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Effects of Spray Nozzles and Spray Volume on *Spodoptera frugiperda* Management and Narrow Row Corn Performance

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ABSTRACT
The high demand of pesticides in the production systems makes the application technology one of the main alternatives to optimize the products efficiency. In this context, the study aimed to evaluate the effects of spray nozzles and spray volumes on spraying deposits, armyworm control and crop corn performance in narrow row sowing system. The experiment was carried out at experimental area of Sao Paulo State University, Campus of Botucatu/SP, Brazil, during the 2009/2010 agricultural season, in randomized blocks with factorial scheme (2×2+1) and four replications. It was tested two flat fan spray nozzles (with and without air induction) combined with two spray volumes (100 and 200 L ha^{-1}) plus a control treatment. There was no influence of spray nozzles (without air induction) in the spray deposits levels on plants. However, the flat fan nozzle with air induction was more effective on fall armyworm, with 100% of control against 47.84% from other at 15 days after spraying. The increase in the spray volume promoted high spray deposits (415.4 and 388.6 μL g^{-1} dry mass for flat fan nozzle with and without air induction, respectively at V_{10} growth stage) and consequently, the highest spray volume (200 L^{-1}) was more efficient in the fall armyworm suppression, with 100% of control. All the technologies tested showed lower plant injury from fall armyworm. The insecticide sprayed with different technologies did not affect the parameters of plant height and leaf area index. The corn productivity was directly related with control efficiency of fall armyworm.

Key words: Application technology, phytosanitary management, plant damage, fall armyworm, cropping systems, *Zea mays*

INTRODUCTION
The crops photosynthetic efficiency depends of the photosynthesis rate per leaf area unit and in the absence of biotic or abiotic stress, the plant leaf surface (leaf density) is the basis of productive potential of crops (Hammer *et al*., 2009). Thus, the grain production can be increased by maximizing the solar radiation interception, which, among other things, is influenced by characteristics of plant architecture and leaves density (Taiz and Zeiger, 2006). So, the space reduction between planting rows is a practice that seeks to optimize the incident radiation from that place (Dahmardeh, 2011). However, only few things are known about the influence of narrow row cropping system on the phytosanitary management in corn.

The corn crop is subject to various environmental factors that directly or indirectly influence its growth, development and economic productivity. These factors, called ecological factors, may be biotic or abiotic (Gimenes *et al.*, 2010). Thus, among the biotic factors responsible for the corn productivity reduction is the fall armyworm (*Spodoptera frugiperda*), which can affect the plant development and economic production.

The spray nozzles are the constituent part of largest influence on the spraying quality. Their functions are determining the correct flow rate, promote the uniform product deposition on the target and establish the adequate droplet diameter of the spraying jet (Ozkan, 2001).

With the necessity to avoid the environmental contamination by spraying drift, the nozzles manufacturers have development models with significant drift reducing called spray nozzles with air induction, which produce coarse droplets (Cunha *et al.*, 2006).

However, there are few reports of the spray nozzle influence on control efficiency of fall armyworm in corn.

These nozzles have the “Venturi” principle to introduce the air into the liquid, resulting in large droplets, which usually have a low drift risk (Miller*et al.*, 2002). However, Derksen *et al.* (2007) warn that there are many variations in the spray jet produced by different models that use the “Venturi” principle, due the different models of the air induction system.

Zhu *et al.* (2004) emphasized the potential of air induction nozzles on target coverage with droplets. In this experiment, the flat fan nozzles with air induction promoted greatest target coverage than hollow cone nozzles. Still, by the authors, the air induction nozzles generate large droplets, which can reach the target more easily. Moreover, the air inside of droplets can cause a different impact on the target, resulting in great coverage. However, this process of droplet contact on the target surface generated by air induction nozzles is still unfamiliar.

Another factor to be considered in relation with spray technology refers to the spray volume. This variable is directly related with the application purpose, droplet size and work pressure (Ishfaque *et al.*, 2005). In additional, the pest control is based in spray volume characteristics. Reductions in the spray volumes, without losses in spray quality and deposits coverage can promote greater efficiencies in the pest control and operating costs reductions (Boller and Machry, 2007).

In this context, this study aimed to evaluate the effects of spray nozzles and spray volume on spray deposits, fall armyworm control and corn crop performance in narrow row cropping system in order to achieve the maximum products efficiency and reduction of environmental contamination.

