Aspects of Applied Biology ***122****, 2014*
International Advances in Pesticide Application

Relationship among variables of sprays applied at reduced volumes in a coffee plantation

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Summary

A coffee plantation was sprayed using reduced application volumes with fixed rate of insecticide per hectare to control *L. coffeella*. Three spraying liquids with 10% of oil were sprayed at the volumes of 46, 67 and 92 $L.ha^{-1}$, while higher volumes at 200 and 400 $L.ha^{-1}$ used 0.5% and 0.25%, respectively. These variables. were analyzed: insecticide deposits; operational field capacity (OFC); Surface tension, contact angle and wetted area of sprayed droplets; Number of *L. coffeella* dead larvae. The variables were submitted to a multivariate statistic analysis of cluster, K-means, principal components and factorial. The treatments were grouped and the variables correlated. The volumes 67, 92 and 200 $L.ha^{-1}$ produced similar biological results. Surface tension and contact angle showed significant positive correlation but negative compared to wetted area, insecticide deposits and OFC. The dead larvae and spray efficiency had positive correlation but negative in relation to surface tension and insecticide deposits.

Key words: Surface tension, application technology, multivariate exploratory

Introduction

Coffee culture in Brazil and worldwide is affected by the occurrence of insects in crops, especially *Leucoptera coffeella* (Guérin - Mèneville & Perrottet, 1842) (Lepidoptera: Lyonetiidae) which requires periodic control (Thuelher *et al*., 2003). Due to the impact of the plant protection treatment, along with the increase in fuel prices and the cost of labor, research has focused on obtaining techniques capable of providing a satisfactory treatment with the use of reduced spraying volumes resulting in greater operational field capacity (Buisman *et al*., 1989; Fernandes *et al*., 2010; Miranda *et al*., 2012).

In sprays with lower application rates, without losses in quality of target coverage, it is necessary the using of nozzles capable of producing small droplets spectra, which carry less spraying liquid and provide good coverage (Hoffmann *et al*., 2009).

The use of droplets with small size increases the chances of losses occurrence by drift (Nuyttens *et al*., 2007). To minimize this problem, it is being used several types of adjuvants in tank mixture, which interfere in the physical properties of the liquid with reflection in the surface tension, contact angle and wetted area of droplets when deposited on the target (Smith *et al*., 2000; Xu *et al*., 2011). Thus, a good spray requires plant protection product deposits in the necessary amount per unit area, which in turn result in effective pest control.

Knowing the characteristics of a spraying liquid and their relationship are determinant for a more controlled application using correct sprayer type nozzle and its regulation, which may interfere on the quality of plant protection treatments. The relationship among these many characteristics offers tools to improve the performance of a good spray.

The aim of this study was to evaluate the relationship among variables of spray deposits, operational capacity, physical characteristics of the spraying liquid and the control of *L. coffeella* in the coffee culture by using reduced spray volumes.

Materials and Methods

An area with coffee plants at São Luís farm, municipality Altinópolis – Sao Paolo State, Brazil, 21.01S and 47.42W, with 975 m of altitude was delimited. The plants had an average height of 2 m and were infested by *Leucoptera coffeella*.

In April 2012 sprays were performed in the area for the control of *L. coffeella* with two air-assisted sprayers and varying the application volumes. The first sprayer was the model Arbus 400® (Jacto enterprise) with nine hydraulic hollow cone nozzles on each side, conventionally used in the property, spraying at volumes of 200 and 400 L ha^{-1}. The second sprayer used was SMART 400 UBV® (PulsFog enterprise) with six flat fan nozzles on each side, spraying the volumes 46, 67 and 92 L ha^{-1}. Both sprayers worked at a rate of 6.4 Km h^{-1}.

The experiment was conducted with five treatments and a control, with four replications, totalling 24 plots distributed in a randomized block design. Each plot consisted of five rows spaced 3.5 m with a length of 15 m, corresponding to an area of 262.5 m^2 per plot. Weather and work conditions at the moment of the sprays are described in Table 1.

