Effect of air blast sprayer application speed on the dye retention of coffee leaves

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10.1590/0034-737X202269060001

ABSTRACT

Improving the effectiveness of pesticide application for controlling insects, mites, and pathogens in coffee cultivation has been a major challenge for coffee farmers, researchers, and consultants. The present study aimed to assess the deposition and distribution of a brilliant blue tracer in the coffee canopy using Jacto's Arbus 2000 Super Export EL and Kuhn's Twiter 2000 air blast sprayers at different application speeds (5 and 7 km h^{-1}). The experiment was conducted using a randomized block design, with a 2 × 2 factorial arrangement (two sprayer models and two application speeds), with six replicates. After spraying, leaves were collected, and the deposition of the tracer was assessed using spectrophotometry. The canopy was divided into lower, middle, and upper heights, and subdivided into external and internal crown positions. The percentage difference in spray deposition between positions was termed relative spray deposition. Spray deposition in the internal crown differed only in the upper third section between sprayers. In the external crown, the application speed affected the deposition of tracer dye for both sprayers, whereas, in the internal crown, the application speed only affected the deposition of tracer dye in the upper crown section only when using the Arbus sprayer.

Keywords: coffee cultivation; spraying; leaf deposition.

INTRODUCTION

Improving the effectiveness of pesticide application for controlling insects, mites, and pathogens in coffee cultivation is a major challenge for coffee farmers (Zampiroli *et al.*, 2017). Indeed, even though a wide range of variable-rate technologies are available to crop farmers, this is not the case for tree crops (e.g., coffee; Dou *et al.*, 2018). In Brazil, for example, there are only a few companies that manufacture air blast sprayers that can apply pesticides in coffee plantations, especially regarding spacing, and have sprayer frames (e.g., shafts, circuit tubing, connections, and spray nozzles) that can withstand the impact of the side branches of coffee trees. For this reason, in Argentina, axial fan sprayers are predominantly used in fruit cultivation (Montoya *et al.*, 2018). However, regardless of the technology used, increasing the spraying efficiency, which is measured as the ability to deposit active ingredients on the target, remains to be one of the greatest challenges for spray technology in coffee cultivation, and is primarily affected by the leaf area index and shape of coffee plants (Silva *et al.*, 2014). Therefore, the search for suitable spraying technologies is a limiting factor in achieving application efficacy.

Hollow cone spray nozzles are commonly used among coffee farmers because common sense suggests that fine

Submitted on February 27th, 2020 and accepted on May 16th, 2022.
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droplets should be used for insect and pathogen control.

Fritz *et al.* (2012) reported that the droplet size determines the deposition of active ingredients, both on and off target, and Ruas *et al.* (2015) reported that the airflow produced by the fan of air blast sprayers is a limiting factor for spray application efficiency. Traditionally, coffee farmers in the Cerrado use air blast sprayers that employ turbulent airflow and axial fans (Silva *et al.*, 2014; Souza Júnior *et al.*, 2017; Zampiroli*et al.*, 2017). However, air-assisted control systems, including variable-rate spraying systems used for fruit growing, are currently being adapted to the requirements of coffee cultivation (Chen *et al.*, 2012; Chen *et al.*, 2013). According to Salcedo *et al.* (2019), the air-assisted control systems of newer variable-rate spraying systems concentrate both airflow and spray, thereby more effectively applying phytosanitary products and improving treatment efficiency. However, Silva *et al.* (2014) reported that the risk of drift caused by the airflow generated by air blast sprayers is high, and as such, treatments applied using air blast sprayers may result in both low biological efficacy and environmental contamination. In addition, the airflow generated by air blast sprayers with axial fans has been reported to generate turbulent airflow, with different directions on both sides of the air outlet, strongly depending on the rotation of the fan (Salcedo *et al.*, 2019).

Thus, the aim of the present study was to evaluate the use of Arbus 2000 Super Export EL and Twister 2000 air blast sprayers in coffee plantations by assessing the deposition and distribution of a brilliant blue tracer in the coffee canopy.

MATERIAL AND METHODS

The present study was conducted in a stand of 'Topázio' coffee at the Machinery and Mechanization Laboratory of the Institute of Agricultural Sciences, Federal University of Uberlândia, in an experimental area of the Bom Jardim Farm. This farm is located in the Municipality of Patrocínio-Minas Gerais (18°56′35″ W, 47°09′04″ E; 913 m above sea level).

