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ORIGINAL ARTICLES

Application technology for chemically controlling coffee leaf miner in the cerrado of Minas Gerais State

Tecnologia de aplicação para controle químico do bicho-mineiro em cafeeiro no cerrado mineiro

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ABSTRACT: Leaf miner is a major coffee tree pest that causes severe losses. Most farmers perform chemical control in an attempt to reduce damage to the crop. Thus, the current study aims to analyze spraying efficiency and control effectiveness according to the management plan adopted in a coffee farm in the Cerrado of Minas Gerais. The application used Arbus sprayer, model 2,000, at the pressure of 600 kPa. The droplet spectrum was analyzed using water-sensitive paper. The plant architecture influence on the application quality was evaluated through the droplet spectrum and control efficacy. We conclude that the plant crown height and depth affected application efficiency. Spraying was an effective phytosanitary control of coffee leaf miner, reaching 87.5% control efficiency ratio, considering that infestation was three times higher than that recommended for the applied pesticide at the time of application.

RESUMO: *O bicho-mineiro é uma das principais pragas do cafeeiro, causando severos prejuízos. O controle químico é realizado pela maioria dos cafeicultores na tentativa de reduzir as injúrias causadas à cultura. Neste sentido, objetivou-se com o presente trabalho analisar a eficiência da pulverização e a eficácia de controle, em função do manejo adotado em uma propriedade cafeeira na região do cerrado mineiro. A aplicação foi realizada utilizando um pulverizador marca Arbus, modelo 2.000, na pressão de 600 kPa. O espectro de gotas foi analisado por meio de papel sensível à água. Avaliou-se a influência da arquitetura da planta na qualidade da aplicação por meio do espectro de gotas e da eficácia de controle e concluiu-se que a arquitetura da planta interferiu na eficiência da aplicação em relação à altura e à profundidade da copa, e que a pulverização foi eficiente para o controle fitossanitário do bicho-mineiro do cafeeiro, atingindo índices de eficácia de controle de 87,5%, considerando que a infestação no momento da aplicação era três vezes maior que aquela recomendada para o inseticida aplicado.*

KEYWORDS
Application of pesticides
Coffea arabica L.
Leucoptera coffeella

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1 Introduction

The coffee culture in Monte Carmelo, Minas Gerais, is critical to the county's development and growth. It has important social function, which is featured by the number of direct and indirect jobs it creates and by its historical function due to the region's tradition of producing Arabica coffee. Therefore, the concern with the environment is mandatory in the properties' daily life, especially the certified ones. The use of techniques and products to help application efficiency and plant protection products' effectiveness comes against the sustainable coffee production precepts in Triangulo Mineiro and Alto Paranaíba regions. The state of Minas Gerais accounts for over 50% of the Brazilian coffee crop, with over one million planted hectares. Five point eight (5.8) million out of the 22.6 million bags of coffee produced in Minas Gerais in 2014 came from Minas Gerais Cerrado (CONAB, 2015).

Phytosanitary product applications in perennial crops, such as coffee, are generally performed using high syrup volume to cover the entire leaf surface and it results in drip-losses caused by excess of syrup application, which exceeds leaves' maximum liquid-holding capacity. Therefore, it is essential to know the plants' leaf area to determine the maximum amount of syrup that can be retained, thus avoiding the loss of water and phytosanitary products (Cunha et al., 2005). As for the citrus industry, which also has arboreal-size plants, Ferreira et al. (2007) showed that drip-losses might reach levels higher than 50% of the applied volume. It may also occur in other crops.

According to Miranda et al. (2012) and Scudeler et al. (2004), the spraying in tree crops such as coffee is influenced by the cultivar to be treated, plant canopy shape and height, length of reproductive branches, fruit amount and size, and by leaf density, among others. Choosing the correct spray tip will produce a droplet size able to overcome all these obstacles. Therefore, Cunha et al. (2010) state that if the produced droplets are adequate, drip- and drift-losses may be avoided, thus ensuring the efficiency in the application of phytosanitary products.

