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Time of application, adjuvants and directed spraying effects on the control of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in a maize crop

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Summary

The larvae phase of *Spodoptera frugiperda* (Lepdoptera: Noctuidae) has been the major cause of productivity losses in corn crops for many years. The aim of this study was to evaluate the control of *S. frugiperda*, in the first infestation, during the day and the night time, directing the spray toward the interior of the corn plant and the total area with insecticide spray liquids with and without adjuvant. This work was carried out with two application modes (located and total area), at two periods (8 a.m. and 8 p.m.), with three insecticide spray liquids (with insecticide, insecticide with vegetable oil and insecticide with nonyl phenol) and treatment without application, following a factorial (2 × 2 × 3) + 1, conducted in a randomized block design. The sowings were proceeded in the seasons of 2012/13 and 2013/14, in which the factors: live larvae (4, 8 and 12 days after application) and dry matter (g plot^{-1}) were evaluated. Better control of the insects was by the nocturnal spray directed to the interior of the corn plants, regardless of the spray liquid used.

Key words: Row spraying, period of application, low application rate

Introduction

Corn (*Zea mays* L.) is one of the crops with the biggest production increase in the world, with sowing occurring practically every day of the year on different environmental management conditions (Lima *et al.*, 2008*a*). Considered the main corn pest in Brazil, the *S. frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae) lives most of its life cycle in the corn whorl and requires at least two applications of insecticides for its control, usually 19 and 47 days after the emergence of the crop (Barros *et al.*, 2010; Costa *et al.*, 2005).

As most insects in the noctuidae family have nocturnal habits, and the main activity of the larval stage is to feed, moving more frequently at night, at which point they are most exposed to spraying (Cruz *et al.*, 2013; Gallo *et al.*, 2002). It is estimated that the insect larvae can cause losses of 15–76% in grain production (Figueiredo *et al.*, 2006) and in Brazil, it causes economic losses of 400 million dollars per year (Cruz *et al.*, 2008).

The main method of control of the caterpillar is through the use of insecticides. Considering that the target is located in a specific region of the plants, a row spraying application may result in the possibility of practicing lower volumes of spraying liquid per hectare and greater efficiency in insect control (Campos *et al.*, 2014).

An efficient plant protection treatment has been sought for a long time, with technologies that can reach the target in the required amount, with minimal contamination of the environment (Matuo, 1990), considering the biology and behaviour of the target to be achieved, in order to increase the efficiency in its control, but in practice, these aspects are not always respected.

The use of adjuvants, such as vegetable oils and adhesive spreaders, is a practice that does not alter the biological efficiency of the active ingredients, promoting spreading and wetting of the target by the applied spray liquid. In general, the spreading products have the function of reducing the surface tension of the spraying liquid formed by the water and the active ingredients (Cunha *et al.*, 2010), which can result in dripping of the droplets directly in the corn cartridge, the main place of the insect life, or even promote a greater coverage of the leaves of the cartridge region, where nocturnal larvae feed and they can be contaminated by contact insecticides, making them more prone to control.

The objective of this work was to evaluate the control of *S. frugiperda*, in the first infestation, with day period and night period sprays, sprayed in a total area and directed to the corn plant cartridge, with insecticidal solutions with and without adjuvants.

Material and Methods

The experiments were carried out in the 2012/13 and 2013/14 seasons, in the Experimental area of the Teaching, Research and Production Farm – FEPE, Sao Paulo State University, Jaboticabal-SP Campus (Latitude 21°15›22" S, Longitude 48°18'58"W and altitude of 595 m).

The corn hybrid BM BM2 (Biomatrix®) was used. Each plot contained four rows of 15 m length spaced at 0.45 m between rows and six plants m^{-1}. Only two central lines were considered as useful areas of each plot, disregarding a 0.5 m border from each end. In the 2012/13 season the sowing took place on 21 November 2012 and for the 2013/14 season, the sowing occurred on 14 November 2013.

For the development of the work, two application modes were used (sprayed to the row of plants and for the total area), two application periods (08:00 h and 20:00 h), three insecticidal spraying liquids (with only insecticide, insecticide plus vegetable oil and insecticide plus nonyl phenol) and a treatment without application in a triple factorial scheme $(2 \times 2 \times 3) + 1$, conducted in a randomized block design with four replicates.

