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## Application techniques of pesticides in greenhouse tomato crops

Gustavo Dario <sup>1</sup>; Laís Maria B Precipito <sup>1</sup>; João Victor de Oliveira <sup>2</sup>; Leonardo Vinicius da S Lucilhia <sup>2</sup>; Rone B de Oliveira <sup>2</sup>

<sup>1</sup>Universidade Estadual Paulista (UNESP), Botucatu-SP, Brasil; [gdustavodario@gmail.com](mailto:gdustavodario@gmail.com); [laisbonadio@gmail.com](mailto:laisbonadio@gmail.com); <sup>2</sup>Universidade Estadual Do Norte Do Paraná (UENP), Bandeirantes-PR, Brasil; [joaovictordeoliveira@hotmail.com](mailto:joaovictordeoliveira@hotmail.com); [rone@uenp.edu.br](mailto:rone@uenp.edu.br); [leonardo\\_lucilhia@hotmail.com](mailto:leonardo_lucilhia@hotmail.com)

### ABSTRACT

Due to the deficiency of information on application technology in horticulture, the aim of this research was to evaluate the effect of three application techniques on different parts of the tomato canopy cultivated under greenhouse. The techniques evaluated were 1= Spray gun with two hollow cone nozzles, model JA-2 (700 kPa), application rate of 618 L ha<sup>-1</sup>; 2= Vertical boom spray equipped with six nozzles, model ATR 0.5 (700 kPa), application rate of 493 L ha<sup>-1</sup>; 3= Vertical boom spray with six standard flat fan nozzles, model AXI 11002 (400 kPa), application rate of 1442 L ha<sup>-1</sup>. As application quality indicators, the relative deposit (quantitative) and the coverage (qualitative) of the tomato leaves in the internal and external collection positions of the plants, in the upper, middle and lower strata of the tomato canopy were measured. In the lower and middle canopy strata, the relative deposit was respectively 21% and 34% smaller in the internal part of the plants in relation to the external, however in the upper stratum there was no difference. On average, the coverage was 2.5 times smaller on the abaxial surface in relation to the adaxial leaf surface. The Spray gun JA-2 (618 L ha<sup>-1</sup>), used in commercial farming, provided better quality of the application. However, there is a need to optimize the application techniques in order to provide better distribution of the spray, mainly in the critical regions, such on the inside of the plants in the lower and middle canopy strata and the abaxial surface of the leaves.

**Keywords:** *Solanum lycopersicum*, application technology, deposit, coverage.

### RESUMO

#### Técnicas de aplicação de produtos fitossanitários no tomateiro em ambiente protegido

Devido à carência de informações sobre tecnologia de aplicação na horticultura, objetivou-se com essa pesquisa avaliar o efeito de três técnicas de aplicação em diferentes partes do dossel do tomateiro cultivado em ambiente protegido. As técnicas avaliadas foram 1= Lança manual com duas pontas de jato cone vazio, JA-2 (700 kPa), taxa de aplicação de 618 L ha<sup>-1</sup>; 2= Barra vertical com seis pontas de jato cone vazio, ATR 0.5 (700 kPa), taxa de aplicação de 493 L ha<sup>-1</sup>; 3= Barra vertical com seis pontas de jato plano simples, AXI 11002 (400 kPa), taxa de aplicação de 1442 L ha<sup>-1</sup>. Como indicadores de qualidade da aplicação, foram mensurados o depósito relativo (quantitativo) e a cobertura (qualitativa) das folhas do tomateiro nas posições de coleta interna e externa das plantas, nos estratos superior, médio e inferior do dossel do tomateiro. Nos estratos inferior e médio do dossel, o depósito relativo foi respectivamente 21% e 34% menor na parte interna das plantas em relação à externa, porém no estrato superior não houve diferença. Em média a cobertura foi 2,5 vezes menor na superfície abaxial em relação a adaxial. A técnica de aplicação Lança manual (618 L ha<sup>-1</sup>), utilizada na lavoura comercial, proporcionou melhor qualidade da aplicação. No entanto, há necessidade de otimização das técnicas de aplicação no intuito de proporcionar melhor distribuição da pulverização, principalmente nas regiões críticas, como a parte interna das plantas nos estratos inferior e médio do dossel e a superfície abaxial das folhas.

