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AIR-ASSISTANCE IN SPRAY BOOMS WHICH HAVE DIFFERENT SPRAY VOLUMES AND NOZZLE TYPES FOR CHEMICALLY CONTROLLING *SPODOPTERA FRUGIPERDA* ON CORN

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Abstract: The study aimed to evaluate the performance of air assistance in spray booms using different types of nozzles and spray volumes. We took into account spray deposits, fall armyworm control and crop corn performance in a narrow row cropping system. The experiment was carried out at the experimental area of Sao Paulo State University, Botucatu/SP, Brazil, during the 2008/2009 agricultural season, in randomized blocks with a factorial scheme (2x2+1) and four replications. Two spray nozzles (flat fan nozzle and hollow cone nozzle) were tested, combined with two air assistance levels in the spray boom (with and without air assistance) and a treatment control. In the experimental spraying, Spinosad insecticide was sprayed in amounts of 48 g active substance (a.s.)/ha. The air assistance in the spray boom increased the spray deposits in the V_4 growth stage of the corn plants. Moreover, the application of this technology showed higher efficiency on fall armyworm control, reaching a 100% level 15 days after spraying, in the V_{10} growth stage of the plants. The hollow cone nozzle increased the spray deposit level on the corn plants compared with the flat fan nozzle, at growth stage V_4. However, the flat fan nozzle, combined with air assistance technology, was more effective for controlling fall armyworm in the same growth stage (V_4), although the hollow cone nozzle increased the deposit levels on the plants. All the technologies tested in the study promoted a reduction of plant damage from fall armyworm attack. Corn productivity is directly related to the control efficiency of fall armyworm.

Key words: spraying technique, nozzles, spray volume, biological efficacy, *Zea mays*

INTRODUCTION

The corn crop is one of the main agricultural crops in Brazil and in the world. The economic importance of this cereal is characterized by various forms of its use. This includes its use in both the quantitative aspect, by the high grain productivities, and also related with the strategic aspect, being the basis of animal nutrition and, consequently, human nutrition (Cruz *et al*. 2002). The cropping system adopted for corn is dependent on the use of pesticides. They act as an important component in crop management. The favourable environment for the occurrence of pests, diseases, and weeds that interfere with the growth, development and grain productivity of this cereal are the reasons for the use of pesticides (FAO 2009).

A crop's photosynthetic efficiency depends of the photosynthesis rate per leaf area unit. In the absence of biotic or abiotic stress, the plant leaf surface (leaf density) is the basis of the productive potential of the crop (Hammer *et al*. 2009). Thus, grain production can be increased by maximizing the solar radiation interception, which, among other things, is influenced by characteristics of the plant architecture and leaf density (Taiz and Zeiger 2009). Space reduction between planting rows is a practice that seeks to optimize the incident radiation in that location (USDA 2010). However, little is known about the influence of the narrow row cropping system on the phytosanitary management in corn.

In Brazil, large *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera: Noctuidae) infestations have recently been found in corn plants, probably due to rotation and/or succession of this cereal with sorghum, wheat and rice. Fall armyworm is a polyphagous species, feeding on up to 23 plant families, especially gramineous (Poaceae), as reported by Waquil (2006). Further, this pest-insect can feed and reproduce during the off-season in spontaneously germinated plants, such as *Digitaria horizontalis* and *Brachiaria plantaginea* (Santiago *et al*. 2008).

The corn losses to fall armyworm are not related with a lack of chemical treatments, since the numbers of pesticide applications have increased over the years. There has been an increase of pesticide-resistant populations, as well as a decrease in natural enemy diversity (biologi-

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cal control agents) caused by the improper use of insecticides (Cruz *et al*. 2002). Several insecticides are used, by means of foliar applications, for *S. frugiperda* control in corn plants, because this method is fast and effective (Tomquelski and Martins 2007; Lima *et al*. 2010). Among the factors that may have a negative impact on the efficiency of insecticides for *S. frugiperda* control are inappropriate application times and inadequate spraying methods (Figueiredo *et al*. 2006).

