. S.; NOLDIN, J. A. Resposta de plantas de beterraba (*Beta vulgaris*) e de cenoura (*Daucus carota*) à deriva simulada de *glyphosate* e clomazone. **Planta Daninha**, Viçosa, MG, v. 26, n. 2, p. 451-456, 2008.

RIZZARDI, M. A.; VARGAS, L.; ROMAN, E. S.; KISSMANN, K. Aspectos gerais do manejo e controle de plantas daninhas. In: VARGAS, L.; ROMAN, E. S. (Ed.) **Manual de manejo e controle de plantas daninhas**. Passo Fundo: Embrapa Trigo, 2008. p. 107-131.

SILVA, F.M.L.; VELINI, E.D.; ROSSI, C.V.; CORRÊA, M.R.; CARBONARI, C.A.; Intervalos de chuva sobre a eficácia de controle químico de trapoeraba (*Commelina benghalensis*). **Revista Agrarian**, Dourados, v.4, n.13, p.197-201, 2011.

SOUZA, G.S.F.; CAMPOS, C.F.; MARTINS, D.; PEREIRA, M.R.R. Ação da chuva sobre a eficiência de Glyphosate no controle de *Eichhornia crassipes e Pistia stratiotes*. **Planta daninha**, Viçosa, MG, v.29, n.1, 2011. Disponível em:<http://www.scielo.br/scielo.php?script=sci_arttext&pid=S010083582011000100007&lng=en&nrm=iso>. Acesso em: 8 mar. 2013.

WAGNER JÚNIOR, A.; TUFFI SANTOS, L. D.; SANTOS, C. E. M.; SILVA, J. O. C.; PIMENTEL, L. D.; BRUCKNER, C. H.; FERREIRA, F. A. Deriva simulada de formulações comerciais de glyphosate sobre maracujazeiro amarelo. **Planta Daninha**, Viçosa, MG, v. 26, n. 3, p. 677-683, 2008.

VARGAS, L.; ROMAN, E. S. Conceitos e aplicações dos adjuvantes. Passo Fundo: Embrapa Trigo, 2006. 10 p. html. (Embrapa Trigo. Documentos Online, 56). Disponível em: <http://www.cnpt.embrapa.br/biblio/do/p_do56.htm>. Acesso em: 17 nov. 2011.

VIANA, R. G.; FERREIRA, L,R.; FERREIRA, M.C.; TEIXEIRA, M.M.; ROSELL, J.R.; TUFFI SANTOS, L.D.; MACHADO, A.F.L. Volumetric distribution and spectrum spraying droplets of nozzles of low drift. **Planta Daninha**, Viçosa, MG, v. 28, no. 2, p. 439-446, 2010.

VOLPE, H. X. L.; DUARTE, R. T.; SILVA, A. G.; BALDAN JR., E.; LEITE, G. J.; FERREIRA, M. C. Distribuição volumétrica de calda contendo *Metarhizium anisopliae*. **Ciencia Rural**, Santa Maria, v. 42, n. 11, nov. 2012. Disponível em:

<http://www.scielo.br/scielo.php?script=sci_arttext&pid=S010384782012001100001&lng=en&nrm=iso>. Acesso em: 5 mar. 2013.

WALTON, W.H.; PREWETT, W.C. Atomization by spinning discs. **Proceedings of Physical Society**, London, v. 62, p. 341-350, 1949.