EVALUATION OF A DEVICE FOR THE APPLICATION OF PESTICIDES ON MECHANIZED COFFEE CROPS (*Coffea arabica* L.)

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SUMMARY

The coffee crop, while representing an important agricultural activity in Brazil, presents enormous technological challenges. This work aimed to evaluate a device that is attached to airblast sprayers for the application of pesticides on coffee crops. The developed equipment, called 'wing', was developed in such a way as to improve the deposition of the spray mainly on the lower internal parts of the plants. It was evaluated with regard to its efficiency in deposition and penetration in the lower, middle and upper parts of the plants, by means of the addition of a tracer for spectrophotometric quantification. The trial was carried out in a randomized block design, with four replications, in factorial model (2×2): two spray volumes (1000 and 600l·ha^{-1}), and absence or presence of the 'wing'. The device proved to be simple, robust and of easy coupling to the traditional hydro-pneumatic sprayer. It can be used in coffee crops of different architecture and planting density. It was efficient in increasing the deposition in the lower inner canopy of the coffee crop, and in so doing it is an important tool in the improvement of pesticide treatments aimed mainly at this area of the plant, without increasing the runoff onto the soil.

Introduction

Rural producers are being forced more and more to use pesticides in a correct and discerning manner. However, what is observed in the field is the lack of information as to the application technology. Frequently, the applications can be effective but not efficient, since the best techniques and equipment, which would determine the use of a smaller amount of active ingredients to obtain the same results, are not used.

The cultivation of coffee (*Coffea arabica* L.) represents an important agricultural activity in Brazil, but with enormous technological challenges. The plants present vegetative development with dense foliage and large foliar area. This results in the need of greater penetration into the foliar canopy in applications aimed to the control of pests and plant pathogens, even for the application of products with systemic action. A similar problem is also present in other trees of perennial leaves with globular shape, such as citrus (Moltó *et al*., 2001). One of the ways of obtaining a good deposition in biological targets is the correct choice of the spraying technique and application volume.

There is little information regarding the application technology on the coffee crop, mainly in what concerns the amount and distribution of spray necessary for the effective control of pests and phytopathogens (Silva *et al*., 2008). Cunha *et al*. (2005) have observed that among other reasons, agrochemical waste is due to the non-adaptation of the volume to be used during an application to the needs of the crop. Considering the structural aspects of the canopy it is important (Rosell Polo *et al*., 2009). In general, it is expected that the increment of the application volume is favorable to the increase in spray volume retained up to a certain point, after which the surface does not retain liquid any longer, resulting in an undesirable runoff. In a study carried out by Derksen and Sanderson (1996) evaluating the influence of spray volume (47-1870l·ha^{-1}) on leaf deposition of pesticide in Euphorbia pulcherrima, the authors verified better covering and less variations in deposition along the canopy with the use of larger application volumes.

Nowadays there is a tendency to reduce spray volumes, in view of reducing application costs and increasing spraying efficiency (Chueca *et al*., 2008; Cunha *et al*., 2008). By using smaller spray volumes the autonomy and operational capacity of the sprayers is increased. However, volume reduction requires improvements in the application technology used in the field, making it necessary to upgrade the spraying equipment that is available, in this case, to the coffee grower. In general, the equipment commercialized in Brazil does not provide good penetration of the spray in the inner part of the crop and does not have the possibility of altering the aerodynamic characteristics of air currents. Thus, it is important to study forms of improving penetration using sprayers already in use, avoiding large investments.