Table 1. *Parameters of work and weather conditions related to the days of the spray*

Sprayer	Volume (L ha^{-1})	Day (April)	Restrictor disk/nozzle	Pressure (MPa)	Temp. (°F)	r.h.	Hour	Wind (km h^{-1})
Smart	46	23	0.5 mm	0.28	79.52	63	3:20 p.m.	5–7
	67	24	0.6 mm	0.31	76.64	73	10:30 a.m.	4–6
	92	24	0.7 mm	0.41	80.06	57	11:45 a.m.	4–6
Arbus	200	24	TXA 80067	1.03	81.86	44	16:10 p.m.	1–2
	400	24	JA-2	1.00	82.76	41	15:15 p.m.	0–1

Analysis of inseticide deposits

The spraying liquids were used at 46, 67 and 92 L ha^{-1} and had 10% of its volume composed by the adjuvant mineral oil Argenfrut® (Agrovant), while the volumes 200 and 400 L ha^{-1} had 0.5 and 0.25% of volume with the adjuvant, respectively. The insecticide used for the control of *L. coffeella* was Curyom 550 EC® (Syngenta), comprising profenofos (50%) + lufenuron (5%) (55% a.i. g L^{-1}) applied at a fixed dose of 800 mL ha^{-1}. The metallic tracer manganese sulfate (31% Mn^{2+}) was added to the sprays at a dose of 20 g L^{-1} for the analysis of spray deposition and hence the amount of pesticide that was deposited on coffee leaves.

After the sprays, coffee leaves were collected in two central plants of each plot. On each plant were collected two leaves of eight distinct sampling points. The distribution of these points aimed to represent the whole plant, sampling the deposit in external parts (upper 1, upper 3, lower 1 and lower 3) and internal (upper 2, upper 4, lower 2 and lower 4), as shown in Fig. 1.

In the laboratory, the collected leaves were put to rest during one hour in 150 mL of 0.2 N HCl solution for extracting the manganese deposited on the leaf surface (Oliveira & Machado-Neto, 2003). Subsequently, the extracts were filtered and taken to reading the manganese concentration

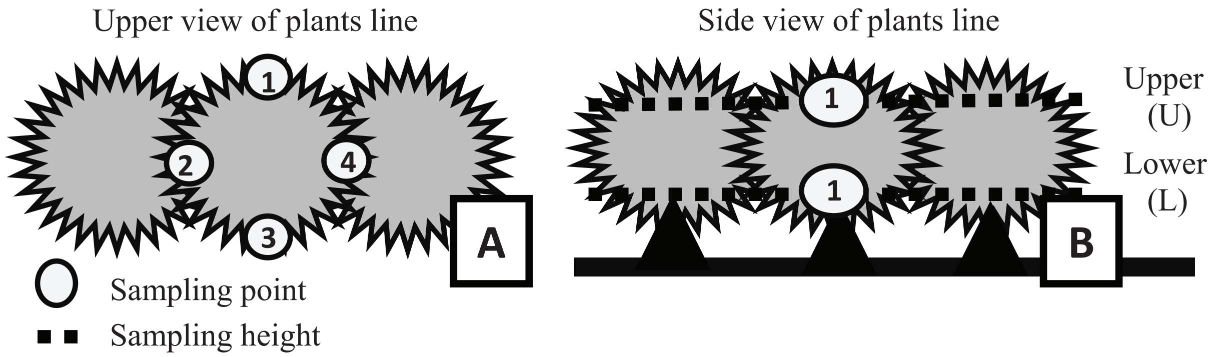

Fig. 1. A. Leaves sampling of external (1 and 3) and internal (2 and 4) points in the coffee plant. B. Leaves sampling of upper (U) and lower (L) coffee plant heights.

by using an atomic absorption spectrophotometer. The results in mg Mn^{2+} mL^{-1} were divided by the area of the leaves used in the extraction, obtained in integrator LI-3100C Area Meter, brand LI-COR®.

Once known the amount of tracer deposited per unit leaf area, along with the amount of marker added to the spraying liquid, were found the volume of spraying liquid deposited per cm^2 of leaf. Finally, from this value, we found the volume in nL of insecticide contained in the spraying liquid that deposited on leaves according to the application volume performed in the experiment.