Spray nozzles have greatly influenced the spraying quality. The nozzles have the ability to determine the right flow rate, to generate uniform product deposition on the target and to establish the adequate droplet diameter of the spraying jet (Ozkan 2001). Yet, there are few reports about the influence of the spray nozzle for controlling fall armyworm in corn. In a comparison between the efficiency of flat fan nozzles and cone nozzles in fall armyworm control, Silva (1999) showed greater efficiencies for the flat fan nozzle XR 8004 than the hollow cone nozzle JA 2. The authors reported that the difference in the droplet diameter was the factor responsible for these results. The air assistance in the spray boom helps to reduce drift, increases the spray deposits and spray coverage on the lower leaf side, improves the penetration of droplets into the canopy, and permits a reduction in the amount and spray volumes of the product used (Raetano and Merlin 2006; Zhu *et al*. 2006). The advantages of this technology depend not only on droplet size, but also on the type of targets, the air speed and the air volume generated by the equipment.

In this context, this study aimed to evaluate the performance of air assistance using two nozzle types. The nozzle types were evaluated in terms of spray deposition, fall armyworm control and performance of the corn crop in a narrow row system in order to achieve the maximum product efficiency and reduction of environmental contamination.

MATERIALS AND METHODS

The experiment was carried out in the experimental area of the Teaching, Research and Production Farm (TRPF) of the Faculty of Agricultural Sciences, Sao Paulo State University UNESP, Botucatu-SP, Brazil, during the 2009/2010 agricultural season. The climate of this region is the Cwa (Koppen 1948); a mesothermal climate which is tropical humid, The three driest months are June, July and August, and rainfall concentration is in the summer.

The experimental design was randomized blocks in a factorial scheme (2x2) + 1, with four replications. Two nozzle types (flat fan nozzle and hollow cone nozzle) were tested – combined with two air assistance levels in the spray boom (without air assistance and assistance operating in maximum fan rotation, generating an average air speed of 29 km/h). In the control treatment no insecticide was sprayed. For the spraying, the Spinosad insecticide was used at a dosage of 48 g active substance a.s./ha.

The corn hybrid B 2 707 was sowed on January 6, 2010, in rows spaced at 0.45 m, with a population of 60,000 plants/ha. The experimental plots were composed of 15 rows of corn crop with a length of 10 m, where the five central rows were the useful area, totalling 18 m^2 of useful area in each plot and 72 m^2 of useful area per treatment. Data on the occurrence of phenological stages of corn plants are described in table 1.

Table 1. Occurrence time of the phenological stages in the corn plants

Phenological stages	Occurrence time (2010)
Emergence	11 – January
V 4 – four fully expanded leaves	23 – January
V 8 – eight fully expanded leaves	07 – February
V 12 – twelve fully expanded leaves	16 – February
R 1 – silking	08 – March
R 2 – blister stage	14 – March
R 3 – milk stage	21 – March
R 4 – dough stage	04 – April
R 5 – dent stage	17 – April
R 6 – black layer	09 – May
Grain harvest	15 – May

To be able to operate with and without air assistance, the tractor-sprayer Advanced Vortex 2000 was used, equipped with an 18.5 m long spray boom and 37 nozzles spaced at 0.5 m intervals. Two spray nozzle types, which generate medium size droplets, were tested: a flat fan nozzle AXI 11002 (Jacto Corp. – Pompéia, São Paulo State, Brazil) operating with 270 kPa of pressure, generating a spray volume of 200 l/ha, and a hollow cone nozzle (JA-2 Jacto Corp. – Pompéia, São Paulo State, Brazil), operating at a pressure of 630 kPa, with the same spray volume. Both of the nozzles were kept at a height of 0.5 m above the top of the corn plants. The tractor-sprayer travel speed was 4.6 km/h.