MATERIALS AND METHODS

The experiment was carried out at the experimental area of Agricultural Sciences Faculty from Sao Paulo State University, Botucatu-SP, Brazil, during the 2009/2010 agricultural season. The climate of this region is the Cwa (Koppen, 1948), which is a mesothermal climate, tropical humid, with three driest months (June, July, August) and rainfall concentration in the summer. The meteorological data from experimental period are presented in Table 1.

The experimental design was randomized blocks in factorial scheme (2×2)+1, with four replications. It was tested two flat fan nozzles (with and without air induction) combined with two spray volume (100, 200 L ha^{-1}), plus a control treatment, where any insecticide was sprayed. For the treatments spraying, it was used the spinosad insecticide at dosage of 48 g a.i. h^{-1} (Andrei, 2009).

The corn sowing, hybrid B 2 707, was made on January 6, 2010, with rows spaced in 0.45 m, with population of 60,000 plants ha^{-1}. The experimental plots were composed by 15 rows of corn crop with 10 m of length, where the five central rows were the useful area, totaling 18 m^2 of useful area in each plot and 72 m^2 of useful area per treatment. The data of phenological stages occurrence of corn plants are described in Table 2.

Table 1: Meteorological data from experimental period (January to June, 2010)

			RU (%)			Temperature (°C)		
Month (2010)	GR (MJ/m² d)	R (mm)	Max.	Min.	Average	Max.	Min.	Average
Jan.	24.3	299	100	72.2	88.7	34.1	20.7	25.8
Feb.	26.1	286	100	64.0	90.1	38.2	23.5	27.5
Mar.	23.9	39	100	41.3	76.9	36.9	19.2	23.9
Apr.	16.7	45	100	49.9	80.2	28.4	18.8	20.6
May	14.1	82	100	52.1	67.8	25.3	12.1	18.0
Jun.	14.9	24	100	24.6	49.6	27.0	12.6	17.5

GR: Global radiation, R: Total rainfall, RU: Relative humidity, T: Air temperature

Table 2: Occurrence time of the phenological stages in the corn plants

Phenological growth stages	Occurrence time (2010)
Emergence	19 January
V_4: Four fully expanded leaves	01 February
V_8: Eight fully expanded leaves	12 February
V_{12}: Twelve fully expanded leaves	24 February
R_1: Silking	16 March
R_2: Blister stage	26 March
R_3: Milk stage	05 April
R_4: Dough stage	19 April
R_5: Dent stage	04 May
R_6: Black layer	13 May
Grain harvest	10 June

By the capacity to operate with and without air assistance, it was used a tractor-sprayer Advanced Vortex 2000, equipped with 18.5 m length of spray boom and 37 nozzles spaced with 0.5 m between them. The nozzles were kept at 0.5 m of height from the top of corn plants, with tractor-sprayer travel speed of 5.0 km h^{-1}.

The insecticide was sprayed in the V_4 growth stage (four expanded leaves) and V_{10} growth stage (ten expanded leaves) of corn plants. During the spraying, the weather conditions were: (1) spraying at V_4 growth stage (relative humidity of 66%, average temperature of 29.5°C and wind speed of approximately 4.7 km h^{-1}, from 3:45 to 5:20 pm) and (2) spraying in the V_{10} growth stage (relative humidity of 76.8%, average temperature of 24.2°C and wind speed of approximately 5.8 km h^{-1}, in the period between 9:00 and 10:50 am).

The evaluations about fall armyworm were performed with 1, 3, 5, 10 and 15 days after second spraying (V_{10}), through the seven corn plants within the useful area of plots. It was quantified the percentage of control efficiency from treatments by Henderson and Tilton (1955) method. Regarding the fall armyworm injury on plants, this was assessed by a visual score scale applied individually for each plants (Cruz *et al.*, 1999).

The spray deposits were evaluated through the technique proposed by Palladini *et al.* (2005). Posteriorly, the plants were placed in a paper bags, labeled and taken to drying in a fan-forced oven at temperature of 65±5°C. After 72 h, the plants were removed and weighed to determine the Dry Mass (DM).

The corn performance was measured by leaves number per plant (LN), Plant Height (PH), Leaf Area Index (LAI), Stem Diameter (SD), thousand grain mass (g) and final productivity (t ha^{-1}).

