AERIAL, GROUND AND CHEMIGATION SPRAY DEPOSITION ON CORN FOR THE CONTROL OF *Spodoptera frugiperda* (LEPIDOPTERA: NOCTUIDAE)

Deposição de calda por aplicação aérea, terrestre e via água de irrigação na cultura do milho para o controle de *Spodoptera frugiperda* (Lepidoptera: Noctuidae)

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ABSTRACT

Pesticides can be applied by aircraft, ground-sprayers or sprinkler irrigation. However, selecting the best option is complicated by the limited number of studies comparing these techniques. Thus, the objective of this work was to study the chlorpyrifos insecticide deposition applied by aircraft (30 L ha^{-1}), tractor-mounted sprayer (200 L ha^{-1}) and chemigation (70,000 L ha^{-1}) for the control of *Spodoptera frugiperda* (J.E. Smith) in two corn (*Zea mays* L.) populations (70,000 and 100,000 plants ha^{-1}). Active ingredient residue on the corn plant leaves was evaluated by gas chromatography, immediately and ten days after the treatments. Armyworm numbers in each plot and control were also evaluated. The experiment was set up in randomized blocks with four replications. Aerial and ground applications of chlorpyrifos led to greater active ingredient deposition in the leaves than chemigation. Neither plant population (70,000 and 100,000 plants ha^{-1}) affected the insecticide deposition in the corn leaves. *S. frugiperda* control was similar for all three application methods. Chemigation, however, resulted in less deposition on the plants and consequently in a greater insecticide loss to the soil, which should be considered in environmental impact.

Index terms: Insecticide application technology, fall armyworm, chemigation, sprayer.

RESUMO

A aplicação de produtos fitossanitários pode ser feita, utilizando-se avião agrícola, pulverizadores terrestres ou via água de irrigação. Contudo, a seleção da melhor técnica é difícil, dada à pequena quantidade de estudos comparativos entre elas. Assim, neste trabalho, objetivou-se estudar a deposição do inseticida clorpirifós na cultura do milho, empregando aplicação aérea (30 L ha^{-1}), tratorizada (200 L ha^{-1}) e via água de irrigação (70.000 L ha^{-1}), para o controle de *Spodoptera frugiperda* em duas populações de plantas (70.000 e 100.000 plantas ha^{-1}). O resíduo do ingrediente ativo nas folhas, imediatamente e dez dias após as aplicações, foi avaliado por cromatografia gasosa. O número de lagartas, em cada parcela experimental e na testemunha, também foi avaliado. O experimento foi conduzido em delineamento de blocos casualizados, com quatro repetições. As aplicações aérea e tratorizada do inseticida clorpirifós proporcionaram maior deposição do ingrediente ativo nas folhas do que via água de irrigação. As duas populações de plantas empregadas (70.000 e 100.000 plantas ha^{-1}) não influenciaram a deposição do inseticida nas folhas de milho. O controle de *S. frugiperda* foi similar para os três métodos de aplicação, contudo, na quimigação, ocorreu menor deposição na planta, o que deve ser considerado para evitar danos ambientais causados por escorrimento de calda para o solo.

Termos para indexação: Tecnologia de aplicação de inseticida, lagarta-do-cartucho, quimigação, pulverizador.

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INTRODUCTION

Spodoptera frugiperda (J.E. Smith, 1797) (Lepidoptera: Noctuidae) is widespread in many of the world's corn producing regions (*Zea mays* L.). This insect is a major pest that affects plant development at all stages (RIOS-DÍEZ; SALDAMANDO-BENJUMEA, 2011; LEON-GARCIA et al., 2012). Its relevance is due not only to the damage it causes, but especially to the difficulty of its control.

Depending on the degree of infestation, *S. frugiperda* can cause huge losses in grain yield and quality and is most often controlled by insecticides. The active ingredient chlorpyrifos belongs to the phosphorous chemical group and is one of the main products used against this pest. In addition to insecticide type, application method and equipment type must also be determined to ensure that the product reaches the target efficiently and with minimal losses (CUNHA, 2008).

Application by tractor-mounted hydraulic sprayer is the most common method used for crop protection. However, losses from plant damages and soil compaction conduct to a lower operational capacity when compared to aerial applications. Furthermore, the challenge of

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spraying crops with enhanced vegetative growth have limited the use of tractor-mounted sprayers and led to significant increases in aerial applications (BUENO; CUNHA; ALVES, 2011).