Operational field capacity of sprayers

The times related to the spray operations were surveyed. Equipment used was a watch, digital timer, tape measure of 50 m, personal protective equipment (PPE), hygrometer and anemometer. The times recorded were: Preparation time in minutes (Tp); Time to sprayer supply, in minutes (Tr); Width of spraying band in meters (L); Length of band sprayed, in metres (C); Distance for refueling, in metres (d); Spraying speed in metres per minute (Vp); Spraying volume in litres per hectare (V); Refueling travel speed in metres per minute (Vd); Tank capacity in litres (Ca), Sprayer turnaround time, in minutes (Tv).

Considering these values, it was found the time in minutes to spray a hectare by means of the expression (Matuo, 1983):

$$t = [10^4/(Vp \times L)] + [(10^4 \times Tv)/(C \times L)] + [(d \times V)/(Vd \times Ca)] + [(Tr \times V)/Ca]$$

As a function of t calculated, the amount of treated area per hour, named operational field capacity (OFC) is given by: Cco= 60/t.

Physical characteristics of spraying liquids

The different spraying liquids were analyzed on its physical characteristics when in contact with adaxial surface of coffee leaves collected physiologically active with the use of surgical gloves to avoid contact with skin oils.

The surface tension of spraying liquids were evaluated in the experiment as well as the value of contact angle and wetted area obtained with droplets applied on coffee leaves surface. These analyses were made in equipment Contact Angle System OCA equipped with high speed and resolution camera, and software SCA20, used for the automation of the equipment and handling of images obtained through the desktop.

The collected coffee leaves were cut into rectangles of 5 cm^2 being attached in a press in such a way to stay with flat surface facing upward, where they were deposited droplets of each spraying liquid. Images were captured every second for 180 s, obtaining an average.

Control and spray efficiency

To evaluate the dynamics of *L. coffeella* population was performed collection of leaves in the central plants of each plots prior to spraying and 7 days after the application. Were collected 25 leaves from the third and fourth pairs of leaves from the tip of branches placed in the middle third of plants (Moraes, 1998).

After 24 h of collection, the leaves were analyzed in the laboratory of Faculdade de Ciências Agrárias e Veterinárias, UNESP, Univ Estadual Paulista, Campus de Jaboticabal, Department of Plant Protection, Sao Paolo State, Brazil. Analyses were conducted with the aid of a stereoscopic microscope (40×) and a fine-tipped needle to open the mines and count the number of dead and live larvae of *L. coffeella*. The number of live larvae was considered for the calculus of spray efficiency (Henderson & Tilton, 1955).

Multivariate exploratory analysis

The results obtained with the treatments were submitted to multivariate procedures of hierarchical clustering and no-hierarchical (k-means) techniques. The variables of insecticide deposits, surface tension, contact angle, wetted area, OFC, number of dead larvae and spray efficiency were taken in order to classify the sprayers and the volumes into clusters.

The values of the variables were previously standardized generating zero average and unit variance (Hartingan, 1975). For treatments grouping toward the hierarchical method was used the euclidean distance among the samples in association with the method of Ward as binding groups. All the variables were taken to create a dendrogram. The treatment group by the no-hierarchical, the euclidean distance matrix was used in the analysis and a plot of means for each cluster was created discriminating the treatments according to the respective cluster.

A principal component analysis was constructed with the auto vectors of the covariance matrix. The Kaiser criterion was used to select the auto values. All the variables were used for this analysis with surface tension as supplementary for comparison. The relationship among the variables was obtained by means of factor analysis wherein the factor rotation utilized was unrotated.

Results

The hierarchical clustering analysis has shown a similarity of treatments 67 and 92 L.ha^{-1} (Fig. 2). These two volumes are very close to the volume 200 L.ha^{-1} that indicates the same behave of these three volumes according to all variables analyzed in the experiment. Far from these volumes are the 400 and 46 L.ha^{-1}, both on opposite sides in the dendrogram, representing two other clusters formed. In general, three clusters could be observed.