The leaf miner is an exotic African pest, and it is considered monophagous because it only attacks coffee trees. After the eggs hatch on the leaf surface, the caterpillars penetrate the leaf through the epidermis and feed on the palisade parenchyma, which may cause up to 70% defoliation, Scalon et al. (2013). Injuries reduce the photosynthetic capacity due to the leaf area reduction observed during intense attacks. High attack levels are observed in years of drought, indicating that their occurrence is strongly tied to meteorological factors, mainly temperature and rainfall. Literature shows that there is no consensus on the level of control in leaf miner integrated management. Matiello et al. (2005) recommend that the control must start when 10% of leaves have caterpillars living on them, whereas Gallo et al. (2002) adopt the rate of 40% to start the control. On the other hand, DuPont™ recommends applying Chlorantraniliprole insecticide when monitoring shows 3% infestation of leaves destroyed by living caterpillars. This difference mainly occurs due to location, weather conditions, time in which the study was conducted and the evaluated cultivars.

Alto Parnaíba and Triângulo Mineiro mesoregion counties with average rainfall of 1300 mm show the occurrence of lesions on leaves throughout the year with two infestation peaks. The first peak occurs from May to June and the second one from September to October. These times are featured as low rainfall months, and from November on, when the first rains start falling, the amount of lesions on leaves rapidly decreases (Conceição, 2005).

The current study investigates the spraying efficiency and the biological efficacy of the leaf miner chemical control according to the handling adopted in a coffee farm in Minas Gerais Cerrado region.

2 Material and Methods

The experiment took place in a commercial area irrigated by drip in Adamantina farm. The farm is located at the coordinates 18° 48' 33" S and 47° 27' 48" W, at 922 m altitude. The experiment was conducted by the staff of the Machinery and Mechanization Laboratory (LAMM - Laboratório de Máquinas e Mecanização) and Entomology laboratory of the Federal University of Uberlândia, Campus Monte Carmelo.

The syrup recommended for application was composed of 100 g ha^{-1} commercial dose of chlorantraniliprole insecticide - from anthranilamide chemical group - added with 660 mL ha^{-1} of an adjunct from the aliphatic hydrocarbons' chemical group. The application was performed using Arbus hydropneumatic sprayer, from Jacto, model 2.000 TP VA, equipped with 36 nozzles – 18 were arranged in each side - with JP-150 piston pump, flow rate of 150 L min^{-1}, 850 mm axial fan, which according to the manufacturer, demands 32 hp at the rated speed of 2100 rpm and achieves wind speed of 30 m s^{-1}, with the presence of mono-jet-type nozzle support and syrup mechanical agitation system.

The sprayer was coupled, pulled and actuated by a Massey Ferguson tractor, model 275, with 75 hp rated engine power, 1800-rpm rotation recorded in tachometer, at the working speed of 4.73 km h^{-1}. The operating pressure was 600 kPa, monitored with manometer from WIKA, with full scale from 0 to 3922 kPa. Psychometric conditions before and during application were monitored using Hygro-Thermo-Anemometer from Instrutemp, ITSP-800.1 model.

The five upper tips on both sides of the plot were closed according to the height of the plants in it. Tips available in the property were used. They were hollow cone nozzles made of ceramic material, from Jacto, JA-2 model, with approximately 200 hours of use.

Technical assistance recommended syrup volume of 660 L ha^{-1} by taking into account the history of the property. The spraying was performed on 10-year-old Topázio cultivar plants, with plant spacing of 4 x 0.70 meters. The volumetric ratio that determines the amount of syrup required to provide good coverage to the plant was correlated to the dimensions of the plants. These dimensions were determined by Equation 1, according to Sutton & Unrath (1988).

$$CV = \frac{H\,D}{S}\ 10{,}000 \tag{1}$$

In which:
CV = Crown volume (m^3 ha^{-1});
H = Plant height (m);
D = Crown diameter (m);
S = Spacing (m).

The volumetric ratio is influenced by the crown volume, the level of infestation and by the psychometric conditions at the application time. However, this ratio was primarily selected based on the knowledge about the area infestation history and the volume needed to provide adequate coverage to the target. The volumetric ratio setting took into account the crown volume and the history of syrup volume sprayed in the area (Equation 2).

$$VR = \frac{SV}{CV} 1{,}000 \quad (2)$$

In which:
VR = Volumetric ratio (mL m^{-3});
SV = Spray volume (L ha^{-1});
CV = Crown volume (m^3 ha^{-1}).