Aerial application is a viable alternative due to its high operational efficiency, which provides quick solutions at short time intervals, even for large tracts of land. Moreover, satisfactory results at low costs are possible if appropriate procedures are adopted (BAYER et al., 2012). Nevertheless, there is little scientific information comparing the effectiveness of aerial and ground applications. Consequently, farmers often distrust the technical feasibility of aerial applications and more significantly, the ability of crop-dusted insecticides to penetrate in crop canopies (CUNHA et al., 2011).

Chemigation is another application technique that has seen substantial development but is still poorly studied worldwide. Chemigation usage is increasing among farmers who have irrigation equipment because it is effective for some products and costs less than other application methods. Some studies have shown that this application method is effective in controlling armyworms in corn, but have not quantified pesticide deposition (YOUNG, 1986; CHANDLER; SUMNER, 1991; SUMNER; CHALFANT; COCHRAN, 1991; CHANDLER; SUMNER, 1994).

One drawback of chemigation is the large quantity of water used, which is especially significant for center pivot systems (VIEIRA; SUMNER, 1999). Ground applications use approximately 300 L ha^{-1}of water at high volume and aerial applications use about 40 L ha^{-1}. Chemigation by center-pivot system, on the other hand, uses more than 50,000 L ha^{-1} of water. This is equivalent to a 5 mm depth of water over the entire application area and can lead to high losses to the soil and low deposition on the desired target. Nevertheless, according to Geary, Hamm and Johnson (2004), chemigation may more evenly distribute pesticide over the entire plant surface than other application techniques using lower volumes of water, due to the redistribution of the pesticide throughout the canopy.

Thus, technical feasibility studies are needed to compare these three pesticide application methods. The spread of biotechnology in some countries has reduced the importance of chemical control of *S. frugiperda*. However, studies of pesticide application technologies are still needed and, given that pesticides act as tracer, they can be carefully extrapolated to different biological targets. Furthermore, it has been observed that even genetically modified corn crops need additional measures to control *S. frugiperda*.

Thus, the objective of this study was to study the spray deposition of chlorpyrifos insecticide on corn by aerial, ground and chemigation applications for the control of *S. frugiperda* in two plant populations.

MATERIAL AND METHODS

The study was conducted at the Monsanto Experimental Farm in the municipality of Cachoeira Dourada (Minas Gerais, Brazil). The farm is located at 18º 36' 49" S latitude and 49º 26' 52" W longitude and at an altitude of 425 m. The experiment was carried out in July, 2010, at a site with center-pivot irrigation and no-till corn. The previous crop at the site was sorghum, which was preceded by corn.

The experiment was set up in randomized blocks (3x2+1) with four replications, with treatments constituted by the combination among three application types, two plant populations and a control (Table 1).

An inbred line of corn (EXP440), that is susceptible to armyworm attack and widely used to develop high-yield hybrids for central Brazil, was used. The plot experimental area was 21 m^2 and consisted of six rows (5 m long) with

Table 1– Description of treatments.

Treatment	Application method	Spray volume (L ha^{-1})	Plant population (plants ha^{-1})
1	Aerial application	30	70,000
2	Aerial application	30	100,000
3	Ground application	200	70,000
4	Ground application	200	100,000
5	Chemigation	70,000	70,000
6	Chemigation	70,000	100,000
7	Control	-	100,000

row spacing of 0.70 m. Between each plot, 5 m of buffer zone was created to reduce inter plot interferences.

Chlorpyrifos insecticide (480 g i.a. L^{-1}) was used at a rate of 1 L ha^{-1}. This insecticide belongs to the organophosphates group, has low water solubility (1.39 mg L^{-1}) and a high sorption coefficient (Koc = 8,498 mL g^{-1}) (PENA et al., 2003). Chlorpyrifos was selected because it is registered by the Brazilian Ministry of Agriculture for the three application methods studied. The pesticide was used to study the effectiveness of *S. frugiperda* control, working as a tracer to compare insecticide deposition on corn leaves in the different treatments.