The leaves number was determined the number in the silking growth stage, by the number of photosynthetically active leaves of seven plants per plot. The leaf area index was obtained using the methodology proposed by PaulettI *et al.* (2010). For the stem diameter, the second internode from the ground of each plant was measured with a digital caliper, also at the silking time. The thousand grain mass was obtained based on the methodology presented in the Brazilian Rules of Seed Analysis (Brasil, 2009). The final grain productivity of corn plants (t ha^{-1}) was estimated after harvesting the corn ears from three central rows into the experimental plots.

Statistical analysis: The Analysis of Variance (ANOVA) and the Tukey's test, at a 95% significance level, were carried out to determine statistical differences using SAS software for windows version 9.3 (SAS Institute, Inc., Cary, NC).

RESULTS AND DISCUSSION

The spray deposits in the growth stages V_4 and V_{10} of corn plants, with different spray volumes (L ha^{-1}) and spray nozzles ranged from 167.3 to 415.4 mL g^{-1} DM (Table 3). There is a significant increase in spray deposits from spraying with high volumes, where 200 L ha^{-1} promoted largest deposition on the targets. Typically, higher volumes provide larger deposits at similar spraying conditions (Matthews, 2000). Bauer and Raetano (2004) also found that higher volumes promoted greater droplets coverage on soybean plants. The costs reduction and optimization of agricultural spraying are directly related with the use of adequate spray volume (Cunha *et al.*, 2006). So, it is necessary broad knowledge of applied technology for achieving this goal. Costa *et al.* (2005) reported that some plant species are able to repel the droplets sprayed according with its leaf surface anatomy. In addition, Zhu *et al.* (2006) reported that the travel speed is one of the main parameters that affect the spray deposition on targets.

The flat fan spray nozzle with air induction (AVI 11002) promoted larger spray deposits spray only with volume of 100 L ha^{-1} when compared with flat fan nozzle without air induction (AXI 11002) in growth stage V_4 of corn, with 197.8 against 167.3 mL g^{-1} DM. For the others conditions, the spray deposits ranged from 286.6 to 302.1 mL g^{-1} DM for treatment with 200 L ha^{-1} at V_4 growth stage, from 203.7 to 239.2 mL g^{-1} DM for treatment with 100 L ha^{-1} at V_{10} growth

Table 3: Spray deposits (mL g^{-1} DM) from spraying in the growth stages V_4 and V_{10} of the corn plants

	Spray nozzles			
	V_4 (μL g^{-1} DM)		V_{10} (μL g^{-1} DM)	
Spray volume (L^{-1})	AXI 11002	AVI 11002	AXI 11002	AVI 11002
100	167.3^{Bb}	197.8^{Ba}	203.7^{Ba}	239.2^{Ba}
200	286.6^{Aa}	302.1^{Aa}	388.6^{Aa}	415.4^{Aa}
CV (%)	29.12		17.39	
HSD volume	30.4		65.5	
HSD nozzles	19.9		44.1	
F nozzles (N)	4.03*		1.89^{ns}	
F volume (V)	9.27*		12.33*	
F (N×V)	0.81^{ns}		2.79^{ns}	

Means followed by same letter in uppercase in the column and lowercase in the rows did not differ significantly by Tukey test at 5% of probability (p>0.05), HSD: Honestly significant difference, *Significant at 5% level of probability, NS: Not significant at 5% level of probability stage and from 388.6 to 415.4 mL g^{-1} DM for the treatment with 200 L ha^{-1} at V_{10} growth stage without influence of spray nozzles on the spray deposits levels (Table 3). By to be the most critical work condition (earliest growth stage-V4 and low spray volume-100 L ha^{-1}), the larger droplets produced by air induction nozzles were more effective on the plants coverage possibly because they are more resistance to drift (Guler *et al*., 2007).

As it can be seen in Table 3, there was no interaction between spray nozzles and spray volumes, concluding that there is effects independence between these factors.

The fall armyworm control efficiency after spraying at V_{10} growth stage according with different spray volume and spray nozzles ranged between 0 and 100% and they are showed in Table 4.