**Palavras-chave:** *Solanum lycopersicum*, tecnologia de aplicação, depósito, cobertura.

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The application technique of pesticides is one of the factors that need improvement in the horticulture sector in greenhouses (Llop *et al.*, 2015a). In this cultivation system, the use of low-tech manual equipment is common. As an example, knapsack sprayers and semi-stationary sprayers, where the operator manually directs the spray into the crop canopy with a

spray gun.

In addition to the difficulties related to equipment choice, the horticulture in greenhouse also needs more information about application technology that can aid professionals in the recommendation, such as application rate, spray nozzle and spray pressure. The fragility of information on application technology contributes to farmers using excessive

application rates and work pressures. Some farmers argue that they feel more confident about the quality of the application when they see the wetting of the drops on the canopy of the crop after the operation (Derksen *et al.*, 2008).

Among the crops cultivated in greenhouses in Brazil, the tomato (*Solanum lycopersicum*) is one of the most susceptible to pests and diseases

(Vale *et al.*, 2013; Silva *et al.*, 2013, 2016). This makes the use of pesticides a frequent practice in this growing environment. Researchers in Spain have shown that the conventional forms of application used in tomatoes, which use excessive application rate and working pressure, provide low target deposition and spray losses of pesticides to the environment (Sánchez-Hermosilla *et al.*, 2011, 2012). In addition, the difficulty of reaching the critical points of the canopy such as the internal part and the abaxial surface of the leaves, results in inefficient control of pests and diseases located at these points (Llop *et al.*, 2015a).

For the Brazilian cultivation conditions, there is few information available to help field professionals make decisions and little is known about the quality of the spray applications. The aim of this research was to evaluate the efficiency of three application techniques on different parts of the tomato canopy cultivated in greenhouse.

## MATERIAL AND METHODS

### Characterization of the experimental area

The experiment was carried out in a commercial area of tomato crop, in Santa Cruz do Rio Pardo-SP (22°47'03"S, 49°30'14"W), in a greenhouse, Londrina model, 600 m<sup>2</sup> (30 m length by 20 m wide) 3.8 m ceiling height (higher side) and 3.0 m (lower side), covered with polyethylene film 100 µm. Seedlings of the hybrid Paipai®, determined growth, were transplanted on February 18<sup>th</sup>, 2017. The cultivation was directly on the soil, spaced 0.4 m between plants and 1.52 m between rows, conducted in the form of single rows and one stem per plant. The greenhouse was composed of 12 planting rows, each 28 m long.

### Determining leaf area index and canopy width

The measurements were made one day before the treatments were applied. Stratum Canopy Width (CW) and Leaf Area Index (LAI) were measured separately for the lower, middle and upper strata of the canopy. The CW was read with the aid of a measuring tape, considering the length parallel to the

ground, from the right side outside to the left side outside of the plant.

To determine LAI, all canopy leaves in a space of 0.7 m long were removed in the direction of the cultivation rows, forming a rectangle of 0.7 m horizontally and 2.1 m vertically (height of the plants). This rectangle was divided into three equal parts (0.7 x 0.7 m) to determine the leaf areas of the lower, middle and upper canopy strata. The leaf area of each stratum was measured separately by an image analysis system (Windias®). The LAI of each stratum was calculated by equation 1 and the general LAI was the sum of the lower, middle and upper strata.

$$LAI = LA / (LC \cdot D) \quad (1)$$

Where LAI is leaf area index for each stratum of the canopy, LA is leaf area of each stratum of the canopy (m<sup>2</sup>), LC is length considered in the cultivation rows for leaf removal (m) and D distance between rows (m).

### Experimental design and treatments

Due to the homogeneity of the canopy, a completely randomized design was used. For the deposit, the split-plot design (3×2) with 15 replications was used, each composed of a plant. The main plot was represented by three application techniques and the subplots were the collection points (inside and outside) of the plants.

For coverage, the split-split-plot design (3×2×2) with fifteen replicates was used. The plots and subplots were identical to the deposit and in the sub-sub-plot the abaxial and adaxial surfaces of the tomato leaves.