The product was applied by boom sprayer, aircraft and center pivot irrigation, 55 days after corn sowing (V8 vegetative growth stage, described by RITCHIE; HANWAY; BENSON (1993)). The tractor-mounted sprayer was composed of a conventional hydraulic circuit with 18 m boom and pulled by a Ford 4600 tractor (46 kW). Spray volume was 200 L ha^{-1} with a liquid pressure of 300 kPa. The boom was set at 0.5 m above the crop and the forward tractor speed was 5 km h^{-1}. Standard flat-fan spray nozzles (Model BD 8002, Magnojet, Ibaiti, Brazil) were used, which, according to the manufacturer, produce fine droplets at the pressure used in this study (300 kPa). Only the six rows (4.2 m) of the experimental plots were sprayed. The others nozzles were looked.

The chemigation was achieved by connecting a metered pump (Indek) to the base of a center-pivot system (50 ha) and irrigating at a rate of 7 mm depth of water (70,000 L ha^{-1}). Conventional overhead impact sprinklers were used. Insecticide was injected into the sprinkler main downstream from the irrigation pump.

A Cessna 188 AG TRUCK was used for the aerial applications. The aircraft was flown at 160 km h^{-1} and 3 m above the corn canopy and was equipped with 30 hydraulic hollow cone nozzles (Model D10-45, Teejet, Wheaton, EUA) operating at a pressure of 206 kPa and producing a swath width of 16 m and a spray volume of 30 L ha^{-1}.

All applications were carried out in the same day under similar climatic conditions that were monitored by an onsite weather station (Table 2).

Plots that were not the target of a specific treatment (application method) were covered with plastic to avoid drift contamination.

Pesticide deposition was evaluated on the leaves in the middle of the plants (around the future ear). This evaluation was carried out twice after each application - the first immediately after application and the second ten days after the first evaluation. Control of *S. frugiperda* was also assessed.

Pesticide deposition was evaluated by gas chromatography. To accomplish this, 50 leaves, from the middle of the plants, were collected from the third and fourth rows of each plot immediately after the pesticide application. These samples were placed in plastic bags, sealed and frozen for later evaluation. Ten days after the first collection, leaves were collected again and also placed in bags, identified, sealed and frozen. Afterwards, both samples were placed in Styrofoam boxes with dry ice and transported to a laboratory for residue analysis. At the laboratory, the samples were crushed and stored at a maximum temperature of -20° C until analysis.

A methodology adapted from Lehotay, Mastovská and Lightfield (2005) was used to extract and measure chlorpyrifos residue. A random sub-sample of 3 g was weighed and placed in a 50 mL centrifuge tube to which 10 mL of cold water (+ 4° C) and 15 mL of a solution containing 1% acetic acid in acetonitrile were added.

The tubes were then sealed and agitated for 1 min. Next, a mixture of magnesium sulphate and sodium acetate (6.0 g + 1.5 g) was added to the extract and the tubes were agitated again for 1 min and then placed in a centrifuge for 10 min at 2500 x g. A 2 mL aliquot of this supernatant was removed and transferred to a 15 mL centrifuge tube containing 200 mg of magnesium sulfate, 50 mg of PSA and 10 mg of GCB. The tubes were then resealed, agitated for 2 min and placed in a centrifuge for 10 min at 2500 x g. An aliquot of 0.5 mL of the supernatant was withdrawn and transferred to another 15 mL centrifuge tube to which 0.05 mL of dodecane was added.

The extracts were evaporated at a maximum temperature of 40° C and then re-suspended with 0.45 mL toluene. Measurements were made with a Trace GC Ultra

Table 2 – Climatic data during the applications.

Application method	Time	Air humidity	Temperature	Wind velocity	Wind direction
Aerial	7:00	64%	21.2° C	3.2 km h^{-1}	North-South
Ground	8:00	55%	21.5° C	3.2 km h^{-1}	North-South
Chemigation	9:00	49%	23.8° C	3.0 km h^{-1}	North-South

Gas Chromatograph (Thermo Fisher Scientific) equipped with an AS-2000 automatic injector, an electron capture detector and a Zebron 5 capillary column (30 m length, 0.25 mm diameter and 0.25 ìm film thickness). The following settings were used for analysis: injector temperature of 250° C, detector temperature of 320° C, hydrogen carrier gas in the column flowing at 1.5 mL min^{-1}, splitless injector mode and an injection volume of 2 µL.

Armyworms were counted (larva plant^{-1}) in the second and fifth rows of each plot to determine the effectiveness of the control. These counts were made one day before and five days after each application.