To evaluate the effectiveness of the Arbus 2000 Super Export EL (Jacto, Pompéia, SP, Brazil) and Twister 2000 (Kuhn of Brazil, Passo Fundo, RS, Brazil) air blast sprayers at different application speeds (5 and 7 km h^{-1}), a randomized block design was used, with a 2 × 2 factorial arrangement (two sprayer models and two application speeds) and six replicates. The blocks were 10 m apart, and to minimize drift, there was 20 m between the plots. Each plot included 10 plants and leaves were collected from the central plant within the plots. In addition, the plant spacing was 3.7 × 0.7 m, and the average crown height and diameter were 3.2 and 2.0 m, respectively, which provided a crown volume and volumetric index of 17.297 m^3 ha^{-1} and 29 mL m^{-3}, respectively, as calculated following the methods of Alvarenga *et al.* (2013), Campos *et al.* (2019), and Salcedo *et al.* (2020). The agricultural land covered 1.2 ha with two empty rows between each planted row.

Two air blast sprayers were evaluated. The Arbus 2000 Super Export EL was operated using a two-port fan (850 mm diameter), spray nozzles in working position "A" (24.3 m^3 s^{-1} volumetric flow rate, 34.3 m s^{-1} airflow rate), a JP 150 high-pressure ceramic cylinder piston pump with 18 anti-drip adjustable flip-over nozzle holders and 36 ceramic nozzles, and multi-blade mechanical and hydraulic agitation, according to the manufacturer's instructions. Meanwhile, the Twister 2000 was operated using a centrifugal, two-port fan (500 mm diameter) with the fan gearbox adjusted to transmission position "II" (4.8 m^3 s^{-1} volumetric flow rate, 69.4 m s^{-1} airflow rate), an MPP33 hydraulic pump (125 L min^{-1}, 540 rpm) with a volumetric flow rate of 91.3 L min^{-1}, a double brass layer nozzle bracket with 40 anti-drip nozzles, and a venturi-type hydraulic agitator, according to the manufacturer's instructions.

The sprayers were individually pulled and transported using tractors (model 4275 Compacto) (Massey Ferguson's, Marau, RS, Brazil), with 4 × 2 auxiliary front wheel drive and 540 rpm in independent power take-off (PTO), which was assessed using a Digital Contact Tachometer (model MDT2238A) (Minipa, São Paulo, SP, Brazil). In addition, the volumetric flow rates of all spray nozzles were determined using measuring cylinders and the coefficient of vertical variation for the nozzle holder/bracket was determined from the volumetric flow rate, following Salcedo *et al.* (2020).

Spraying was performed using hollow cone spray nozzles, with MAG 1 (MagnoJet, Ibaiti, PR, Brazil) spray nozzles used in the Arbus sprayer, at 421 and 924 kPa, and MAG 1.5 spray nozzles used in the Twister sprayer, at 648 and 1.324 kPa, according to the manufacturers' instructions, producing fine droplets in both cases. The sprayers were calibrated to apply 500 L ha^{-1}, and the control of the coffee leaf miner at adult and larval stages was the focus.

After spraying, leaves were collected from the north and south sides of each plant to assess spray deposition, adapting the method of Sasaki *et al.* (2013). The plants were divided into upper, middle, and lower heights, and each section was further divided into external (corresponding to the third or fourth leaf pair of the plagiotropic branch) and internal (at 0.30 m from the external section) portions, adapting the method of Salcedo *et al.* (2020). Four leaves were collected at each position.

The collected leaves were taken to the laboratory and the dye was removed by washing the leaves in 30 mL distilled water, under agitation, for 30 s, adapting the method of Miranda *et al.* (2012). After washing, each solution was refrigerated for 24 h to allow impurities to settle and spray deposition was measured by spectrophotometry, measuring the absorbance of the Brilliant Blue dye (FD&C n.1) (Duas Rodas, Jaraguá do Sul, RS, Brazil) at a concentration of 4.0 g L^{-1} (2000 g ha^{-1}). Thereafter, the leaf area was measured following the method of Sasaki *et al.* (2013), using a leaf area meter (model LI-3100C) (Li-Cor, Lincoln, NR, USA) to calculate the leaf deposition.

Relative spray deposition was defined as the percentage difference in the deposition calculated for the external and internal positions, and calculated to demonstrate the dye deposition uniformity at the external and internal positions of the canopy at different heights. Notably, lower values represented greater homogeneity in deposition. These data were calculated using descriptive statistics, such as mean values and percentages. To reduce experimental differences, the nozzle spray angle was aligned for framing proportional to the effective height of the crown with leaves, thereby reducing ground-directed and above-crown-height jet losses, following the method of Montoya *et al.* (2018).

The weather conditions during spraying were monitored using a thermo-hygro-anemometer (model ITSP-800.1) (Instrutemp, São Paulo, SP, Brazil) and the average temperature, relative air humidity, and wind speed were 29.7 °C, 52%, and 2 km h^{-1}, respectively.