For the application of the different techniques, nine lines were chosen in the greenhouse, three for each technique. The area of 10 m was considered the useful area of each line arranged alternately and each repetition was spaced 2 m apart.

### Applications

The treatments were applied 80 days after transplanting the seedlings, when the tomato was beginning the maturation phase of the first clusters.

The three application techniques evaluated were: **Technique 1**= Farmer standard, spray gun with two hollow

cone nozzle, model JA-2 (700 kPa), fine drops, 618 L ha<sup>-1</sup> application rate and 0.57 m s<sup>-1</sup> travel speed. **Technique 2**= Vertical spray boom with six hollow cone nozzle, model ATR 0.5 (700 kPa), very fine drops, 493 L ha<sup>-1</sup> application rate and 0.84 m s<sup>-1</sup> travel speed; **Technique 3**= Vertical spray boom with six standard flat fan nozzles, model AXI 11002 (400 kPa), fine drops, 1442 L ha<sup>-1</sup> application rate and 0.83 m s<sup>-1</sup> travel speed. The application of technique 1 was carried out by the same operator, maintaining the same calibration and equipment commonly used in spray applications for phytosanitary control in the commercial area. The operator manually tilted the spray jet approximately 45° upwards, in order to reach the abaxial surface of the tomato leaves.

For the techniques 2 and 3, a manually pulled trolley was developed to move between the tomato line, manually driven and with support for fixing a vertical spray boom of 1.95 m in length, containing six spray nozzles with anti-drip, spaced 0.35 m apart, according to the spacing that presented the best results in a study by Nuyttens *et al.* (2004). In the spray boom, the first nozzle was installed at a height of 0.20 m from the ground. The equipment has manometer and line filter (60 mesh), located before the spray boom.

The definition of technique 2, with vertical boom and ATR 0.5 nozzle (493 L ha<sup>-1</sup>), was based on the principle of reducing the rate of application in comparison to those used in commercial tomato crops. The technique 3, with vertical boom and AXI1102 standard nozzle (1442 L ha<sup>-1</sup>), was established according to the LAI of the culture, according to equation 2 proposed by Pergher & Petris (2008) and adapted by Sánchez-Hermosilla *et al.* (2013b).

$$Q = 2 \cdot 10^2 \cdot d \cdot LAI / \varepsilon \quad (2)$$

Where Q is application rate (L ha<sup>-1</sup>), d is average foliar deposit (µL cm<sup>2</sup>), LAI is leaf area index and ε is Fraction deposited on the canopy.

The values used were: d= 1.5 µL cm<sup>-2</sup> and ε= 0.75 as established by Sánchez-Hermosilla *et al.* (2013b), based on studies with greenhouse tomatoes. The LAI= 3.92 was obtained through the sum of the three layers of the tomato

canopy (lower, middle and upper), as described in the experimental design.

For the three techniques, the equipments (spray gun and manually pulled trolley) were connected by a 40 m long and 1/4" diameter hose to a semi-stationary motor pump assembly, consisting of a three piston pump, Yamaha®, with capacity of 18 L min<sup>-1</sup> flow rate, driven by a 3.73 kW gasoline engine. The system contains manual pressure controller, manometer and 50 L capacity spray tank.

The spray solution used in the applications was composed of water plus Brilliant Blue FD & C-1 (deposition marker) and Fluorescent Yellow marker (coverage marker), both in the concentration of 6 g L<sup>-1</sup>. During its use, the spray solution was kept under constant shaking.

All applications were performed on both sides of the tomato line (right and left), representing the most used form in the commercial tomato crop. The travel speed of the operator was determined based on the time taken to spray each plot. In order to avoid contamination between the treatments, in all the applications a plastic sheet was placed separating the crop line. At the time of application, the temperature was 30°C ± 2 and the relative humidity of 64% ± 4, measured using a thermo-hygrometer, brand ICCEL, model HT-208.

#### Application Quality Indicators

The analyzed parameters were the relative deposit (quantitative), which consisted of the percentage of spray solution deposited in the target in relation to the total sprayed volume and the coverage (qualitative), in which the percentage of the target that was covered by the spray drops.