The insecticide used was from the chemical group of pyrethroids with emulsion concentrated (EC) formulation, composed of lambda-cyhalothrin in the dose of 150 mL ha^{-1} (Jackpot 50 EC® Rotam CropSciences, Campinas - SP). The adjuvants were based on vegetable oil in the dose of 500 mL 100 L^{-1} (Veget'oil®, Oxiquímica Agrociência, Jaboticabal - SP) and nonyl phenol in the dose of 60 mL 100 L^{-1} (Gotafix® Milenia Agrociências, Londrina - PR). All products were used at the doses recommended by manufacturers for 100 L of water.

The arrangement of the spray nozzle in the spray boom was distinct for each mode of application (Fig. 1). For the application in the total area, the distance between the nozzles was 0.50 m and the nozzles were placed at 0.40 m from the top of the plants (a); in the row spraying, the spray fan was positioned on top of the plant row, without overlapping, with 0.45 m between nozzles and height of 20 cm of the plant (b). In both cases, the spray boom was fixed in front of the tractor and composed of four nozzles.

The spray applications were made at a constant speed of 7.7 km h^{-1}, maintained by a tractor-mounted sprayer, in which the spraying liquid was constantly pressurized (CO_2). The application rate was 100 L ha^{-1} on the working pressure of 276 kPa.

For the row spraying, the pre-orifice even flat fan spray tip (model DG 95015 EVS Teejet) was used and for the application in the total area, the conventional flat-fan spray tip with pre-orifice (model LD 110015 Jacto), both producing coarse droplet. The flow rate for each nozzle in the worked pressure was 0.567 L min^{-1}, resulting at the application rate of 99.12 L ha^{-1}.

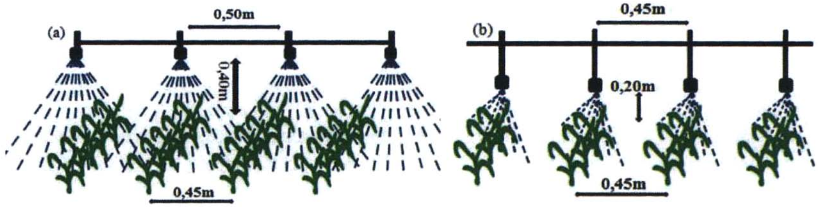

Fig. 1. Projection scheme of the jets used for spraying in the total area (a) and directed to the corn plant cartridge (b). Jaboticabal - SP.

In both experiments, the spraying was performed when 20% of the plants were in the phenological stage V4, 4 leaves unfolded (BBCH14 - Fig. 2) (Gallo *et al.*, 2002). The application in the 2012/13 season occurred at 13 days after plants emergence, while in the 2013/14 season, the application occurred at 14 days after plants emergence.

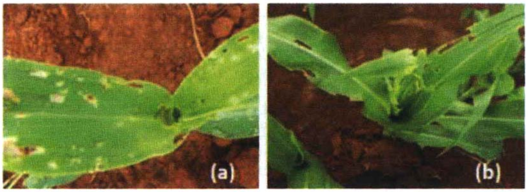

Fig. 2. Damage caused by *S. frugiperda*, in the first infestation, in the corn crop. (A) Scraping and perforation of sheets; (B) Total destruction of the plant cartridge. Jaboticabal - SP. Source: Author.

The average meteorological data for applications in the 2012/13 season in the morning, from 8:00 to 9:40 a.m., were: 85% relative humidity (R.H.), 27.46°C temperature (T) and 3.3 $km.h^{-1}$ wind (W), measured at 1,8 m height. For overnight applications, from 8:00 to 9:10 p.m., it was: 80% (R.H.), 25.76°C (T) and 6.16 $km.h^{-1}$ (W). The average meteorological data for applications in the 2013/14 season in the morning, from 8:00 to 9:53 a.m., were: 75% relative humidity (R.H.), 27.2°C temperature (T) and 2.1 $km.h^{-1}$ wind (W). And for overnight applications from 8:00 to 9:30 p.m., were: 70% (R.H.), 27.3 °C (T) and 1.8 $km.h^{-1}$ (W). In both seasons, therefore, the climatic conditions were suitable for spraying.