The spectrum, droplets density and coverage percentage produced by the syrup on the leaf surface were evaluated using water-sensitive paper distributed on the plant canopy, according to Jamar et al. (2010). The water-sensitive papers were positioned on the upper, middle and lower canopy of the crown, on the central portion of the plant - leaving two plants on either side as borders - in the outer, median and inner depths, totaling 12 tags on each canopy level, 36 tags per plant and 144 tags in the four replications. After the application, tags were collected, individually packed and taken to LAMM for analysis, using Gotas® software developed by the Brazilian Agricultural Research Corporation (EMBRAPA, 2014).

The leaf miner was weekly monitored during the 30 days preceding the application in order to quantify the infestation level at the time of application. The coffee farmer considered the post-harvest to be the best time for chemical control due to factors involving the farm's operational procedures - because the tractors were being used for harvesting -; the lower leafiness of plants and to avoid fruit loss; the product grace period was another reason. After application, the leaf miner population inventory was performed every three days in order to monitor population fluctuation in relation to the control level of 3% living larvae recommended by the chemical manufacturer. This form of monitoring was adopted because, in Monte Carmelo region, coffee farmers usually control leaf miner based on the application timetable and they do not meet the control levels referenced in the integrated pest management.

An extensive zigzag pathway sampling was conducted during monitoring, and aspects such as the third or fourth pair of leaves from the plants' middle part branches and the areas with highest insect incidence were observed; one hundred (100) leaves in each 2000 plants per plot were randomly observed due to the size of the area. The sample exceeded the amount used by Amaral et al. (2010) since the current study aimed to cover the entire plot of 1.75 hectares and approximately 5000 plants. Thus, Vieira Neto et al. (1999) state that the sampling plan may vary depending on the sampling point. Then, the leaves were removed from the plant and taken to the entomology laboratory to determine the number of perforations with dead and living larvae, without larvae and with intact leaves.

Insect population behavior curves were drawn throughout the monitoring according to the leaf miner population data. Subsequently, the control efficacy was calculated using the relation between the number of living leaf miners in the portion before and after application, according to Abbott (1925), (Equation 3).

$$Ef. = \frac{T\text{-}I}{T} 100 \quad (3)$$

Ef. = Effectiveness, (%);
T = Percentage observed before application, (%);
I = Percentage observed after application, (%).

The experiment was conducted in 3 x 3 factorial design, with three heights and three depths in the plant canopy in randomized blocks. The portion consisted of five plants with four repetitions, totaling 20 plants. Data were subjected to variance analysis and they were transformed when necessary to obtain residue normality and variance homogeneity.

3 Results and Discussions

Weather conditions were not favorable to phytosanitary control at the time of application; however, there was short period available for pest control due to the farm's operating procedures, so it had to be done. The wind speed was 0.4 m s^{-1}, relative humidity of 46% and temperature of 30 °C. Under these conditions, the water vapor pressure deficit in the air was 2.3 kPa, i.e., conditions that may favor droplets evaporation and volatilization, thus corroborating Alvarenga et al. (2014).

The crop had uniform plant size, which dimensions corresponded to 3.25 meters high and 1.90-meter crown diameter, totaling crown volume of 15,437.5 m^3 ha^{-1}. The leaf application volumetric ratio of 42.75 mL m^3 was determined based on these values. This ratio is high; however, crown density and pruning management are critical to its definition. According to Homer et al. (2010), the volumetric ratio was adjusted to 93.7 mL m^{-3} in high volume applications in fruit-growing areas in the United States, especially in apple crops.

$Dv_{0.1}$ is one of the key parameters for spraying evaluation. There was significant interaction effect between crown height and depth. Sensitive paper analysis showed that larger droplets were found in the lower-outer position of the plant's canopy (Table 1).

The highest $Dv_{0.1}$ value found on the lower-outer part of the coffee tree skirt was assigned to plants showing denser canopy at the lower part, i.e., their upper part has smaller leaf density. Higher $Dv_{0.1}$ was found on the outer side of the coffee tree lower third due to the axial fan projection and rotation direction. The droplets composing this parameter showed no

Table 1. Effect of the interaction between crown height and depth in droplet spectrum for the $Dv_{0.1}$ variable.