The resulting data were subjected to Lilliefors' normality test and Cochran's homogeneity of variance test. Pesticide deposition data were subjected to analysis of variance, and means were compared by Tukey test at a probability level of 0.05. Armyworm quantity data were submitted to analysis of variance and the means from the plots treated with insecticide were compared to a control (nontreated plot) by Dunnett test at a probability level of 0.05. Statistical analysis was performed with the software Assistat (version 7.6) (SILVA; AZEVEDO, 2002).

RESULTS AND DISCUSSION

The results for insecticide deposition (Table 3) showed significant differences between application methods but no difference between plant populations. Both evaluations showed that ground and aerial applications produced the highest depositions, and chemigation the lowest. These results are consistent with the findings of Vieira and Sumner (1999), who stated that leaf deposition from fungicide applications were much higher from ground and aerial spraying than from chemigation (immediately after or one or two days after application).

However, this difference tends to decrease with the time. Ground and aerial applications deposited 10.19 and 9.37 mg kg^{-1} more insecticide on the leaves than chemigation. Nevertheless, after ten days, these differences were 1.45 and 0.92 mg kg^{-1}.

Similarly, McMaster and Douglas (1976) showed that fungicide applications by an experimental irrigation system (spray volume of 4,200 L ha^{-1}) resulted in chlorothalonil residues of 0.1 µg cm^{-2} (2 days after application) and 0.1 µg cm^{-2} (10 days after application), whereas applications by agricultural aircraft (spray volume of 28 L ha^{-1}) resulted in chlorothalonil residues of 5.5 µg cm^{-2} (2 days after application) and 0.1 µg cm^{-2} (10 days after application).

Bynum et al. (1991) evaluated spray deposition on corn and sorghum by aerial application and chemigation and found that the chemigation resulted in the lowest amounts of tracer measured on plants. Furthermore, this confirms again that lower-volume application techniques lead to a greater fixation of active ingredients on plants.

Applications via center-pivot irrigation use much more water than those by aircraft or boom sprayer. Additional water effectively washes the leaves and results in a loss of active ingredient to the soil. However, differences in water rate used by these methods are not directly proportional to the consequent concentration differences of active ingredient on the leaves.

Table 3 – Chlorpyrifos deposits on corn leaves (mg kg^{-1}) immediately (first evaluation) and ten days after the application (second evaluation) using different methods and two plant populations.

Application method	Spray deposit (mg kg^{-1})					
	First evaluation			Second evaluation		
	Plant population (plants ha^{-1})					
	70,000	100,000	Mean	70,000	100,000	Mean
Aerial	11.71	11.10	11.41A	0.99	1.10	1.05A
Chemigation	1.86	2.22	2.04B	0.13	0.14	0.13B
Ground	11.32	13.14	12.23A	1.53	1.64	1.58A
Mean	8.30 a	8.82a		0.88 a	0.96a	
CV	17.44%			27.35%		

ANOVA for repeated measures: Main effects (first evaluation): Application method (F = 115.1670; p < 0.01), plant population (F = 0.7350; p = 0.40), and interaction (method X population; F = 1.3500; p = 0.29). Main effects (second evaluation): Application methods (F = 11.9220; p < 0.01), plant population (F = 0.0930; p = 0.76), and interaction (method X population; F = 0.0180; p = 0.98).
Values in the column with the same upper case letter are not significantly different at α = 0.05 using Tukey's means separation test. Values in the row with the same lower case letter are not significantly different at α = 0.05 using Tukey's means separation test.

Chemigation used 350 and 2,333 times more water than applications by boom sprayer and aircraft, respectively. Deposition by boom sprayer and aircraft, however, was only 6.0 and 5.6 times greater than chemigation. After 10 days, these values were 12.2 and 8.1. This shows that the decrease in deposition caused by chemigation is not proportional to the increase in water volume.

Cunha et al. (2011) evaluated the effect of ground and aerial applications on fungicide deposition into soybean canopies. This study found that there is no direct relationship between spray volume and deposition. Other factors such as plant architecture, leaf area, characteristics of the spray liquid and spray process influence target retention of the pesticide.

Nevertheless, it should be taken in consideration that the lower deposition from chemigation is probably linked to a greater pesticide loss to the soil, which may lead to a greater environmental contamination. Therefore, it is necessary a particular attention to avoid surface water pollution and groundwater.