Eight plants were collected from each experimental plot to verify the number of live caterpillar prior to application (before); these values were used only for efficiency analysis, at 4, 8 and 12 days after application (DAA), with caterpillars characterized in sizes from 0–2 cm.

The values obtained were submitted to the calculation of the efficiency percentage using the Henderson & Tilton (1955) formula, in which the values obtained are classified according to the criteria of low efficiency (less than 80%), good efficiency (between 80% and 90%) and high efficiency (above 90%).

At 12 DAA, eight whole plants were collected from each plot, taken to the forced air circulation hothouse, at a constant temperature of 60°C, to obtain dry matter (grams per plot). Data were submitted to the F test of the analysis of variance and the means of the treated plots compared to each other using the Tukey's test ($P<0.05$). The number of live caterpillars was transformed into $\sqrt{(x+1)}$, to stabilize the analysis residue variance. The AgroEstat system was used for the statistical analysis of agronomic trials - version 1.1.0.0694, 2011 (Barbosa & Maldonado Jr., 2011).

Results

It was verified that most of the treatments that received row spraying (RS) showed good to high efficiency in the two seasons studied (Table 1), except for 12 DAA for the application placed in the morning using a spraying liquid with insecticide only (C1) and at eight and 12 DAA for Application placed in the morning with adjuvants (C2 and C3). The evaluation of the number of live caterpillars before application (Previous evaluation) shows that the plots constituting the treatments were uniform in season 2012/13 and 2013/14, with a general average of 7.17 and 10.63 caterpillars per eight plants, respectively.

For the applications made in the total area (TA), the treatments showed a lower percentage of efficiency when compared to the localized ones. The lowest percentage of efficiency was the combination of the application at 8 h with spraying liquid with vegetable oil (C2), for both seasons. In the 2012/13 season, all spraying liquids applied during the night period obtained good efficiency at 8 and 12 DAA. At 4 DAA, the only good efficiency for this mode of application was the combination of application at 8 h with addition of nonyl phenol (C3). In the 2013/14 season, most treatments showed good efficiency at 20 h and higher values compared to the same application at 8 h.

In general, for the last evaluation interval of live caterpillars (12 DAA), both applications in the day and night periods were equivalent, presenting good to high efficiency (Season 2012/13). The same was not observed in the 2013/14 season, when the modes presented low daytime efficiency and good efficiency at night, for row spraying and in the total area, respectively.

Table 1. *Average number of live caterpillar before spraying and percentages of treatments efficiency in the control at 4, 8 and 12 days after application in corn crop (Jaboticabal-SP)*

					Control Efficiency (%)[1]					
	Previous evaluation[2]				4 DAA[3]		8 DAA		12 DAA	
Treatments[9]	2012/3		2012/4		2012/3	2013/4	2012/3	2013/4	2012/3	2013/4
RS[4]+08h+C1[6]	7.5	a	10.0	a	83.1	84.7	88.9	80.4	91.2	70.7
RS+08h+C2[7]	6.7	a	10.0	a	83.8	81.8	96.8	71.8	92.7	74.8
RS+08h+C3[8]	6.0	a	10.7	a	83.8	88.6	95.3	78.3	96.4	77.5
RS+20h+C1	6.7	a	10.5	a	90.0	100.0	84.4	89.4	90.9	91.9
RS+20h+C2	7.0	a	9.2	a	92.8	90.4	88.7	92.7	93.4	91.9
RS+20h+C3	7.5	a	10.2	a	91.7	94.1	91.2	96.8	90.4	92.9
TA[5]+08h+C1	6.5	a	11.2	a	77.7	76.1	94.2	72.3	91.6	71.5
TA+08h+C2	6.2	a	11.5	a	65.5	72.6	78.8	67.8	96.4	74.9
TA+08h+C3	7.0	a	11.2	a	80.7	82.3	92.1	79.4	88.1	70.9
TA+20h+C1	8.0	a	10.7	a	66.6	89.3	88.5	81.6	86.0	79.7
TA+20h+C2	8.5	a	11.0	a	70.7	86.5	82.4	88.1	92.3	89.8
TA+20h+C3	8.5	a	11.5	a	70.9	82.2	87.2	82.9	81.2	89.5
Control	8.2	a	10.4	a						
General Mean	7.17		10.63							
Treatment × Control	0.72	ns	0.64	ns						
C.V. (%)	25.06		14.17							

[1](% E): Percentage of efficiency calculated by the formula of Henderson & Tilton (1955). [2]Average number per treatment of live caterpillar at 8 plants before spraying. [3]DAA: days after application; [4]RS: Row Spraying; [5]TA: Application in total area; [6]C1: Insecticide; [7]C2: Insecticide + vegetable oil; [8]C3: Insecticide + nonyl phenol. The means in the columns followed by the same lowercase letter do not differ by Tukey's test ($P \leq 0.05$). [9]The sample presentation of the portion of each treatment was eight plants.