Tabela 1. Efeito da interação entre a altura e a profundidade da copa no espectro de gotas para a variável $Dv_{0,1}$.

Variable	Height	Depth		
		Outer	Median	Inner
$Dv_{0.1}$ (µm)	Lower	175aA	137aB	118aB
	Middle	119bA	132aA	117aA
	Upper	147abA	133aA	133aA
		DMD = 33; VC = 29.4%		

Means followed by the same lowercase letters in the column and uppercase letters on the line do not differ from each other according to Tukey's test at 5% probability. Volumetric Median Diameter (VMD) e VC coefficient of variation.

values less than 100 µm. Therefore, regarding the drift, spraying was considered safe according to the local weather conditions.

The $Dv_{0.9}$ droplets spectrum variables and the Volumetric Median Diameter (VMD) were influenced by plant height. $Dv_{0.5}$, $Dv_{0.9}$ and Span were higher in the lower part of the plant (Table 2).

The $Dv_{0.5}$ or bigger-sized Volumetric Median Diameter (VMD) was found in the lower canopy of the crown; there was droplets coalescence on sensitive paper in this position due to the axial fans construction design, which produced higher number of droplets during spraying. Although the droplet analysis programs perform the correction based on scattering, Alvarenga et al. (2012) found very low $Dv_{0.5}$ values in new JA-2 tips. The larger droplets are able to reach the upper canopy, as shown by the results. However, droplets size is overestimated in the sensitive paper due to droplets coalescence in the lower canopy.

The $Dv_{0.9}$, which represents a droplet size bigger than that of 90% of the droplets produced by the tip, was bigger in the lower canopy. It happened due to the coalescence and the fans design, since the droplets composing this parameter show great tendency to drain. Thus, measuring them becomes difficult in artificial targets. As for the application using hydropneumatic sprayers, large droplets reach the leaves under critical weather conditions due to the distance between the tips and the plant's upper canopy.

The difficulties in correctly measuring the droplets size reflect in the droplets spectrum amplitude. Thus, higher Span values were found in the lower canopy of the crown due to heterogeneity in the droplet size classes, which results, for instance, from $Dv_{0.9}$ overestimation. It happens due to the bigger distance between the droplets forming $Dv_{0.1}$ and $Dv_{0.9}$; regarding field conditions and tips with approximately 200 hours of use.

The $Dv_{0.5}$ and $Dv_{0.9}$ parameters were influenced by the depth of the plant, and higher values were found on the outer and median parts of the crown (Table 3).

The outer part of the plant received bigger amount of droplets during application. It happened due to the droplets ease of contact with the leaves from the outer side and the absence of physical barriers to leaf deposition. There is greater distance in the inner part of the crown regarding the droplets' launching point, fact that reduces the amount of droplets reaching the leaves in that position. There is also the ability of smaller droplets to overcome obstacles, since they are carried by the wind currents and more easily penetrate plants' canopy. Thus, the air speed adjustment produced by the fan is essential. Inadequate airflow makes leaves move in a way they form the so-called wall effect, in which the outer-part leaves prevent most droplets to penetrate the inner part of the canopy, and that is why smaller droplets get to the inner part of the canopy. This behavior may occur in all droplets composing the spectrum, having less effect on smaller droplets. The droplets spectrum may also have been affected by the effect of adding an adjuvant to the syrup, as discussed in many papers found in the current literature.

Droplets density was affected by the crown height and a bigger number of droplets was found in the lower canopy (Table 4).

Droplets density was greater in the lower canopy due to the design of the axial fans, which deposited larger amounts of syrup in these positions, mostly on the right side, due to the rotation direction. There was also the semicircle setting of the bar, which left the upper part tips far from the plant. Consequently, big amounts of droplets were extinguished before they reached the target, mainly because the application was performed under inadequate weather conditions, thus favoring evaporation and volatilization. The application performed under such weather conditions produced drop density for insect control greater than that recommended by Barthelemy et al. (1990), which is 50 to 70 droplets cm^{-2}.