Data were subjected to tests for normality, using the Shapiro–Wilk test, and for homogeneity of variance, using the Tukey–Anscombe test, before being subjected to analysis of variance. Upon significant differences, as indicated by the F-test, means were compared using Tukey's test, with a 5% probability. All tests were performed using R (R Development Core Team, 2019), which is a free programming language and software environment for statistical computing and graphics.

RESULTS AND DISCUSSION

The coefficients of vertical variation, which were calculated from the volumetric flow rates of samples collected from the Arbus and Twister spray nozzles, were 4.6% and 3.5%, respectively. These results were similar to the findings of Montoya *et al.* (2018) and Salcedo *et al.* (2020). Knowing the distribution of liquid in the nozzle holder/bracket makes it possible to adjust the sprayer to the size and geometry of the crop. This difference in the coefficient of vertical variation indicates that the uniformity of the vertical spray distribution in the nozzle holders/brackets and hydraulic nozzles was sufficient, and that the hydraulic system, hoses, and connections had few points of pressure loss or spray leakage. Greater differences were reported by Souza Júnior *et al.* (2016) when working with air blast sprayers with different configurations.

The uniform distribution of the spray in the nozzle holder/brackets and hydraulic nozzles was reflected in the homogeneous deposition of tracer dye on the coffee leaves in different sections of the canopy. In the external portion, both sprayers showed a similar tracer deposition pattern, with a difference of only 7 km h^{-1} when using the Twister sprayer (Table 1).

Table 1: Tracer deposition (µL cm^{-2}) in the external sections of coffee tree canopies.

Application speed (km h^{-1})	Canopy positions					
	Lower		Middle		Upper	
	Arbus	Twister	Arbus	Twister	Arbus	Twister
5	0.80 aA	0.55 bA	0.56 bA	0.58 aA	0.35 bA	0.34 aA
7	0.98 aA	0.86 aA	0.88 aA	0.66 aA	0.65 aA	0.28 aB
CV (%)	27		22		37	

Means followed by different lowercase letters in columns and uppercase letters in rows in each canopy position differed from each other according to Tukey's test ($p > 0.05$).

The deposition of tracer dye in the lower and middle sections of the external canopy was similar to the values reported by Santinato *et al.* (2017). However, in the present study, lower values were observed for leaves from the internal, upper section, possibly because this section was more difficult to access. There were no differences between the lower, middle, and upper canopy sections, even at different leaf densities.

Higher application speeds increased tracer deposition in the external canopy when using both sprayers. This was possibly due to the air volumetric flow rate, which was 406% greater for the Arbus sprayer than that for the Twister sprayer and the airflow rate, which was 102% higher for the Twister sprayer than that for the Arbus sprayer. Meanwhile, at a lower application speed, due to the longer period of plant exposure to the flow, the air produced by the fan itself could blow off the product from the leaf surface. The behavior of airflow in the field is dynamic because the environment imparts movement to the droplets, as described by Zhai *et al.* (2018), who reported that the application efficiency is affected by airflow, application speed, and surrounding natural air asymmetry.

In the upper canopy section, the Twister sprayer promoted more homogeneous spray deposition, owing to the vertical position of its nozzle bracket in relation to the plants. This was in contrast to the spray nozzle holder of the Arbus sprayer, which was positioned farther from the target, owing to its semicircular shape. This shape favored losses by drift and evaporation, even though the nozzle holder/bracket of the Twister sprayer contained more spray nozzles. In addition, the airflow produced by the fans differ depending on the sides of the nozzle holder/bracket and at different heights on the same side, as reported by Zhai *et al.* (2018), even though the industry attempts to even out the airflow on both sides. In the internal section, the sprayer type only affected the spray deposition on the upper third section of the canopy (Table 2).

When using the Arbus sprayer, the high air volumetric flow rate associated with air speed indicates deficiencies in the axial fan, which promotes greater branch and leaf movement, and accounts for the different deposition rates observed in the present study. However, substantial energy is lost, and droplets are pulled into the fan blades because of the way in which the air is sucked. The Twister sprayer produces a lower air volumetric flow rate at a higher speed than the Arbus sprayer, thereby losing less energy because the air is channeled into ducts. As such, the droplets are more evenly targeted on the canopy, promoting less branch and leaf movement, thereby enhancing droplet penetration. Furthermore, differences in the airflow projection of the Arbus and Twister sprayers onto the plants affected leaf movement, penetration, and droplet turbulence.