Derksen and Sanderson (1996) found different results. These authors evaluated the influence of spray volume (47-1,870 L ha^{-1}) on the foliar deposition of pesticides on poinsettia (*Euphorbia pulcherrima*). They found better pesticide deposition and lesser variation in canopy deposition with high spray volumes. They explained that higher volumes allow product redistribution from top to bottom, which leads to a greater deposition on the lower parts of the plants and to a better deposition uniformity. However, the highest spray volume tested by these authors (1,870 L ha^{-1}) was much lower than the highest tested in the current study (70,000 L ha^{-1}), which explains the difference in findings.

Deposition from chemigation would be even lower if the chemical used were more soluble in water. Viana and Costa (1998) evaluated the efficacy of insecticides applied through irrigation water to control *S. frugiperda* in corn. According to their study, the products with the greatest pest control had very low water solubility. Products with high water solubility tend to be more carried away by water at a higher rate than products with low water solubility.

Similarly, a literature review by Young (1980) found that the least water soluble insecticides were the most effective and that the addition of non-emulsified oil could further increase their effectiveness.

According to Silveira, Hills and Yates (1987), insecticides with higher water solubility are washed from the crop canopy during irrigation and fall to the ground, reducing the efficiency of pest control on the plants. Insecticides with low water-solubility and that are oil-soluble are encapsulated in droplets within the irrigation pipes and do not lose their integrity in water. These insecticides adhere to plants and insect cuticles during application, which increases their efficiency.

The leaf canopy of larger plant populations forms a barrier that tends to impede spray deposition. However, in the current study, plant population did not influence deposition. This is probably because row spacing, which facilitates spray penetration, was the same for both populations, even though plant density differed. Moreover, the leaves collected for residue analysis were not from the bottom part of the plants, which is the most critical region for determining spray penetration.

According to Madalosso et al. (2010), chemical protection throughout the entire canopy, especially the middle and lower parts, is impeded by vegetation density. This disruption of penetration and coverage means make that the active ingredient can not reach its target in adequate quantity and quality, reducing residual control.

Five days after the chlorpyrifos application, the number of armyworms per plant in the treated plots differed significantly from the untreated control. This demonstrates the control provided by the insecticide regardless of application method (Table 4).

There was no difference between the treatments that received insecticide. This shows that even with less leaf deposition, insecticide applied by chemigation might have been able to reach armyworms and consequently provided a level of control similar to that of the other methods. The control had 1.05 armyworm per plant, which according to Cesconetto et al. (2005) may result from the cannibalistic behavior of the armyworms which would lead to a single armyworm per plant. Overall, there were no armyworm concentrations on any single plant. Instead, they were uniformly distributed throughout the area.

The concentration of active ingredient in spray liquid applied by chemigation is much lower. Nevertheless, the small amount of insecticide in contact with the armyworms was sufficient to their control. Other methods with lower spray volumes had higher concentrations of product in water, but more difficulty in reaching the target. This reasoning is explained by Viana and Costa (1998), who state that, to apply the same amount of insecticide, conventional applications use between 200 and 300 L ha^{-1},while chemigation uses from 25,000 to 100,000 L ha^{-1}. It might seem that the lower concentration used in the chemigation would be less effective. However, in practice chemigation is effective against *S. frugiperda* because it is better able to reach the armyworms.

Table 4 – Number of fall armyworms (*S. frugiperda*) per corn plant five days after the chlorpyrifos application using different methods and two plant populations.

Application method	Number of armyworms per plant		
	Plant population (plants ha^{-1})		Mean
	70,000	100,000	
Aerial	0.59^{Ψ}	0.67^{Ψ}	0.63
Chemigation	0.68^{Ψ}	0.56^{Ψ}	0.62
Ground	0.65^{Ψ}	0.67^{Ψ}	0.66
Mean	0.64	0.63	
Control	1.05		
CV	19.52%		

ANOVA for repeated measures: Main effects: Application method ($F = 0.2040$; $p = 0.82$), plant population ($F = 0.0145$; $p = 0.9056$), and interactions (method X population; $F = 1.1949$; $p = 0.33$), (treatments X control; $F = 32.1273$; $p < 0.01$).
Values followed by Ψ were significantly different from the untreated control (Dunnett's test, $p < 0.05$).

CONCLUSIONS

Chlorpyrifos application by tractor-mounted sprayer and aircraft deposited more active ingredient on corn leaves than chemigation. However, this difference was not proportional to the volume of water used and tended to decrease with the time. Control of *S. frugiperda* was similar for all three application methods; however, chemigation led to lower deposition on the plants and consequently to a greater insecticide loss to the soil, which should be taken into account to avoid damage to the environment.

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