#### Relative Deposit

In order to evaluate the application deposit, in each repetition, the tomato canopy was divided into three strata (lower, middle and upper) and in each stratum, two leaves were collected from the outside of the plants, one on the right side and one on the left side and one leaf on the inside of the plant, totaling 135 leaves per application technique. This sample model was adapted from Bernardes *et al.* (2014) and Llop *et al.* (2015a).

The collected leaves were individually placed in a plastic bag (0.2 x 0.1 m), then 25 mL of distilled water was added and shaken for one minute to remove the Brilliant Blue marker. The resulting liquid was placed in a plastic pot with 100 mL capacity and the absorbance reading was performed by a spectrophotometer (630 nm), Femto® brand, model 600 S. The leaves were then removed from the plastic bags and the leaf area measured with the image analysis system (Windias®). A linear equation ( $y = b + ax$ ) was calculated by means of a standard curve (with 17 known concentrations of the spray solution and their respective absorbance values) to allow the determination of the concentration of the dye in mg L<sup>-1</sup>, as a function of the absorbance measured in each sample. With the concentration values determined, the volumes of spray solution retained in the target, in  $\mu\text{L}$ , by equation (3).

$$V_i = [(C_f \cdot V_f) / C_i] \cdot 1000 \quad (3)$$

Where  $V_i$  is initial volume which deposited on the leaves ( $\mu\text{L}$ ),  $C_i$  is initial concentration of spray ( $\text{g L}^{-1}$ ),  $V_f$  is final volume of water used in the washing of the leaves (mL) and  $C_f$  is final concentration of the sample ( $\text{mg L}^{-1}$ ).

The volume of the sample retained in the target was divided by its respective leaf area to determine the deposit in volume / area ( $\mu\text{L cm}^{-2}$ ), which is known as an effective or absolute deposit.

The theoretical deposit was also calculated (Equation 4), which represents a perfectly uniform distribution of the total volume applied, that is, without losses and totally uniform on the plants.

$$D_{\text{theoretical}} = V / (\text{LAI} \cdot 10^2) \quad (4)$$

Where  $D_{\text{theoretical}}$  is theoretical deposit ( $\mu\text{L cm}^{-2}$ ),  $V$  is application rate ( $\text{L ha}^{-1}$ ) and LAI is leaf area index.

After the calculation of the theoretical deposit, the relative deposit (Equation 5) was calculated, from the relationship between effective deposit and the theoretical deposit.

$$D_{\text{relative}} = (D_{\text{effective}} / D_{\text{theoretical}}) \cdot 100 \quad (5)$$

Where  $D_{\text{relative}}$  is relative deposit (%),  $D_{\text{effective}}$  is effective deposit ( $\mu\text{L cm}^{-2}$ ) and  $D_{\text{theoretical}}$  is theoretical deposit ( $\mu\text{L cm}^{-2}$ ).

#### Coverage

To evaluate the coverage, the sampling points were the same as those used in the deposit, but the collected leaves were stored in paper bags (0.2 x 0.1 m). The evaluation was performed on the adaxial and abaxial surfaces of the leaves by observation of the Yellow Fluorescent marker in a dark environment with ultraviolet light (black light) using a scale of 0 to 100% with 10% intervals. For the preparation of the scale, 50 randomized leaves of plants sprayed under the same conditions of the test were collected and then 10 leaves with 10% interval coverage were selected at 10%, 0% corresponding to the minimum and 100% the maximum coverage obtained by different application techniques, according to Graziano *et al.* (2017).

#### Statistical analysis

The data of the lower, middle and upper strata of the canopy were analyzed individually and were not compared to each other.

The normality of the data was verified by the Shapiro-Wilk test ( $p \leq 0.05$ ) and the homogeneity of the variances by the Levene test.

For the relative deposit, the effect of the application techniques and the collection site in the canopy were assessed by analysis of variance. The application techniques were compared by the SNK test ( $p \leq 0.05$ ) and the collection points in the plants by the Student t test ( $p \leq 0.05$ ).

For the cover, the effect of the application techniques, collection site in the canopy and side of the leaf was analyzed by analysis of variance. The application techniques were compared by the SNK test ( $p \leq 0.05$ ). The collection points in the plants and the leaf surfaces were compared by the Student t test ( $p \leq 0.05$ ).