Among the organisms that attack the coffee crop, some types of mites are prominent and can cause reduction in the production and quality of coffee. The mite *Oligonychus ili-*

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EVALUACIÓN DE UN DISPOSITIVO PARA LA APLICACIÓN DE PRODUCTOS FITOSANITARIOS EN CAFETALES (*Coffea arabica* L.) MECANIZADOS

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RESUMEN

El cultivo del café constituye una actividad agrícola importante en Brasil, pero presenta grandes desafíos tecnológicos. Este trabajo tuvo como objeto evaluar un dispositivo para acoplamiento a pulverizadores hidroneumáticos desarrollado para la aplicación de productos fitosanitarios en cafetales. El equipo, denominado 'ala', fue desarrollado de forma de mejorar la deposición del líquido atomizado principalmente en la zona interna inferior de las plantas. Fue evaluado en cuanto a la eficiencia de la deposición y penetración en las partes inferior, media y superior de las plantas, por medio de la adición de un trazador para cuantificación espectrofotométrica. El ensayo se llevó a cabo con un diseño de bloques aleatorios con cuatro repeticiones, en un esquema factorial (2×2): dos volúmenes de pulverización (1000 y 600l·ha^{-1}), y en ausencia o presencia del equipo diseñado. El dispositivo resultó simple, robusto y de fácil acoplamiento al pulverizador hidroneumático tradicional, pudiendo ser utilizado en cafetales con diferentes arquitecturas y densidades de plantación. Fue eficiente en aumentar la deposición del producto en la parte interna inferior de las plantas, constituyendo por lo tanto una herramienta importante para mejorar los tratamientos fitosanitarios dirigidos principalmente a esta parte de la planta, sin incrementar la escorrentía hacia el suelo.

AVALIAÇÃO DE UM DISPOSITIVO PARA APLICAÇÃO DE PRODUTOS FITOSSANITÁRIOS EM CAFEEIROS (*Coffea arabica* L.) MECANIZADOS

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RESUMO

A cultura do café representa importante atividade agrícola no Brasil, mas com grandes desafios tecnológicos. Este trabalho teve como objetivo avaliar um dispositivo para acoplamento em pulverizadores hidropneumáticos desenvolvido para aplicação de produtos fitossanitários em cafeeiros. O equipamento, denominado Asa, foi desenvolvido de forma a melhorar a deposição de calda principalmente na parte interna inferior das plantas. Ele foi avaliado quanto à eficiência de deposição e penetração nas partes inferior, média e superior das plantas, por meio da adição de um traçador para quantificação por espectrofotometria. O ensaio foi conduzido no delineamento em blocos ao acaso, com quatro repetições, em esquema fatorial (2×2): dois volumes de pulverização (1000 e 600l·ha^{-1}), e ausência ou presença do equipamento desenvolvido. O dispositivo mostrou-se simples, robusto e de fácil acoplamento ao pulverizador hidropneumático tradicional, podendo ser utilizado em cafeeiros de diferentes arquiteturas e densidades de plantio. Foi eficiente em aumentar a deposição de calda na parte inferior interna do cafeeiro, constituindo, portanto, em uma importante ferramenta para melhorar os tratamentos fitossanitários que visem principalmente esta região da planta, sem aumentar o escorrimento para o solo.

cis (McGregor, 1917) (Acari: Tetranychidae), also known as the red coffee mite, is one of the main plant-eating (phytophagous) mites attacking this crop (Reis *et al*., 2007b). The mite attack usually occurs in small areas. However, if the conditions are favorable to the mite and control is not carried out at the beginning of the infestation, the whole plantation can be affected. Periods of drought, with a prolonged dry season, are favorable conditions for mite proliferation, can cause leaf shedding in plants and induce delays in the development of young plants (Potenza *et al*., 2005; Franco *et al*., 2009). Incidence is greater on internal leaves, branches and fruits of the lower and medium parts of the coffee plant. This fact hinders chemical control, due to the barrier exerted by the leaves on insecticide penetration. In spite of this, the chemical control of the mite pest in coffee crops in Brazil is not well known, in contrast to what happens in the case of citrus (Reis *et al*., 2007a).

The purpose of this work is to evaluate a device that was designed to be coupled to airblast sprayers so as to improve the application of pesticides in coffee crops.

Materials and Methods

The equipment, denominated 'wing', was developed to be coupled to any airblast sprayer, working together in such a manner so as to improve deposition mainly on the inner lower parts of young plants, as well as of full leafed adults. This provides control of the biological targets located in this ecological niche in particular.