The insecticide was sprayed in the V_4 growth stage (four expanded leaves, 40–50 cm high), and V_{10} growth stage (ten expanded leaves, 80–90 cm high) of the corn plants. The leaf area index (LAI) for the V_4 stage was 0.3 and for the V_{10} stage was 1.8. The evaluations were performed 1, 3, 5, 10 and 15 days after spraying (DAS).

For evaluation of the treatments, seven randomized corn plants were chosen within the useful area of plots. The percentage of control efficiency from the treatments was quantified using the Henderson and Tilton (1955) method. The fall armyworm damage to plants was assessed by a visual score scale applied individually to each plant (Cruz *et al*. 1999). Damage to the six central leaves of the plants was noted and given the following scores: 0 – no injured leaves; 1 – presence of scraping in the leaves; 2 – presence of a hole in the leaves; 3 – presence of damage to the leaves and some damage in the whorl of plants; 4 – whorl completely destroyed and; 5 – dead plants.

To determine the spray deposition (in the V_4 and V_{10} stages), the technique proposed by Palladini *et al*. (2005) was utilised, using Brilliant Blue (FD & C 1) dye as a marker, added to the spray solution at a concentration of 1,500 mg/l. Immediately after the sprayings, ten corn plants were collected and stored separately in plastic bags (but none from the control plots because those plants were not sprayed). The samples were taken to the laboratory and washed with 150 ml of distilled water. To measure the marker concentration, the optical density (absorbance at 630 nm) was determined from the washed solutions with a Shimadzu UV-visible spectrophotometer. Posteriorly, the plants were placed in paper bags, labelled and dried in a fan-forced oven at a temperature of 65°C ± 5°C. After 72 hours, the plants were removed and weighed to determine the dry mass (DM).

The quantification of the spray volume deposited on the plants was performed according to the following equation (E_1):

$$C_1V_1 = C_2V_2, (E_1)$$

where:

C_1 – initial concentration of spraying volume (1,500 mg/l);
V_1 – initial volume, in this case, the volume used to wash the plants (150 ml);
C_2 – final concentration (found in the spectrophotometer reading, in mg/l);
V_2 – final volume (the amount of spray volume deposited per plant in ml).

The final grain productivity of the corn plants (t/ha) was estimated after harvesting the corn ears from three central rows in the experimental plots. The data was analysed by ANOVA followed by Tukey's test at 5% of probability.

RESULTS AND DISCUSSION

The results for the spray deposits (ml/g DM) from spraying in the growth stages V_4 and V_{10} of the corn plants with different spray techniques, are shown in table 2. The insecticide was sprayed in the V_4 and V_{10} growth stages of the corn plants. The evaluations were performed 1, 3, 5, 10 and 15 days after spraying. During the spraying, the weather conditions were: a) spraying at V_4 growth stage (relative humidity of 62%, average temperature of 28.3°C and wind speed of approximately 5.2 km/h, from 8:30 am to 10:10 am), b) spraying in the V_{10} growth stage (relative humidity of 71.5%, average temperature of 27.1°C and wind speed of approximately 4.7 km/h, in the period between 2:50 pm and 4:00 pm).

In general, it is possible to observe the influence of the nozzle type on the spray deposit levels on corn plants. The largest spray deposits are associated with the hollow cone nozzle (JA 2), except for the treatments in which 100% of air assistance was used on the plants at growth stage V_{10}. In this case, the performance of both spray nozzles (flat fan nozzle and hollow cone nozzle) was similar (Table 2). The hollow cone nozzle has a smaller droplet diameter than the flat fan nozzle, and produces better coverage of the target, which can result in the largest spray deposition (Cunha *et al*. 2006). It is necessary to emphasize the potential risk of environmental contamination due to drift.

The air assistance in the spray boom promoted a significant increase in the spray deposits for both nozzles (flat fan and hollow cone nozzles) on plants at growth stage V_4. As concerns spraying at growth stage V_{10}, this technology was applied only in spray deposits from the flat fan nozzle, since it is not different than the hollow cone JA 2 (Table 2). The deposit levels in the target plants depend not only on the applicator equipment, but also on the stage, architecture and density of the plants, in addition to the operating conditions (Cooke *et al*. 1990). As a consequence of being in an advanced growth stage (V_{10}), the plants have a greater leaf area. The small droplets produced by the hollow cone nozzle may have been captured most effectively by these plants, regardless of the air assistance technique (Table 2).