In the 2012/13 season there was a significant difference between the modes of application for the average number of live caterpillars in plots treated in 4 DAA only. In the 2013/14 season, there was a significant difference for all evaluated days, both for the application modes and for the application periods. There was no significant difference for any of the spraying liquids treatments evaluated in the both seasons. In all days after application, there was significant difference in the two seasons in relation to the treatment without application (control) (Table 2).

There was a significant interaction in the mode of application and application period for 4DAA, in the 2012/13 season, with a lower number of live caterpillars (DMS (5%): 0.2196) at 8:00 a.m. For the same evaluation (4 DAA), occurred also a significant interaction between the mode of application and the spray liquids (DMS (5%): 0.2689), with better results for row spraying with the three spray liquids. For the 8 DAA evaluation (DMS (5%): 0.2513), the spray liquid formed by insecticide with vegetable oil interacted significantly with the application modes, with a row spraying resulting in fewer caterpillars.

Table 2. *Average number per treatment*[2] *of* S. frugiperda *(Lepidoptera: Noctuidae) caterpillars at 4, 8 and 12 days after application according to the application modes, application periods and spraying liquids used (Jaboticabal - SP)*

Application mode (AM)	4 DAA 2012/13		4 DAA 2013/14		8 DAA 2012/13		8 DAA 2013/14		12 DAA 2012/13		12 DAA 2013/14	
Row Spraying	0.79	b	0.75	b	0.50	a	0.95	b	0.45	a	0.95	b
Total Area	1.70	a	1.58	a	0.83	a	1.50	a	0.62	a	1.37	a
Application period (AP)												
08:00	1.20	a	1.45	a	0.54	a	1.66	a	0.41	a	1.62	a
20:00	1.29	a	0.79	b	0.79	a	0.79	b	0.66	a	0.70	b
Spraying liquid (SL)												
Insecticide	1.18	a	1.00	a	0.62	a	1.31	a	0.56	a	1.25	a
I.1+ vegetable oil	1.18	a	1.18	a	0.56	a	1.06	a	0.62	a	1.12	a
I.+ nonil fenol	1.37	a	1.31	a	0.81	a	1.31	a	0.43	a	1.12	a
F Test												
AM	17.29	**	15.35	**	2.89	NS	7.13	*	1.1	NS	8.36	**
AP	0.02	NS	13.88	**	1.77	NS	18.86	**	2.57	NS	40.30	**
SL	0.27	NS	0.72	NS	0.64	NS	0.74	NS	0.47	NS	0.39	NS
AM *vs* AP	5.68	**	0.36	NS	0.23	NS	0.17	NS	1.1	NS	0.13	NS
AM *vs* SL	0.67	NS	0.38	NS	2.83	NS	0.34	NS	1.33	NS	0.30	NS
AP *vs* SL	0.67	NS	2.21	NS	0.07	NS	1.40	NS	0.59	NS	0.34	NS
AM *vs* AP *vs* SL	0.67	NS	0.33	NS	0.39	NS	0.47	NS	0.05	NS	0.89	NS
Control *vs* Factorial	109.13	**	149.3	**	154.43	**	107.87	**	216.53	**	183.13	**
C.V. (%)	16.88		16.46		17.9		15.62		15.93		11.35	

The means in the columns followed by the same lowercase letter do not differ by Tukey's test ($P \leq 0.05$), [1]I. - Insecticide. [2]The sample representation of the plot of each treatment was eight plants, the numerical data are real and he statistical analysis represented by the $\sqrt{(x+1)}$.