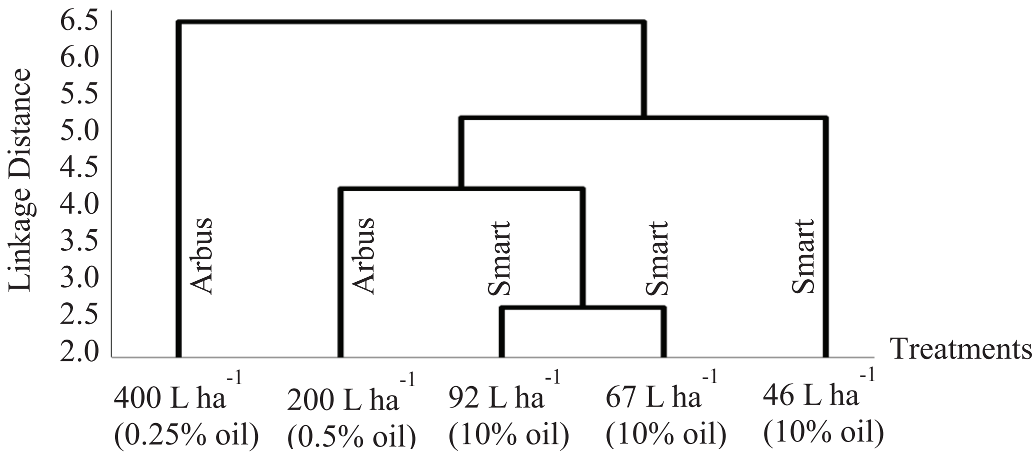

Fig. 2. Dendrogram of similarity among the treatments as a function of the linkage distance by using hierarquical clustering analysis. Treatments described according to application volume, oil concentration and sprayer utilized.

According to the information obtained in the Fig. 2, it was possible to adopt three clusters in which the volumes were classified by the non- hierarchical analysis as shown in the Fig. 3.

The cluster composed by the volume 400 L.ha^{-1} had the highest values of surface tension, contact angle, dead larvae of *L. coffeella* and spray efficiency. However, this cluster showed the smallest values of leaves wetted area, insecticide deposits and OFC (Fig. 3).

The cluster composed by the volume 46 L.ha^{-1} presented the highest values of insecticide deposits and OFC, while with the smallest values of dead larvae of *L. coffeella* and spray efficiency (Fig. 3).