Differences in the volumetric flow rate and airflow rate observed in the present study indicated differences in spray spillover. When using the Arbus sprayer, the air spilled over onto the plants in adjacent rows and all plots showed airflow with droplets on both sides of the plant. In contrast, the Twister sprayer yielded lower droplet airflow spillover. Most likely, double spraying enables the Arbus sprayer to achieve spray deposition that is equal to or greater than that of the Twister sprayer in some sections of the canopy when the air volumetric flow rate is low and the airspeed high, as demonstrated on fruit trees by Campos *et al.* (2019).

When using the Arbus sprayer, the effect of the application speed was stronger for internal leaves because the deposition was 33% higher at 7 km h^{-1}. However, the Twister sprayer yielded lower spray deposition rates in the upper canopy at the same application speed, at both internal and external positions. The crown shape of the cultivar grown in the experimental area was conical, with a lower leaf density in the upper canopy. This enhanced deposition when using the Arbus sprayer, despite differences in nozzle holder/bracket shape and differences in the distance between the spray nozzles and leaves. Similarly, Santinato *et al.* (2017) reported that spray deposition on coffee plants increases with plant volume but decreases with leaf density.

The diameter of the air outlet is smaller in the Twister sprayer than that in the Arbus sprayer, and even though the volumetric flow rate of the Twister sprayer is also lower, the smaller outlet diameter increases the airflow rate. However, at the higher application speed, the smaller outlet diameter may affect the sprayer's ability to deposit droplets at positions further from the nozzles due to the conical shape of the crown. In fact, this was observed for the deposition rates of the internal middle and upper canopy sections, thereby corroborating the findings of Campos *et al.* (2019). Nevertheless, few studies have made attempts to translate the dynamic airflow behavior of the air blast sprayer fans under field conditions.

The calculation of relative spray deposition provides insights into the airflow homogeneity and airflow capacity of both sprayers in promoting droplet penetration into the internal and external canopies (Table 3).

Table 2: Tracer deposition (µL cm^{-2}) in the internal sections of coffee tree canopies.

Application speed ($km\ h^{-1}$)	Canopy positions					
	Internal		Middle		Upper	
	Arbus	Twister	Arbus	Twister	Arbus	Twister
5	0.30 aA	0.38 aA	0.19 aA	0.32 aA	0.14 bA	0.15 aA
7	0.43 aA	0.40 aA	0.31 aA	0.17 aA	0.21 aA	0.13 aB
CV (%)	47		51		34	

Means followed by different lowercase letters in columns and uppercase letters in rows in each canopy position differed from each other according to Tukey's test (p > 0.05).

Table 3: Relative spray deposition in the internal and external sections of coffee tree canopies.

Application speed ($km\ h^{-1}$)	Canopy					
	Lower		Middle		Upper	
	Arbus	Twister	Arbus	Twister	Arbus	Twister
5	63	31	50	46	60	56
7	57	53	66	74	68	54

Independent analyses of the sources of experimental variation indicate that, in the lower canopy, the Twister sprayer promoted a more homogeneous deposition of tracer dye, regardless of the application speed. In the middle canopy, the air blowing effect was stronger at 5 km h^{-1} as both sprayers produced more homogenous deposits in the internal and external canopy sections. These results reinforce the observation that application speed could affect spray deposition. The effect of application speed on the upper canopy was similar to that observed in the lower canopy, albeit with less homogenous deposits. Overall, the Twister sprayer promoted a more homogeneous distribution of tracer dye than the Arbus sprayer, regardless of the application speed or canopy section. Similar results were reported by Salcedo *et al.* (2020).

The MAG 1 and 1.5 spray nozzles typically produce fine droplets, which is important because the droplet size is a determinant of heterogeneity among canopy sections. In the present study, the airflow of each sprayer was sufficient to move the plant canopy and to blow droplets into the interior, corroborating the results of Fritz *et al.* (2012). In the upper canopy, the Arbus sprayer at the application speed of 7 km h^{-1} promoted greater spray deposition in both internal and external positions. However, in these positions, the distance from the nozzle to the leaves was longer and less of the previously deposited product was blown away because the environment virtually nullified the airflow, thereby balancing the force between the sprayer and surrounding airflow.

CONCLUSIONS

The deposition of tracer dye was lower in the upper crown than that in the middle or lower crown sections, regardless of sprayer type.

In the external crown, the application speed affected the deposition of tracer dye for both sprayers, whereas in the internal crown, the application speed only affected the deposition of tracer dye in the upper crown section only when using the Arbus sprayer.

Finally, the Twister 2000 sprayer yielded more homogeneous tracer deposition in the internal and external parts of the canopy.

ACKNOWLEDGMENTS, FINANCIAL SUPPORT, AND FULL DISCLOSURE

The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) for supporting this study.

The authors declare no conflicts of interest.

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