In the 2013/2014 season, there was a significant interaction between the mode of application and the period of application and, in general, the row spraying obtained lower mean values of live caterpillars for all evaluations. In addition, the applications made at night resulted in greater control of *S. frugiperda* too (Fig. 3).

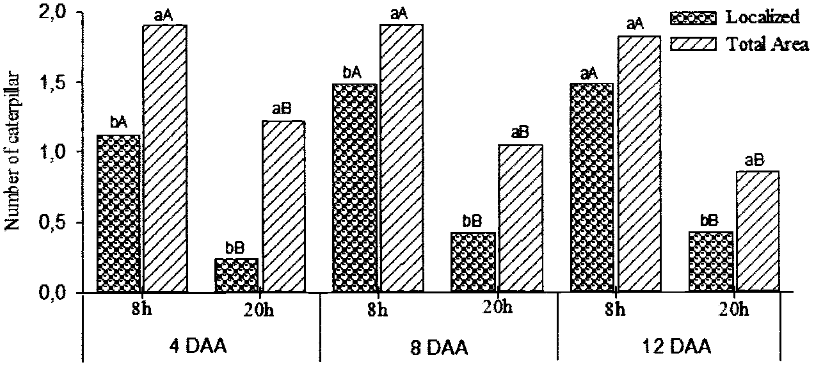

Fig. 3. Control of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in maize at 4, 8 and 12 days after application (DAA), for interaction between mode of application and schedules. Columns followed by the same lowercase letter for time schedules relative to the application modes and capital letter for the application mode in relation to the schedules do not differ by Tukey's test ($P \leq 0.05$). Each sample was represented by eight plants, the numerical data are real, and the statistical analysis represented by the transformation $\sqrt{(x+1)}$. Localized means Row Spraying.

Discussion

The moment that the application was required, in the first 15 days of the crop cycle, demonstrates that the pest attacks the crop very early. Tomquelski & Martins (2007) also verified the necessity of the first application of insecticides in the plants 15 days after the seeds' emergence. According to the authors, in this period, the damage caused by the pest was quite severe. When the pest occurs in the early stages of the crop, it can cause plant death and decrease the crops population in the field and crop yield (Lima *et al*., 2008*b*).

In the research conducted by Polato & Oliveira (2011), to evaluate the effectiveness of different spraying schemes in the total area in the control of *S. frugiperda* on the corn crop, it was observed that the highest efficacy values were at night at 0:00, 4:00 and 20:00 hours. In this way, the cited work may be related to the factors also observed in this study for nocturnal applications, clarifying that the relation between nocturnal habit of the insect and the application methods of phytosanitary products are effective to control.

There is a possibility of the product may enter the plant cartridge and cause a direct mortality effect of the larvae by contact, as well as the displacement of the caterpillars out of the cartridge, exposing them to the product on the leaves. Because of the movement of the caterpillars and their nocturnal feeding habits, there is a chance of increment in the insect exposure with the applied product, resulting in greater control efficiency.

The fact that this pest remains protected during the day inside the plant cartridge makes it difficult to control due to the lower exposure of the caterpillar to the insecticide during daytime (Waquil, 2006). This behaviour can happen because, at the larval stage, the insects are sensitive to exposure to sunlight and the conformation of the corn plants serves as protection. These characteristics may have contributed to the higher number of *S. frugiperda* caterpillars in the experiment in the morning applications, since the insecticide has contact and ingestion action, and its effectiveness depends on the exposure of the target to the spray.

For the application method, Silva (1999) found better results for the control of caterpillars using row spraying with the nozzles placed at a distance of 20 cm from the crop, against the application of the conventional total area using nozzles spaced 50 cm and at 50 cm from the top of the crop. The application rate of 300 L ha^{-1} was used for both treatments. The row spraying method was also better for Campos *et al.* (2014), where good results were found even for the lowest application rate (50 L ha^{-1}), not differing for the highest one (150 L ha^{-1}).

When a total area application is used, the higher application rate may result in better control of the caterpillar (Cunha & Silva, 2010). On the other hand, if a localized spray application is used, especially at night spraying, it is possible to reduce application rates without losses in the control of this type of caterpillar. This is possible because of the better placement of the pesticide on the pest.

The use of localized spray and nocturnal application result in better control of *S. frugiperda*, and the presence of adjuvants on the spraying liquid did not improve the results of control on both modes of application.

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