The spray system is made up of a metallic structure in wing shape, with an internal piping. It has outlets to ten spray nozzles which face upwards, placed on both sides of the sprayer, close to the soil, under the outer leaves of the coffee crop (Figures 1 and 2). The 'wing' is attached to the sprayer using a central base with an articulated frame. The disposition and type of spray nozzles to be used depend on the requirements of the target being aimed at. Hollow cone nozzles with a large nominal flow rate should be used if a wide coverage is necessary, and a low flow otherwise.

The 'wing' has a central base which can be screwed in place on the head of the sprayer, independent of the type of machinery being used. A support arm is coupled on this structure, allowing for spacing adjustment to planting space between lines and height at which it works. On the arm, the articulate structure shifts position according to the unevenness of the land, providing conformity, as well as protection against impacts and abrasions. It also attaches the wings on the right and left side of the sprayer. The distributing boom is inserted in the wings being held in place by means of bearings couplers, and the nozzle

Figure 1. Device for pesticide application (wing) on the lower inner part of the canopy of coffee crops.

blocks are coupled on it. So, in order to use the 'wing' together with the sprayer, a divider must be installed on the hoses coming from the command box.

The equipment was evaluated as to its efficiency in deposition and penetration, in a commercial plantation of coffee, Catuaí variety, belonging to Cooperativa Agrícola de Monte Carmelo, located in the municipal district of Monte Carmelo, Minas Gerais State, Brazil. The spacing between coffee plants was 4.0×0.7m, average plant height of 2.1m and average diameter of canopy projection of 1.7m. The topography of the area was flat and it had been recently harvested, but showed good leaf presence as can be seen in Figure 3. The applications were made seeking to simulate a mite-insecticide treatment aimed to control mites, which constitute a big phytosanitary problem for coffee crops in post harvest period.

The trial was carried out in randomized block design, with four replications, in factorial model (2×2): employing two spray volumes (1000 and 600l·ha^{-1}), and with absence or presence of the 'wing'. In all treatments, eight nozzles were used on each side of the sprayer (vertical parabolic boom on left and right) and in the treatments using the 'wing', eight other nozzles were used on both sides.

The application was carried out using a hydro-pneumatic sprayer (airblast sprayer) (Arbus 2000, Jacto) drawn by a tractor (MF265, Massey Ferguson). It had two curved booms in vertical position with eight nozzles each. The tractor speed in all the treatments was 6.4km·h^{-1}, using a 1700rpm motor and 540rpm in the power takeoff. The sprayer had a 2000 liter tank, one pump with 75l·min^{-1} nominal flow rate (38-300l·min^{-1}), maximum working pressure of 2570kPa and fan diameter of 0.725m, providing an average speed of air displacement of 151km·h^{-1} and air volume of 9.7m^3·min^{-1}. The equipment did not have any mechanism to alter the aerodynamic characteristics of the air currents.

The selection of spray nozzles (disc-core cone spray nozzles, D series, Teejet) and work pressures was carried out in such a manner as to obtain the desired spray volumes. An electronic flow meter was used for equipment calibration (Nozzle Tester, AAMS).

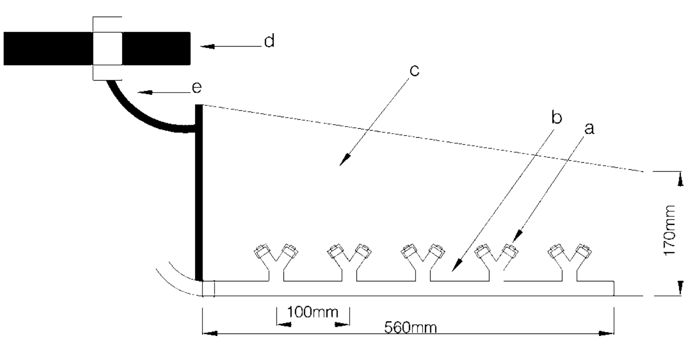

Figure 2. Schematic diagram of the main components of the device. a: spray nozzle, b: boom, c: wing shape, d: central base, and e: articulated frame.