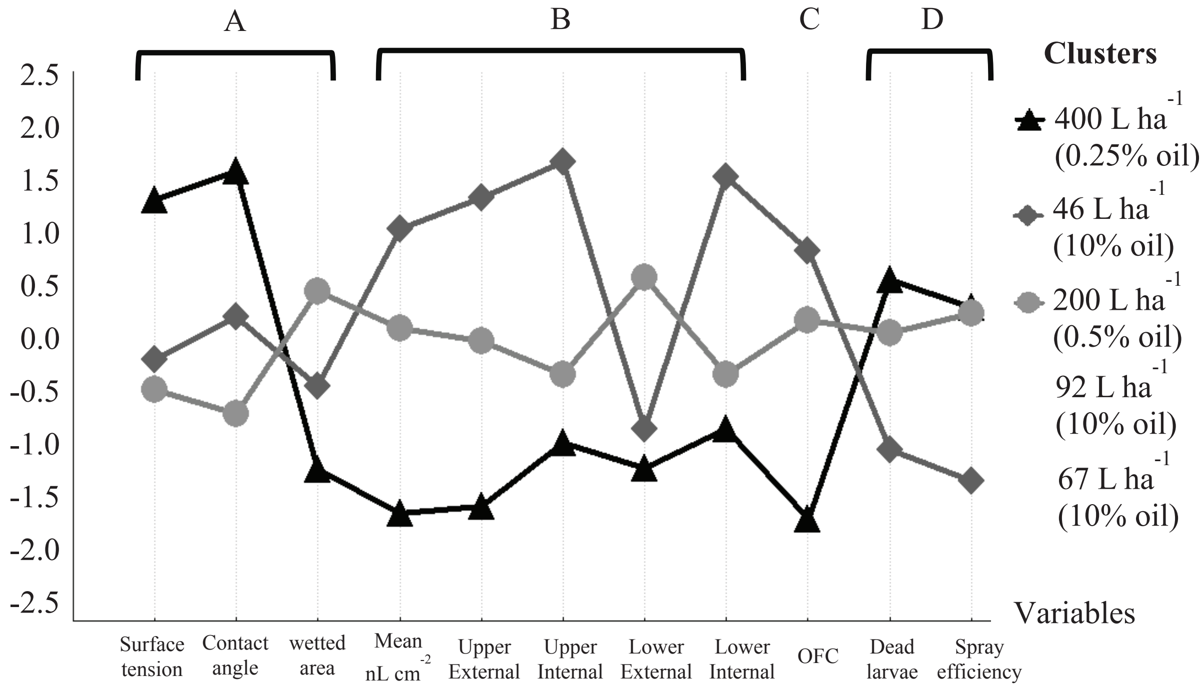

Fig. 3. Plot of mean for each cluster considering the variables analyzed in the experiment. Similar treatments belong to a same cluster. A. Variables related to physical characteristics of spraying liquids. B. Variables related to insecticide deposits on coffee leaves. C. Operational field capacity of sprays. D. Variables related to the *L. coffeella* control by the sprays.

The cluster composed by the volumes 67, 92 and 200 L.ha^{-1} showed the smallest values of droplets surface tension and contact angle on coffee leaves, while the other variables manifested intermediate values with high number of dead larvae and spray efficiency (Fig. 3).

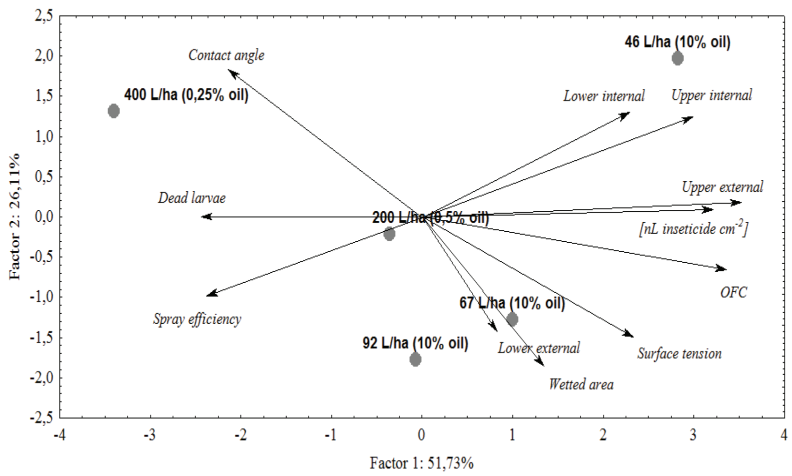

Fig. 4. Projection of treatments (bold type) and variables (italic type) as well as their relationship according to principal component analysis. Close variables indicate positive correlation. The closer to the treatment the higher is the value of the respective variable.

When submitted to principal component analysis, the treatments were placed according to their proximity with the variable. The closer is the volume to the variable the higher is its value as observed in Fig. 4.

The volume 400 $L.ha^{-1}$ had the higher value of contact angle and number of dead larvae of *L. coffeella*. The volume 200 $L.ha^{-1}$ presented the higher value of spray efficiency for controlling *L. coffeella*. The volume 92 and 67 $L.ha^{-1}$ had the highest values of coffee leaves wetted area, surface tension and insecticide deposits on lower external sampling point of plants. The volume 46 $L.ha^{-1}$ had the highest mean values of insecticide deposits and OFC while presented the smallest value of spray efficiency of control (Fig. 4).

The volume 200 $L.ha^{-1}$ with Arbus sprayer and the volumes 67 and 92 $L.ha^{-1}$ with Smart sprayer showed to be similar in relation to proximity in projection of principal component analysis. The volumes 400 $L.ha^{-1}$ (Arbus) and 46 $L.ha^{-1}$ (Smart) Like in hierarquical and non-hierarquical clustering analysis, there was the formation of three distinct groups.