Bauer and Raetano (2004) reported that the use of air assistance in the spray boom on a soy bean crop resulted in higher deposits. Vigano and Raetano (2007), though, showed similar spray deposits in both the presence and absence of this technology. According to the authors, it is possible that the better utilization by the plant canopy of droplets with smaller diameter, produced this similarity between treatments, as was also observed in this study.

After the statistical analysis, the results showed that there was no interaction between air assistance and the spray nozzle type at the two growth stages of the corn plants (V_4 and V_{10}) on the spray deposit levels. These results indicated that the effects were independent from these technologies (Table 2).

The control efficiencies (%) for fall armyworm from spraying on plants in growth stage V_4, after spraying Spinosad insecticide at a dosage of 48 g active substance (a.s.)/ha, are shown in table 3. At 1, 3, 5 and 10 days after spraying, the air assistance in the spray boom was more efficient for fall armyworm suppression than treatments without air assistance. As this alternative provided the best spray deposits of droplets (Table 2), there was probably more spray coverage on the biological target (*S. frugiperda*), resulting in more effective control.

At 15 DAS of insecticide, the flat fan nozzle (AXI 11002) combined with air assistance was more effective in fall armyworm control. The hollow cone nozzle used without air assistance had the worst performance, at below 80% control efficiency (Table 3). In this case, such a low efficiency may be related to the difficulty of ensuring the insecticide reaches the target, since the fall armyworm is protected inside the whorl of the plants.

Table 4 shows the control efficiency (%) of fall armyworm after insecticide spraying, on the V_{10} growth stage of the corn plants. The flat fan nozzle (AXI 11002) without air assistance in the spray boom, had lower control efficiency on fall armyworm, especially at 1 DAS. In this period, this treatment was worse than the others (Table 4). Being a non-systemic insecticide (Andrei 2009), the Spinosad insecticide requires good target coverage. This may explain the lower effectiveness of the flat fan nozzle compared with the hollow cone nozzle, since the latter provides better target coverage by droplets (Table 2).

Regarding the evaluation 3, 5, 10 and 15 days after spraying, the data showed that treatments with air assistance had better performance. This effect was especially true at 15 DAS, when treatments with air assistance provided the highest control level (Table 4). Due to the growth stage of plants (V_{10}), the greater number of leaves

Table 2. Spray deposits [ml/g DM] from spraying at growth stages V_4 and V_{10} of the corn plants

Air-assistance in spray boom	Spray nozzles			
	V_4 [µl/g DM]		V_{10} [µl/g DM]	
	AXI 11002	JA - 2	AXI 11002	JA - 2
0	146.1 B (b)	248.2 B (a)	183.5 B (b)	359.4 A (a)
100%	198.6 A (b)	321.7 A (a)	342.0 A (a)	373.1 A (a)
CV [%]	33.52		21.28	
HSD air-assisted	51.7		32.2	
HSD Nozzles	37.8		47.3	
F air-assisted (A)	12.76*		28.23*	
F Nozzles (N)	5.63*		17.91*	
F (A x N)	1.99 ns		0.62 ns	

Means followed by same letter in upper case in the column and lower case in the rows did not differ significantly by Tukey test at 5% of probability ($p > 0.05$); CV – Coefficient of variation; DM – dry matter; V_4 – four expanded leaves; V_{10} – ten expanded leaves; HSD – honestly significant difference; * – significant difference; ns – non-significant difference

Table 3. Control efficiency [%] of fall armyworm after Spinosad insecticide spraying in the V_4 growth stage of corn plants