Figure 3. Details of the developed device coupled to the sprayer in the field.

For the application of 1000l·ha^{-1} (total flow rate of 42.7l·min^{-1}) using the 'wing' device, two D4 discs, with a DC33 core, in the upper part, plus six D2 discs, with a DC23 core, were used. In each 'wing' eight D3 discs, with a DC23 core, were used. Work pressure was 1930kPa. All nozzles used in the trial were made of polymer.

When applying 1000l·ha^{-1} without 'wing', two D4 discs, with a DC33 core, were used in each boom of the sprayer, in the upper part, and six D4 discs, with a DC25 core. Work pressure was 1793kPa.

For the application of 600l·ha^{-1} (total flow rate of 25.6l·min^{-1}) using the 'wing' device, eight D2 discs, with a DC25 core, were used in each boom of the sprayer; and in each 'wing'eight D2 discs, with a DC23 core, were used. The work pressure was 965kPa. In the application with 600l·ha^{-1} without 'wing', eight D3 discs, with a DC25 core, were used in each boom of the sprayer. The work pressure was 1379kPa.

A tracer composed of food coloring (Brilliant Blue; classified as FD&C Blue n.1) was used to evaluate the deposition. The tracer was used at the dose rate of 400g·ha^{-1} and was detected by absorption in a spectrophotometer (SP22, Biospectro) with a tungsten-halogen lamp.

Ten plants were arbitrarily marked in each plot and from each plant three leaves were collected after spraying: one from the upper part, one from the middle part and the third from the lower part of the canopy, all near the main stem. Subsequently, the leaves were grouped by position on the plant and placed in plastic bags, to which 50ml of distilled water were added. These bags were closed, shaken for 30sec and placed in recipients provided with thermal and luminous isolation for transport to the Laboratory of Agricultural Mechanization of the Federal University of Uberlândia, Minas Gerais, Brazil. Later, quantification of the coloration by absorption at 630nm was carried out following Palladini *et al.* (2005). According to Pinto *et al.* (2007), the Brilliant Blue tracer is stable for a period of up to 5h of solar exposition. Once the leaves' contours were digitalized, their area was determined with the image analysis program Image Tool" (University of Texas, USA).

In order to estimate spray runoff, four glass slides with an area of 37cm^{2}were placed on the soil, close to the stem. After spraying, they were collected and stored in plastic bags with 50ml of distilled water added, and later analyzed in the same manner as the leaves.

With the use of the calibration curves obtained with standard solutions, the absorbance data were transformed into concentration (mg·l^{-1}) and, once having the initial concentration of the spray and dilution volume of the samples, the tracer mass retained in the target was determined. The final step was to divide the total amount recorded by the foliar removal area, so as to obtain the amount of deposit in μg·cm^{-2} of leaf.

The environmental conditions were monitored during tracer application. They were temperature maximum of 28.0°C, minimum relative humidity of air 34%, and wind speed maximum of 5.8km·h^{-1}. In spite of the low humidity, these are the normal climatic conditions used during spraying of mite insecticide on postharvest coffee plantations in the region, which is carried out during the driest months of the year (July and August).

Deposition data were submitted to variance analysis, and the averages compared using the Tukey test at 5% probability. To verify the effect of the 'wing' device on the uniformity of tracer distribution along the plant, a comparison was made by the F-test, at 5% probability, of the variances of retained masses with and without the use of the device, for volumes of 600 and 1000l·ha^{-1}. The SAEG 9.0 computational statistical program was used (University of Viçosa, Brazil).

Results and Discussion

Upon analysis of the tracer deposition in the upper part of the coffee crop it was seen that the interaction between the use of the spraying device and volume application was significant. This indicates dependence between the two factors. For the middle and lower positions and for run off the differences were not significant.