## RESULTS AND DISCUSSION

The data on the left and right sides of the plants for the relative deposition and coverage did not present a significant difference by the Student t test ( $p \leq 0.05$ ), therefore, the mean for each collection point was performed.

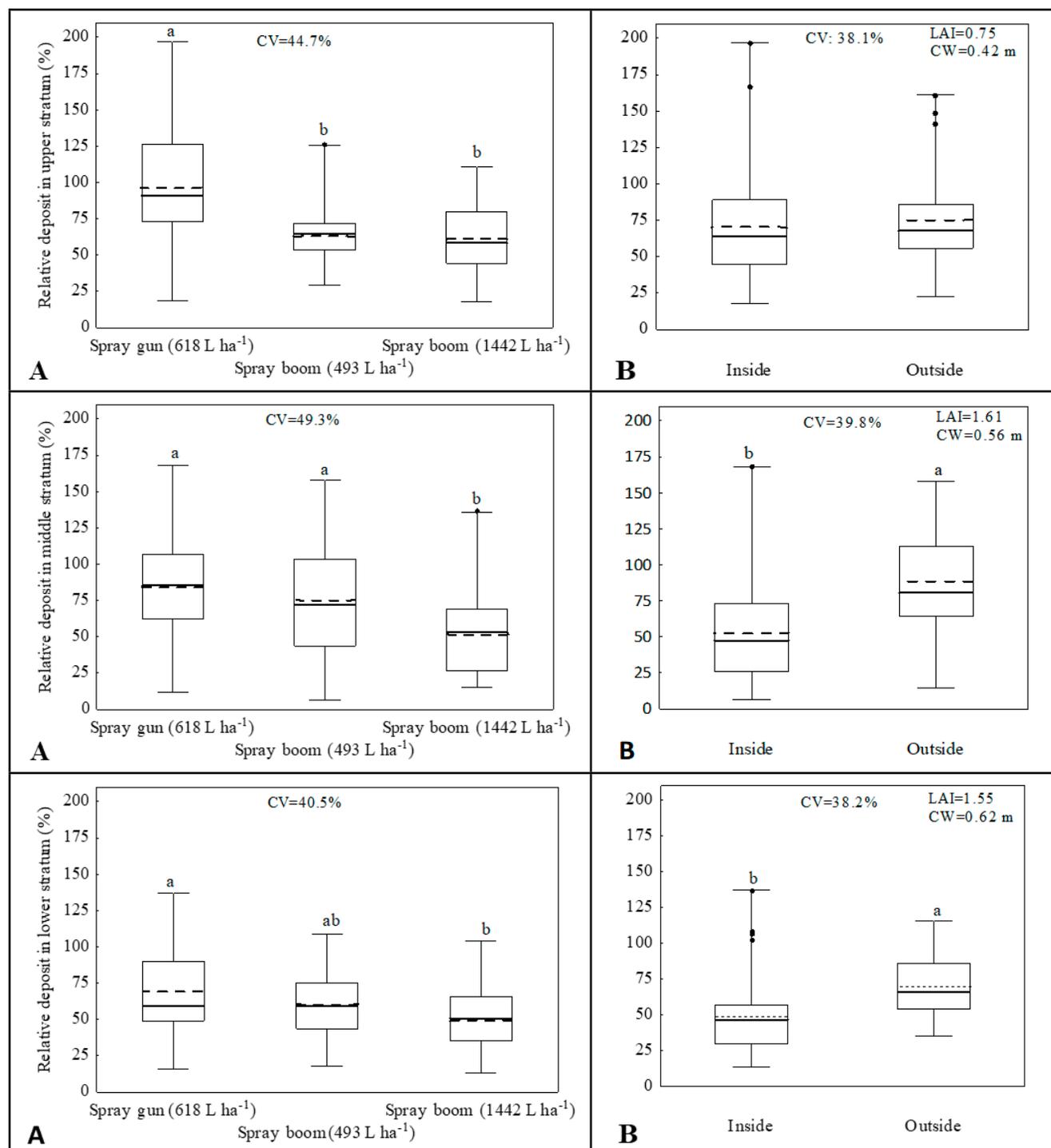
For the relative deposit, there was

no interaction between the application techniques and the sample points (inside and outside) of the plants in all strata of the canopy, so the means of the factors were compared separately (Figure 1). Regarding the techniques, the Spray

gun JA-2 (618 L ha<sup>-1</sup>) provided higher deposition than the Spray boom-AXI 11002 (1442 L ha<sup>-1</sup>) in all canopy stratum (Figure 1A). While the Spray boom-ATR 0.5 (493 L ha<sup>-1</sup>) presented an intermediate behavior, being equal to the