The air induction nozzles, combined with spray volume of 200 L ha^{-1} promoted control efficiency of 87.65% with one day after spraying, which is above the standards set by Henderson and Tilton (1955), that they classified the control efficiency above 80% as adequate. For the others treatment, the results ranged from 8.10 to 36.87%, being unsatisfactory efficiencies (below 80%). From the third day after spraying, the control efficiency reached its maximum level (100%) for the treatment with air induction nozzles, combined with spray volume of 200 L ha^{-1}. In this case, probably the good performance is related with the greater droplets number generated by higher volume spray (200 L ha^{-1}) associated with the greater droplets size produced by air induction nozzle. According to Zhu *et al*. (2004), these droplets can reach more easily the target, especially in parts with difficulty of penetration. Still, the air contained inside the droplets induces a differential impact on the target surface, resulting in larger coverage. Due they did not have these same characteristics simultaneously (high droplet number and high droplet size), the others treatments showed unsatisfactory performance of fall armyworm suppression, with results ranging from 0 to 73.24%. The low residual effect of the Spinosad insecticide (Azimi *et al*., 2009) may have contributed to the low efficiency performance.

The pesticides from naturalyte group (spinosad) are effective in *S. frugiperda* suppression at any growth stage first days after application. However, probably there will efficiency reductions over the time, due the insecticide molecules degradation by climatic factors such as solar radiation (Rashid *et al*., 2003).

The data regarding treatment with 100 L ha^{-1} combined with flat fan nozzles without air induction, at 15 DAS, had null control efficiency (Table 4). The low spray volumes tend to have more difficulties to penetrate into the canopy (Bauer and Raetano, 2004). Coupled with the difficulty of droplets penetration by advanced growth stage of plants (V_{10}), the low residual effect may have impaired the insecticide performance on fall armyworm control.

Table 4: Control efficiency (%) of fall armyworm after spinosad insecticide spraying in the V_{10} growth stage of corn plants

	Days after spraying (DAS)				
Treatments	1	3	5	10	15
100 L ha^{-1}+AXI 11002	8.10^{c}	1.75^{c}	0.00^{d}	0.00^{c}	0.00^{c}
100 L ha^{-1}+AVI 11002	36.87^{b}	51.73^{b}	31.36^{c}	15.30^{c}	8.45^{c}
200 L ha^{-1}+AXI 11002	24.25^{b}	57.88^{b}	73.24^{b}	71.90^{b}	47.84^{b}
200 L ha^{-1}+AVI 11002	87.65^{a}	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}
CV (%)	17.28	10.55	13.81	21.13	8.03
HSD	13.69	34.70	21.24	18.93	27.08

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

All of technologies showed lower plant injury by *S. frugiperda* when compared with treatment control (Fig. 1), reiterating the importance of new technologies in the phytosanitary management. However, Kandil *et al.* (2008) emphasizes that problems with resistant pests to chemicals products tends to worsen severely due the increase of selection pressure by insecticides, especially in regions where the corn crop is grown throughout over the year.

In the treatments with 100 L ha^{-1} of spray volume, for both spray nozzles (with and without air induction), there was a concentration of score four (Fig. 1a-b). In other hand, the spraying with 200 L ha^{-1} of spray volume, there was predominance of score one, with 66 and 57% of the total scores (Fig. 1c-d). Due the scores relatively low, it can be affirmed that this technology (200 L ha^{-1}) is indicated for plants protection with respect to fall armyworm attack.

In the treatment control, there was concentration of scores four (Fig. 1e). These results are similar with control efficiency of fall armyworm, where the treatment control also had lower levels of efficiency (Table 4). In this context, the incidence of highest number of fall armyworm resulted in highest injury scores. Farinelli and Filho (2006) also showed a direct relation between injury scores and infestation level of *S. frugiperda* in the corn plants.