As regards the 600l·ha^{-1} application volume, the use of the 'wing' did not differ from the treatment without the device. However, the 1000l·ha^{-1} treatment without the 'wing' provided greater retention of tracer in the upper part of the foliage (Table Ia). Probably this is due to the placement of two nozzles of greater discharge in the upper extremity of the vertical boom of the sprayer with a volume of 1000l·ha^{-1}. By comparing the application volumes one notices that with the 'wing' attachment there was no differentiation, but without it the greater volume propitiated greater deposition.

In Table Ib the deposition in the middle part of the plants is shown. It can be noticed that values obtained with the two application volumes did not differ from each other, but the treatment carried out without the 'wing' provided greater spray retention. By using the device, the part of the spray that would be used in the vertical boom is rerouted for application on the lower part of the canopy. In this manner, it is expected that a reduction in material deposited in the upper and middle parts occurs, while at the same time causing a consequent increase on the lower parts. The relationship between these volumes can be defined by the person responsible for the application. This is done by the selection of spray nozzle discharge while taking into account the area for greater coverage. The person responsible for the application can also choose to close or open the nozzles of the 'wing' and sprayer.

TABLE I
TRACER MASS RETAINED IN FOLIAGE IN THE UPPER, MIDDLE AND LOWER PARTS OF COFFEE PLANTS, AFTER APPLICATION WITH AND WITHOUT THE 'WING', IN TWO APPLICATION VOLUMES

Application equipment	Retained tracer (μg·cm^{-2} of leaf)		
	Application volume (l·ha^{-1})		Average
	600	1000	
a: Upper part			
With 'wing'	0.40 Aa	0.61 Ab	0.51
Without 'wing'	0.70 Ba	1.44 Aa	1.07
Average	0.55	1.03	
b: Middle part			
With 'wing'	0.46	0.56	0.51 b
Without 'wing'	1.04	0.85	0.95 a
Average	0.76 A	0.71 A	
c: Lower part			
With 'wing'	1.50	1.21	1.36 a
Without 'wing'	0.64	0.77	0.71 b
Average	1.07 A	0.99 A	

Mean values followed by different capital letters in the lines and small letters in the columns differ significantly among themselves (Tukey test, P<0.05).

In the lower part of the coffee plant (Table Ic) the efficiency of the device in increasing spray deposition and penetration is noticeable. The tracer mass retained with the use of the device was, on average, 92% greater when compared to treatment without the 'wing'. This can promote an improvement in the action of pesticides for the control of several diseases and pests in the coffee crop. Among them are the foliate rust (*Hemileia vastatrix*) control, the efficient protection of blooms, the interruption in the population cycle of *Leucoptera coffeella*, *Oligonychus ilicis*, *Brevipalpus phoenicis*, *Planococcus minor*, *P. citri* and *Coccus viridis*. The attachment developed can also be used to promote a better use of foliar fertilizers which are commonly applied on the coffee crop.

With regard to spray volumes, no significant difference was noticed in deposition. This shows that the volume of 600l·ha^{-1} can be used without jeopardizing the treatment and with gains as to operational capacity of the tractor-sprayer unit. It is common practice in coffee crops to carry out phytosanitary treatments with volumes >1000l·ha^{-1}. However, it is possible and viable to reduce these volumes, with significant earnings in revenue.

The available literature includes very few studies on deposition in coffee crops. Nevertheless, similar results have been found in citrus; Salyani and Farooq (2003), studying the covering of leaves by spraying, did not find any difference in using spray volumes from 250 to 3950l·ha^{-1}. In another work, Farooq and Salyani (2002) found greater deposition of the spray on citrus trees with a volume of 980l·ha^{-1}, compared with 250l·ha^{-1}, but above this value little increment takes place until a volume of 1945l·ha^{-1} is reached.