Spray boom-AXI 11002 (1442 L ha<sup>-1</sup>) in the upper stratum, equal to the Spray gun JA-2 (618 L ha<sup>-1</sup>) in the middle stratum and did not differ from both techniques in the lower stratum.

In general, researches comparing

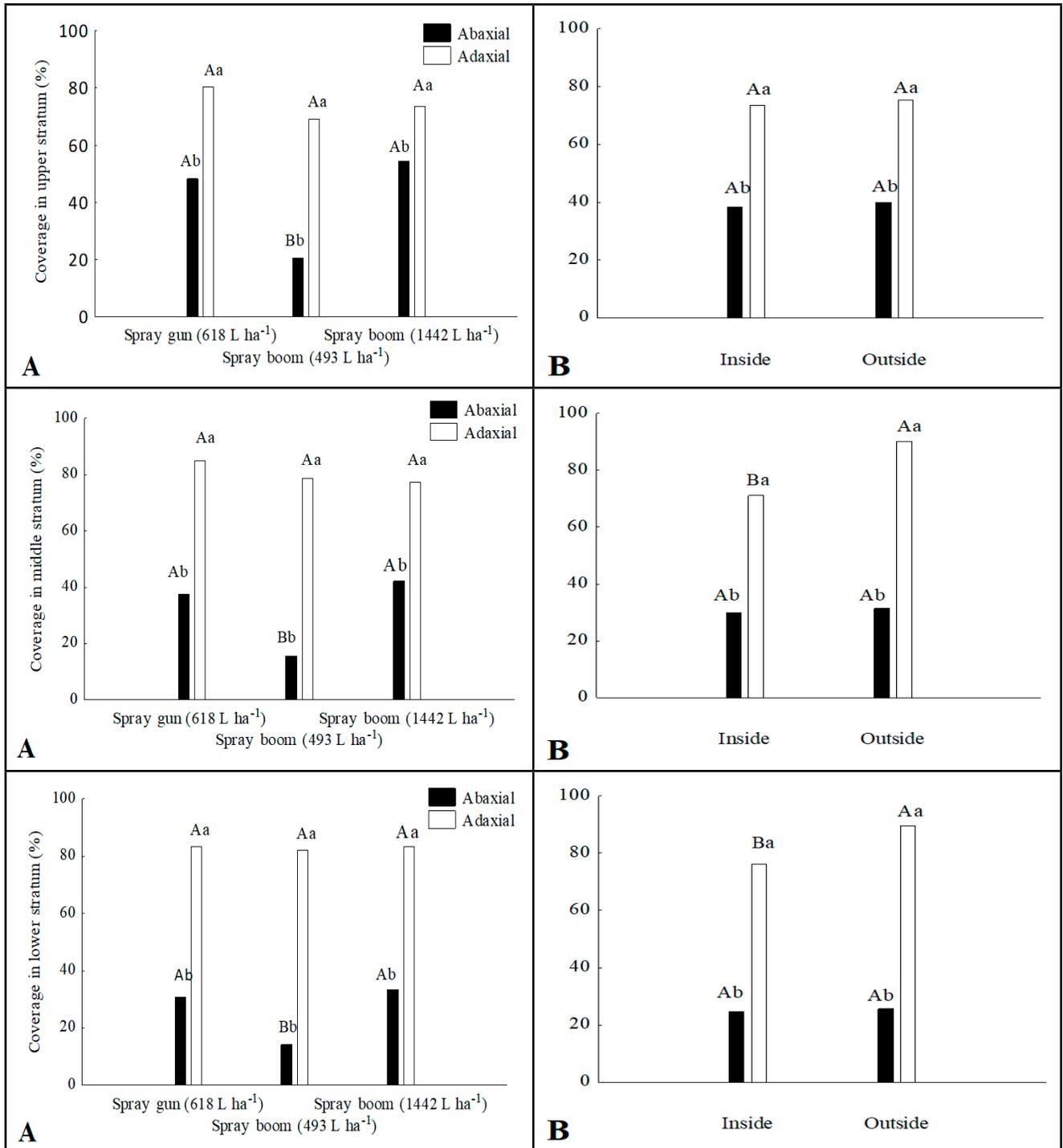


**Figure 1.** Relative deposit of spray solution (%) according to application techniques (A) and collected points in tomato plants under greenhouse (B). Different letters for application techniques showed significant difference by the SNK test ( $p \leq 0.05$ ) and for collection points in the plants by the Student t test ( $p \leq 0.05$ ). Coefficient of variation (CV), Leaf area index (LAI), Canopy width (CW), "Outliers" (•), Average (---), Median (—), Range (I) 25%-75% (...) (GD2). Bandeirantes, UENP, 2017.

application techniques with spray gun and spray boom on tomato crops show opposite results, where the spray boom provided a higher deposit than the spray gun. However, these researches were carried out with cultivars, leaf area index

and in a different cultivation system from the present study. Other differences are in the equipment configurations and calibrations from this research, mainly in relation to the application rate and spray pressure. As an example, the

application with the spray gun was performed at the application rate of 1600 L ha<sup>-1</sup> and pressure of 2200 kPa (Sánchez-Hermosilla *et al.*, 2012) and 1800 L ha<sup>-1</sup> and 1500 kPa (Sánchez-Hermosilla *et al.*, 2011), possibly may



**Figure 2.** Leaf coverage (%) on the abaxial and adaxial surface, according to pesticides application techniques (A) and collected points in tomato plants under greenhouse (B). Different capital letters show differences for application techniques by SNK test ( $p \leq 0.05$ ) and collected points in the plants by Student t test ( $p \leq 0.05$ ). Different lowercase letters present difference to the surface of the leaves by the Student's t test ( $p \leq 0.05$ ). Bandeirantes, UENP, 2017.

occur losses due to high pressure (Van Os *et al.*, 2005; Sánchez-Hermosilla *et al.*, 2013a), or due to the runoff caused by high rate of application (Chaim *et al.*, 1999).