Treatments	Days after spraying (DAS)				
	1	3	5	10	15
100% air-assistance + AXI 11002	36.23 a	50.26 a	64.08 a	91.74 a	95.73 a
100% air-assistance + JA 2	33.45 a	47.20 a	63.25 a	85.85 a	88.55 ab
0% air-assistance + AXI 11002	22.46 b	30.25 b	51.44 b	71.42 b	81.39 b
0% air-assistance + JA 2	22.96 b	30.77 b	42.92 b	64.10 b	69.60 c
CV [%]	16.3	9.5	14.1	18.8	10.9
HSD	7.04	11.22	10.31	12.99	8.58

Means followed by the same letter in the column do not differ significantly by Tukey test at 5% of probability ($p > 0.05$); HSD – honestly significant difference

Table 4. Control efficiency [%] of fall armyworm after Spinosad insecticide spraying in the V_{10} growth stage of corn plants

Treatments	Days after spraying (DAS)				
	1	3	5	10	15
100% air-assistance + AXI 11002	33.58 a	85.67 a	88.59 a	100.00 a	100.00 a
100% air-assistance + JA 2	38.96 a	73.56 b	83.82 a	92.01 b	100.00 a
0% air-assistance + AXI 11002	19.82 b	57.08 c	58.68 b	71.57 c	36.06 c
0% air-assistance + JA 2	35.29 a	52.91 c	62.62 b	58.73 d	87.90 b
CV [%]	9.42	11.38	21.80	13.25	17.76
HSD	8.40	6.39	14.03	7.04	9.91

Means followed by the same letter in the column do not differ significantly by Tukey test at 5% of probability ($p > 0.05$); HSD – honestly significant difference

tends to hinder the droplet penetration into the canopy. Air assistance may have helped the droplet penetration through the "air curtain" produced, optimizing the insecticide's action on the target. In the same evaluated period (15 DAS), once again the flat fan nozzle without air assistance showed the lowest control efficiency (36.06%). These results can be derived from the spray coverage (droplets cm^{-2}) by insecticide from the AXI 11002 nozzle (Table 2), because in general, good control efficacies are associated with good target coverage. This result has been confirmed by Zhu *et al*. (2008), who also suggest that the greater the amount of product deposited on the target surface homogenously, the greater will be its action.

The damage caused by fall armyworm varied according to the technologies tested, as can be seen in figure 1. Where the air assistance was used in the spray boom, there was a predominance of 0 and 1 scores (Fig. 1a, b). The air assistance technology combined with the flat fan nozzle (Fig. 1a) provided the minimum score (0) in 28% of the total scores. The same air assistance, but now combined with the hollow cone nozzle, resulted in a score of 0 in 21% of the total scores (Fig. 1b). In these same treatments, no plants received the maximum score (5). When there was no air assistance, the predominance of a score of 3 was verified in 61 and 54% of the total scores, respectively, for the flat fan and hollow cone nozzles (Fig. 1c, d) . In the treatment where the crop was exposed to the fall armyworm attack for the whole cycle (Fig. 1e), the leading injury score was 4, in 58% of the total scores, followed by a score of 5, with 31%. Similar results were reported by Figueiredo *et al*. (2006), who found a predominance of the scores of 4 and 5 in the treatments where the plants were exposed to attack by *S. frugiperda* for a long period without control.