In Table II a comparison is presented of the variances of the tracer mass retained in the foliage with and without the use of 'wing' while considering the whole plant. It is apparent that for the volume application of 1000l·ha^{-1} there was no significant difference. This denotes that the deposition variability along the plant was not influenced by the use of the equipment. However, for 600l·ha^{-1} the use of the 'wing' promoted a large variability, caused by a greater deposition of tracer on the inferior part of the plants. This data shows that the device can promote an increment in deposition on the lower part, mainly due to the

TABLE II
VARIANCE IN TRACER MASS RETAINED IN FOLIAGE OF COFFEE PLANTS AFTER APPLICATION WITH AND WITHOUT THE 'WING', IN TWO APPLICATION VOLUMES

Application volume (l ha^{-1})	Application equipment	Variance	F-test
1000	With 'wing'	0.1099	0.78 NS
	Without 'wing'	0.1396	
600	With 'wing'	0.3380	5.32 *
	Without 'wing'	0.0635	

NS: no significant difference between the variances according to F-test, at 5% probability;
* There is significant difference between the variances (F-test, 5% probability).

TABLE III
TRACER MASS SHED FROM COFFEE CROP LEAVES (μg·cm^{-2} OF COLLECTOR), AFTER APPLICATION WITH AND WITHOUT 'WING', IN TWO APPLICATION VOLUMES

Application equipment	Shed tracer runoff (μg·cm^{-2})		
	Application volume (l·ha^{-1})		Average
	600	1000	
With 'wing'	0.36	0.50	0.43 a
Without 'wing'	0.31	0.37	0.34 a
Average	0.34 A	0.44 A	

Mean values followed by different capital letters in the lines and small letters in the columns differ significantly among themselves (Tukey test, P<0.05).

flow rate selection of the nozzles. Should one wish to increase the distribution on the lower part, without causing great variability along the plant, nozzles of greater discharge can be placed in the upper part of the vertical boom of the sprayer, as shown in Table II for volumes of 1000l·ha^{-1}.

Concerning spray-runoff (Table III), no difference was noticed among the treatments. Neither the application volumes nor the use of 'wing' influenced the tracer mass collected on the soil under the canopy of the coffee crop. In fact, while using the device one could have expected an increase in runoff, which would not be desirable. However, this did not happen in practice. It is important to analyze this factor when selecting the nozzles to be used in the 'wing' because with larger volumes, or with a coffee crop with fewer leaves, the spray can be lost to the soil, leading to a reduction in treatment efficiency.

The results show that the device developed presents satisfactory potential to improve deposition on the lower part of the plant. However, it was shown that it is very important to select the adequate flow rate of the sprayer nozzles. Coffee, different from other crops, has a plant architecture that varies markedly from plantation to plantation, depending on the planted variety, as well as the fact that the coffee plants depend directly on the manner in which they are cultivated, mainly as regards pruning. There is a wide range of canopy shapes, plant heights, leafing, and planting densities.

Therefore, it is almost impossible to establish an ideal protocol for all pesticide applications in coffee crops, with indication of the ideal flow rate of nozzles. It is very important to supply those responsible for the application with the necessary tools that will allow to carry out each application in an appropriate way, according to the goals pursued, be it on the upper part, middle part or lower part of the plant, be it externally or internally. In the field, an analysis with water-sensitive papers can help to decide if the use of the device is necessary and adequate.

The equipment developed was coupled to the sprayer without difficulty, proving to be practical and easy to transport, according to user needs. Its adjustments allow adaptation to different types of land, spacing between lines, and plant architecture. Its use allows for greater flexibility as to sprayer adjustment, mainly in those sprayers that do not have air flow adjustment, common in Brazil. This becomes of great importance in the extent and penetration of spray in arboreal crops (Celen, 2008).

Conclusions

The device developed is shown to be simple, robust and of easy coupling to the traditional airblast sprayers. It can be used in coffee crops of different architectures and planting densities. It was efficient in increasing spray deposition on the lower interior parts of the coffee crop, constituting an important tool for the improvement of pesticide treatments and aimed especially at this area of the plant, without increasing runoff onto the soil.

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