In the present work, the pressure for the spray gun was 700 kPa and the application rate was 618 L ha<sup>-1</sup>, less than half the pressure and application rate used in the above works, which may have contributed to Spray gun JA-2 (618 L ha<sup>-1</sup>) to provide deposition similar to the Spray boom-ATR 0.5 (493 L ha<sup>-1</sup>) and higher than the Spray boom AXI 11002 (1442 L ha<sup>-1</sup>).

On the upper stratum, Spray gun JA-2 (618 L ha<sup>-1</sup>) provide higher relative deposition in comparison to the spray boom, which did not differ from each other. At the moment of application, there was oscillation of the bar caused by the irregularity of the greenhouse ground, being more accentuated at the upper end of the bar due to the point of attachment of the bar located at its lower end. Oscillations in the application boom change the distance between the nozzle and the target, negatively affecting the deposition (Pontelli & Mucheroni, 2009).

Comparing both vertical spray boom, the technique Spray boom-ATR 0.5 (493 L ha<sup>-1</sup>) promoted similar deposition to the technique Spray boom-AXI 11002 (1442 L ha<sup>-1</sup>) in the lower and upper strata of the culture and 21% higher in the middle stratum, with the advantage of saving water. The use of lower application rates is beneficial from the environmental point of view, since it reduces the amount of water in direct contact with pesticides, as well as the lower risk of loss of active ingredient due to runoff to the soil (Rodrigues *et al.*, 2011).

In the lower and middle strata of the canopy, the deposition in the inside was 21% and 34%, respectively, lower than in the external part (Figure 1B). In contrast, in the upper stratum there was no difference in deposition between the internal and external parts of the canopy. The LAI and CW were different in the canopy strata, with higher values in the lower and medium, indicating that the increase of these values reduces the deposition in the inside, due to the

barrier imposed by the leaves of the outside of the plants being larger.