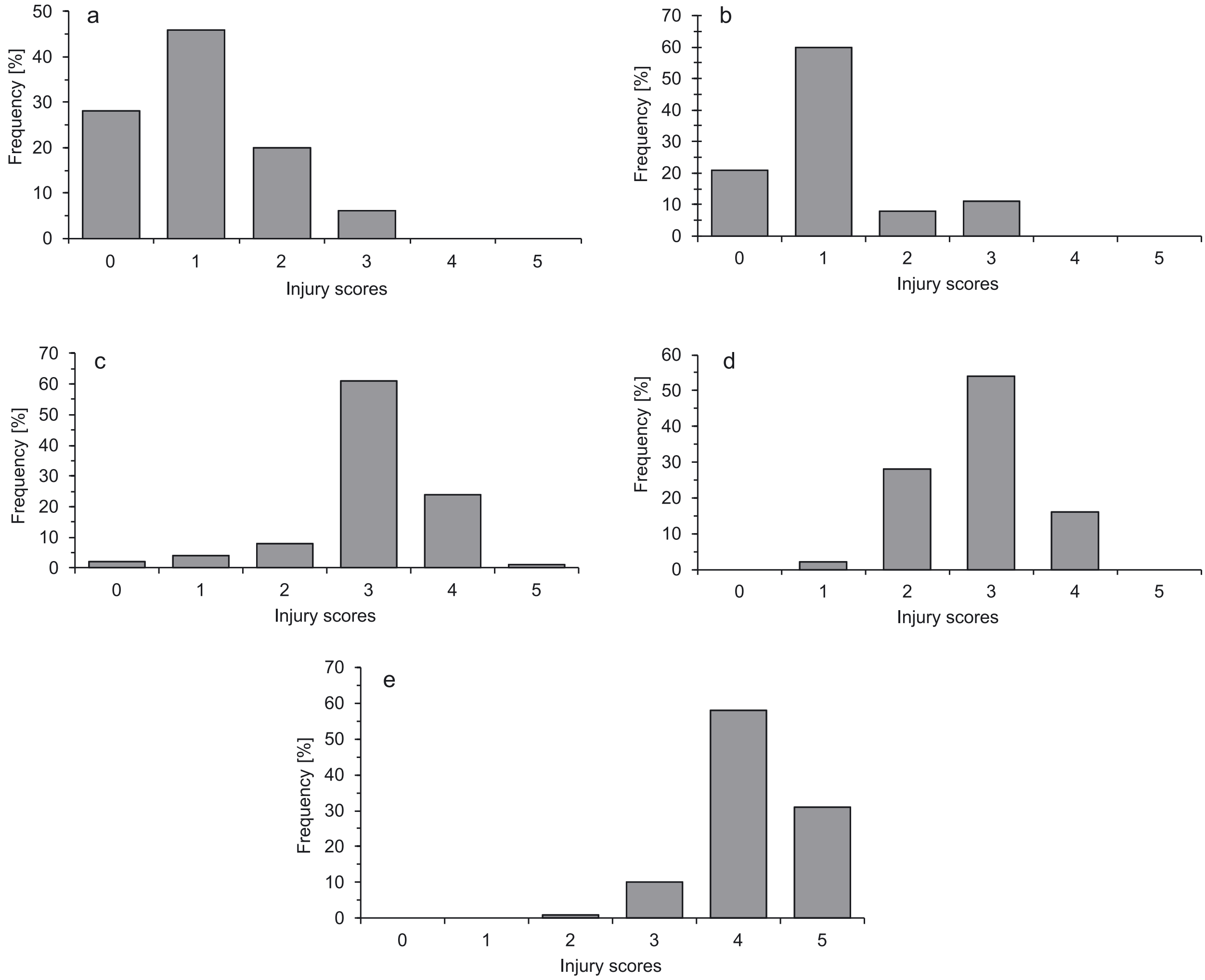

Fig. 1. Frequency of damage scores from *S. frugiperda* infestation on corn plants in V_{10} growth stage at 15 days after spraying of Spinosad insecticide: (a) 100% air-assistance + AXI 11002; (b) 100% air-assistance + JA 2; (c) 0% air-assistance + AXI 11002; (d) 0% air-assistance + JA 2; (e) treatment control