Crown depth affected the sensitive papers' coverage percentage, which represents the amount of droplets deposited on the leaves, and greater coverage was found on the outer side of the crown (Table 5).

Covering targets is critical to phytosanitary control effectiveness. The biggest coverage of the outer side of the crown results from the tags' greater exposure to sprayed droplets. On the other hand, coverage decreased inside the canopy due to obstruction by the outer leaves, causing the so-called "wall effect". As for the inner part, there was less coalescence capacity of smaller droplets, which penetrate the plant canopy and deposit themselves on the leaves. The product applied to control the leaf miner works by contact and ingestion, reason why it is essential to evenly cover the target. As for the middle and inner parts, coverage was well below the value recommended by Minguela and Cunha (2010) as sufficient

Table 2. Effect of plant crown height on droplets spectrum.

Tabela 2. Efeito da altura da copa das plantas no espectro de gotas.

Variable	Height			DMD	VC (%)
	Upper	Middle	Lower		
$Dv_{0.5}$ (µm)	262.40ab	229.65b	292.90a	50.39	39.81
$Dv_{0.9}$ (µm)	382.39ab	342.58b	449.60a	80.16	42.33
Span	0.90a	0.93a	1.02b	0.07	17.02

Means followed by the same letters on the line do not differ from each other according to Tukey's test at 5% probability. Volumetric Median Diameter (VMD) e VC coefficient of variation.

Table 3. Effect of the plant's canopy depth on the droplets spectrum.

Tabela 3. Efeito da profundidade no dossel das plantas no espectro de gotas.

Variable	Depth			DMD	VC (%)
	Outer	Median	Inner		
$Dv_{0.5}$ (µm)	303.08a	257.22ab	224.65b	50.39	39.81
$Dv_{0.9}$ (µm)	450.72a	392.21ab	331.65b	80.16	42.33

Means followed by the same letters on the line do not differ from each other according to Tukey's test at 5% probability. Volumetric Median Diameter (VMD) e VC coefficient of variation.

Table 4. Crown height influence on droplets density.

Tabela 4. Influência da altura da copa na densidade de gotas.

Variable	Height			DMD	VC (%)
	Upper	Middle	Lower		
Density (droplets cm^{-2})	119.96b	108.78b	208.20a	40.26	57.15

Means followed by the same letters on the line do not differ from each other according to Tukey's test at 5% probability. Volumetric Median Diameter (VMD) e VC coefficient of variation.

Table 5. Coverage percentage according to the plant crown depth.
Tabela 5. Percentagem de cobertura em função da profundidade na copa da planta.

Variable	Median			DMD	VC (%)
	Outer	Depth	Inner		
Coverage (%)	36.57a	14.77b	8.43b	10.31	107.01

Means followed by the same letters on the line do not differ from each other according to Tukey's test at 5% probability . Volumetric Median Diameter (VMD) e VC coefficient of variation.

for most treatments, which is 20 to 30%; however, they still resulted in good biological efficacy

The coverage percentage and the droplets population are the main sensitive-paper measurable parameters to diagnose the quality of the spraying pesticides available to producers. The $Dv_{0.1}$ $Dv_{0.5}$ and $Dv_{0.9}$ parameters, droplets density and the coverage percentage were influenced by the volume of syrup; Chlorantraniliprole is recommended by the manufacturer to be applied at 400 L h^{-1} volume. However, the recommendation was of 660 L ha^{-1}, 61% higher volume than that recommended by the manufacturer.

The mean flow rate obtained from the tips with 200 hours of use was 0.76 L min^{-1}. Regarding the volume of syrup, difference was observed between the two sides since the flow on the left side was 5.33% higher than that on the right side (Figure 1).

The measurement of the individual flow from all tips indicated many problems related to the flow uniformity produced by the bar tips. The biggest difference was found in tip 11, in which the flow rate went from 0.79 to 0.63 L min^{-1}, between the left and right sides, respectively, thus corroborating Ruas et al. (2015) who also found variations along the bar due to the hydraulic tips wearing. The difference between the tips helps increasing droplet spectrum heterogeneity in relation to both crown height and depth. The tips conservation status helps spreading the idea that hydropneumatic sprayers are inefficient, thus corroborating Higashibara & Dutra (2013). However, the axial fans design, the semicircle shape of the bars and the airflow from the fans are the main responsible for product losses. The effects can be seen in the product deposition, despite the leaf retention capacity, thus affecting the efficacy of chemical products.