The low deposition in the inside of the tomato canopy is reported in the literature (Sánchez-Hermosilla *et al.*, 2013a; Llop *et al.*, 2015a) and in extreme situations the relative deposit was only 6.8% in this region (Braekman *et al.*, 2010). These results highlight the importance of the development of application equipment that provide better penetration of droplets inside the canopy, in order to contribute mainly to the control of pests and diseases that are located inside the canopy (Sánchez-Hermosilla *et al.*, 2011; Llop *et al.*, 2015b).

In all situations, the range in the relative deposition is large, showing that there are occurrences of underdoses and overdoses. The occurrence of subdoses makes the control of pests and diseases located in this region difficult. On the other hand, overdoses can cause phytotoxicity of the crop or increase the level of residues of pesticides in the fruits. In greenhouses, the risk of residues in fruits is higher, since the degradation of pesticides can be prolonged when compared to crops in the open field (Allen *et al.*, 2015; Li *et al.*, 2017).

The representation of the data by means of box-plot allows the demonstration of the variability of the spray deposit and indicates that exploration of the deposition data only through the mean is not sufficient, since at this value there may be high frequency of discrepant data.

In relation to leaf coverage by spray droplets, there was interaction between the application techniques and the leaf surface in all canopy strata and between collection sites in the plants and leaf surface in the lower and middle strata (Figure 2).

The Spray boom-ATR 0.5 (493 L ha<sup>-1</sup>) provided lower coverage of the abaxial surface of the leaves, when compared with the Spray gun JA-2 (618 L ha<sup>-1</sup>) and Spray boom-AXI 11002 (1442 L ha<sup>-1</sup>), which did not differ from each other (Figure 1A). The lower coverage of the abaxial surface provided by Spray boom-ATR 0.5 (493 L ha<sup>-1</sup>) in relation to Spray boom-AXI

11002 (1442 L ha<sup>-1</sup>), may be related to the lower application rate used in the first technique, one of the factors that are directly related to the target coverage (Courshee, 1967). Specifically for the Spray gun JA-2 (618 L ha<sup>-1</sup>), the spray gun inclination upward, exerted by the farmer in ordinary applications to control pests that are located in the abaxial part of the leaves, may have contributed to coverage being greater than Spray boom-ATR 0.5 (493 L ha<sup>-1</sup>) and equal to Spray boom-AXI 11002 (1442 L ha<sup>-1</sup>), which used higher application rate. Researches carried out to evaluate the effect of spray jet angle have shown positive results for spray jet angulation. As an example, the spray nozzle inclination at 30° upwards increased the deposition on the abaxial surface of the leaves of ornamental plants cultivated in protected environment (Foque *et al.*, 2014).

Considering only the coverage of the abaxial surface of the leaves, there were no differences among the application techniques, however, in all situations the cover was superior compared to the abaxial surface. Considering the average of the three strata, in the adaxial surface there was 80% coverage, while in the abaxial coverage was 32%, or 2.5 times lower.

Irregular coverage is a challenge of the technology of application in the tomato crops, in general, research has shown less coverage on the adaxial surface of the leaves and in the inner part of the canopy (Lee *et al.*, 2000; Sánchez-Hermosilla *et al.*, 2012; Llop *et al.*, 2015a).

In the lower and middle strata, the cover of the adaxial surface of the leaves was smaller in the internal compared to external part of the plants; however, in the upper stratum, there was no difference (Figure 2B). The LAI and CW of the lower and middle strata are higher in relation to the upper stratum, which made it difficult for the sprayed drops to penetrate into the canopy, resulting in less leaf coverage of this part.

The low uniformity of coverage, both between the leaf surfaces and between the internal and external parts of the canopy, is of concern, mainly for the application of pesticides with

contact action, which require a better distribution of the spray droplets. An example is copper fungicides, which are frequently used in the preventive control of diseases caused by fungi and bacteria (Pontes *et al.*, 2017), may have reduced disease control efficiency in cases of low uniformity of coverage. In conclusion, the technique of application Spray gun (618 L ha<sup>-1</sup>), used by commercial farming, provides better quality of the application. However, all the application techniques evaluated need to be optimized in order to provide better distribution of the spray, mainly in the critical parts, such on the inside of the plants in the lower and middle canopy strata and the abaxial surface of the leaves.

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