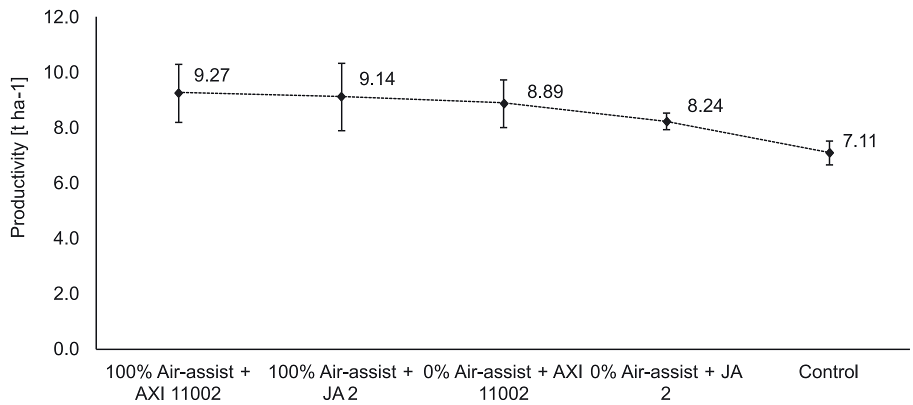

Fig. 2. Corn productivity [t/ha] according to different technologies tested

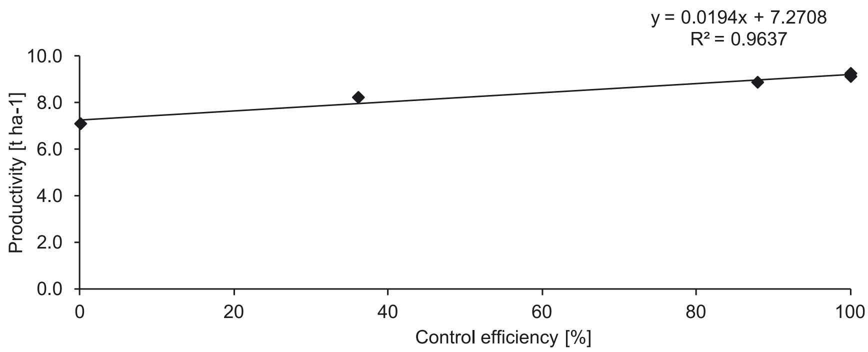

Fig. 3. Relation between corn productivity [t/ha] and control efficiency [%] of fall armyworm

The final corn productivity is represented by figure 2. The corn productivity, when exposed to fall armyworm attack without insecticide spraying (the control treatment), was 7.11 t/ha, which was significantly lower than all of the other treatments. In a corn crop, according to Freeman *et al*. (2007), the light factor interferes with the grain productivity per plant, unless some other factor is severely limiting. It seems probable, therefore, that where there was insecticide spraying, these treatments provided greater solar radiation interception because they had more leaf area remaining and, consequently, higher productivity.

The fall armyworm preferentially infests younger leaves expanding from the plant's whorl. This may have intensified the productivity decline in treatment control, since Taiz and Zeiger (2009) reported that higher photosynthetic activities are found in the younger plant leaves.

The relation between corn productivity and control efficiency of fall armyworm was significantly described by the equation Y = 0.0194 X + 7.2708 (R^2 = 0.96), demonstrating that the lowest control level of *S. frugiperda* provided reductions in grain productivity (Fig. 3). Considering the extreme values of productivity, there were losses of 23.3% according to the infestation of fall armyworm. Negrisoli *et al*. (2010) also found losses estimated at 25% in corn crops related to infestation of *Spodoptera frugiperda* tolerant to certain chemicals.

CONCLUSIONS

Under the experimental conditions of this experiment, it is possible to conclude that:

1. The spray deposition on corn plants (hybrid 2 B 707), cultivated with a narrow row system is not influenced by air assistance and spray nozzles.
2. Phytosanitary treatments, with spraying over the total area, reduced the damage levels from fall armyworm on corn plants, hybrid B 2 707 in a narrow row cropping system.
3. The corn productivity of hybrids B 2 707 is directly influenced by the control efficiency of fall armyworm, where greater efficiencies provide higher grain productivities.
4. These results can assist the implementation of integrated pest management of *S. frugiperda* in a narrow row corn crop, by predicting appropriate pesticide spraying technologies for fall armyworm control. Damage by this insect to the corn plants can then also be predicted.

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