After Chlorantraniliprole application, there was slow decrease in the percentage of living larvae, which remained at 9.6% three days after the application. The temperature and relative humidity during the monitoring period influenced the insect population behavior and their effects favored the high infestation level. The application was held on September 10, 2014, between 8 and 10 am, although the conditions were deemed unsafe for conducting pest control due to the high risk of loss by chemical product evaporation and volatilization (Figure 2).

There was increase in the percentage of living caterpillars up to the application day. However, this percentage decreased and the percentage of dead caterpillars increased after application; it happened due to the action of the phytosanitary product.

Chlorantraniliprole's control efficacy was 87.5%. After this period, the percentage of living caterpillars declined. Therefore, meteorological factors may also have contributed to infestation decrease because there was 83 mm precipitation in the property from 08.22.2014 to 09.11.2014 and it resulted in elevated relative humidity and reduced temperature. The leaf wetness resulting from rainfall is also an unfavorable condition for the leaf miner caterpillar.

The control efficacy could be better; however, the infestation level recommended by the manufacturer is 3% of living caterpillars. Nine point six percent (9.6%) of living caterpillars were recorded at the time of application, i.e., an infestation above the level recommended by the manufacturer for Chlorantraniliprole use. Even so, the application was efficient because of the change in weather conditions after the product application complemented the reduction tendency in the leaf miner population.

The weather conditions in the 2014 dry season were quite favorable to leaf miner, and irrigation worked as an important

Flow (mL)	Tip	Tip	Flow (mL)
710	13	13	710
710	12	12	710
790	11	11	630
750	10	10	710
710	9	9	710
750	8	8	790
790	7	7	710
790	6	6	710
710	5	5	630
710	4	4	750
750	3	3	710
750	2	2	710
750	1	1	750
750			710

Figure 1. Flow from the tips of an Arbus 2000 sprayer, at the pressure of 600 kPa.

Figura 1. Vazão das pontas de um pulverizador Arbus 2.000, na pressão de 600 kPa.

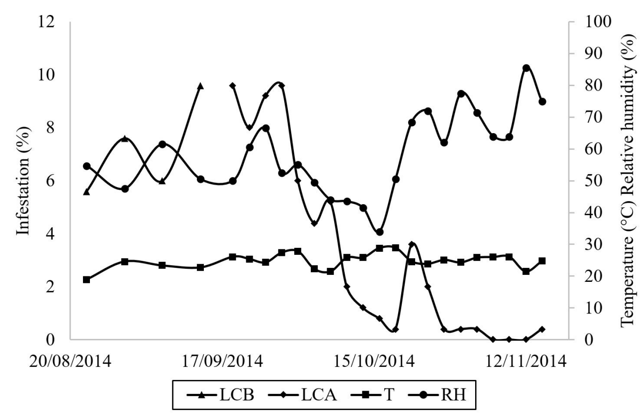

Figure 2. Leaf miner population fluctuation in commercial farming, and weather conditions in the 2014 harvest. Monte Carmelo-MG. LCB = living caterpillars after application; LCA = living caterpillars before application; T = mean temperature and RH = mean relative humidity.

Figura 2. Flutuação populacional do bicho-mineiro em lavoura comercial, e condições meteorológicas na safra 2014, Monte Carmelo-MG. LCB = Larvas vivas antes da aplicação, LCA = Larvas vivas depois da aplicação, T = Temperatura média (ºC) and UR = Umidade Relativa média.

palliative to prevent further damages to the crop, thus corroborating Assis et al. (2012) who found greater losses in dryland areas.

4 Conclusions

Spraying is effective in the phytosanitary control of coffee leaf miner.

The JA-2 tip, at the pressure of 600 kPa, produces volumetric median diameter suitable for controlling leaf miner.

Plant architecture affects the application efficiency in relation to the crown height and depth.

The 87.5% control efficacy is high due to an infestation higher than that recommended for the herein used insecticide.

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