Similarity and distinction among the volumes can be explained with the behaviour of the variables found by multivariate factor analysis in which two factors unrotated show all the correlations (Table 2).

The first factor comprises information about the physical characteristics of the spraying liquid in relation to insecticide deposits and OFC while the second factor explains relationships among physical characteristics of the spraying liquid and *L. coffeella* control (Table 2).

For factor 1 there were positive correlation among surface tension and contact angle, both with negative correlation in relation to wetted area, insecticide deposits in the sampling points and OFC (Table 2).

For factor 2 the variables surface tension and contact angle were negatively correlated with the variables wetted area, number of dead larvae of *L. coffeella* and spray efficiency of control. The quantity of insecticide deposited in the lower external point of the coffee plants showed to be positively correlated with the control of *L. coffeella* (Table 2).

Table 2. *Relationship among variables according to two factors generated by factor analysis with unrotated factor rotation*

Variable		Factor 1	Factor 2
Spraying liquid	Surface tension	-0,7720511	0,582582
	Droplets angle	-0,701540	0,673149
	Wetted área	0,533796	-0,789602
Deposit [nL inseticide cm^{-2}]	Mean	0,840064	0,270902
	Upper external	0,961497	0,241279
	Upper internal	0,715157	0,689564
	Lower external	0,287563	-0,470362
	Lower internal	0,524785	0,703583
Operational	OFC	0,985772	-0,148565
Control	Dead larvae	-0,705702	-0,024629
	Eficience of control	-0,581492	-0,491665

[1]Values with same negative or positive signal in the column have positive correlation.

Discussion

The information obtained with the variables analyzed divided the treatments into three different groups. The volumes 200 (Arbus), 67 and 92 L ha^{-1} (Smart) are considered equal and have the same performance in a spray aiming to control *L. coffeella* in coffee plants. So, the application volume was not important because the biggest volume of 400 L ha^{-1} was similar to smaller volumes which agree with other researches (Wise *et al*., 2010).

Considering the variables, surface tension is known as the linkage force that molecules of liquids are grouped (Iost & Raetano, 2010). Liquids with low surface tension form droplets with small contact angle when deposited in a surface what results in a larger wetted area.

Spraying liquids with higher surface tension may have resulted in larger droplet spectra sprayed and deposited on the coffee leaves. These droplets have low spreading with high contact angle formed what decreases the leaf area wetted. The smaller is the recovery of coffee leaves by the droplets the smaller was the control for *L. coffeella* once its larvae is protected inside mines and requires a good spray recovery for an efficient control.

Larger deposited droplets of high contact angle are more susceptible to run-off which may have decreased the amount of insecticide on the leaves of all the coffee plants sampling point in this experiment (Xu *et al*., 2011). Thus, lower surface tension of a spraying liquid decreases the contact angle of deposited droplets and provides a better spreading and deposit of liquid.

By using an adjuvant aiming to reduce surface tension of spraying liquids it is possible to obtain equal or better insecticide deposit for controlling pest even with reduced spray liquid volumes. Hence, by reducing this application volume, the OFC presents positive correlation with wetted leaves area and negative with surface tension.

The occurrence of *L. coffeella* larvae feeding on coffee leaves is predominantly in external canopy what explains the positive correlation among the variables of control and the amount of insecticide deposited in lower external points (Thuelher *et al*., 2003).

Thus, only changing the application volume is not a correct way to proceed aiming to control *L. coffeella* in coffee plants. The recognition of variables acting in the spray and the using of an adjuvant able to interfere on the surface tension are important to provide to reach control by spraying reduced volumes.

Acknowledgements

We are grateful to Mr Gilson José Leite from the UNESP for his support during all of the steps of the experiments. We thank to the financial support granted by Foundation for Research Support of the Sao Paolo State - FAPESP and National Counsel of Technological and Scientific Development - CNPq.

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