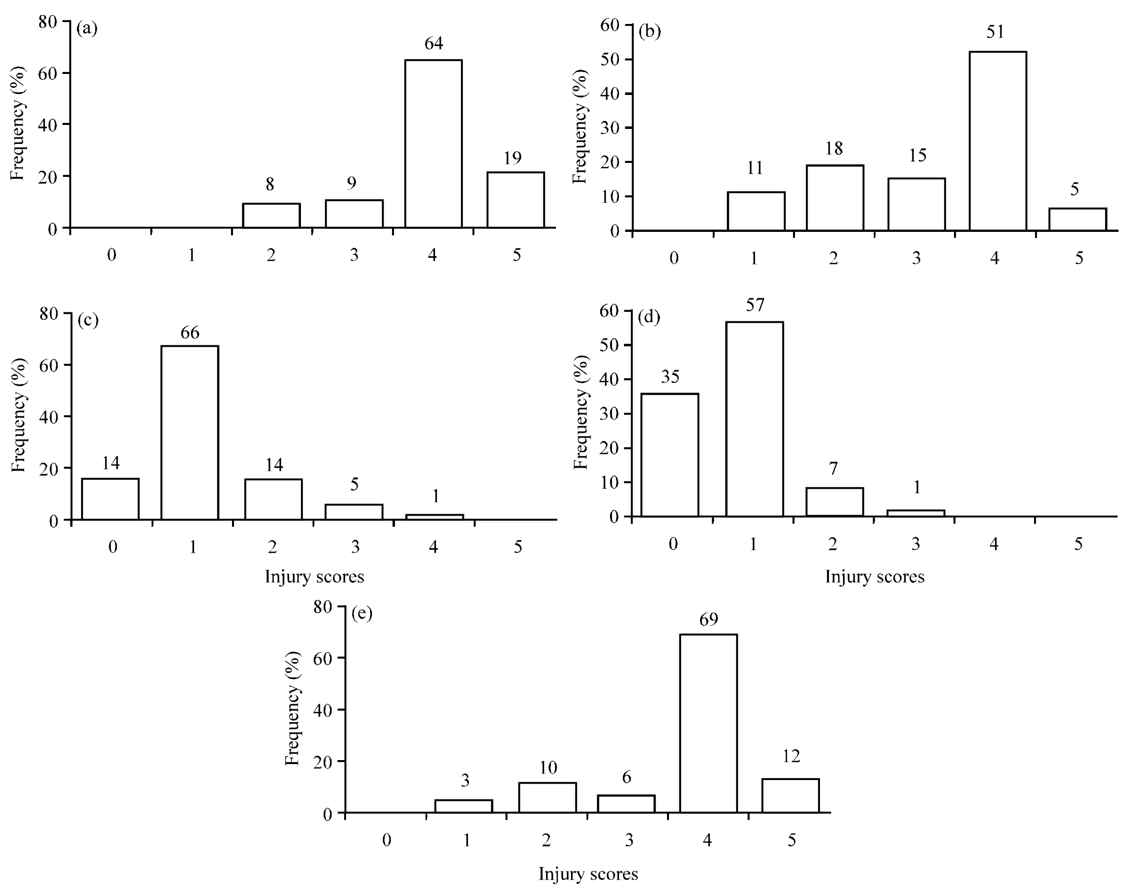

Fig. 1(a-e): Frequency of injury scores from *Spodoptera frugiperda* infestation on corn plants in V_{10} growth stage at 15 days after spraying of spinosad insecticide: (a) 100% air assist.+AXI 11002, (b) 100% air assist.+JA 2, (c) 0% air assist.+AXI 11002, (d) 0% air assist.+JA 2 and (e) Treatment control

Table 5: Plant height (PH), leaves number (LN), leaf area index (LAI), stem diameter (SD) and mass of thousand grains from corn plants according different technologies

Treatment	PH (cm)	LN	LAI	SD (cm)	1000 grains (g)
100 L ha^{-1}+AXI 11002	211.78^{a}	12.12^{b}	3.46^{b}	2.79^{a}	309.02^{b}
100 L ha^{-1}+AVI 11002	210.43^{a}	11.99^{b}	3.70^{b}	2.55^{a}	301.29^{b}
200 L ha^{-1}+AXI 11002	217.12^{a}	14.21^{a}	4.45^{a}	2.63^{a}	336.73^{a}
200 L ha^{-1}+AVI 11002	214.24^{a}	14.03^{a}	4.82^{a}	2.24^{a}	329.49^{a}
Treatment control	201.97^{b}	11.85^{b}	3.51^{b}	2.11^{a}	299.85^{b}
CV (%)	23.41	11.38	21.13	23.41	21.77
HSD	8.03	1.70	0.38	8.03	18.93

Means followed by the same letter in the column do not differ significantly by Tukey's test at 5% of probability (p>0.05), HSD: Honestly significant difference

The Table 5 shows the phytotechnical parameters of corn crop according with treatments. The corn plants presented height from 201.97 to 217.12 cm and it was affected only by treatment where any insecticide was sprayed (treatment control). The similarity between the effects of different technologies used for this factor (plant height) can be explained by the high capacity of injury recovery suffered by plants in low-infestation of fall armyworm (Azevedo *et al*., 2004). It is possible to note, as well, that the similarity of effects from sprayed treatments may be related with the growth stage of corn plant, where there is attenuation of fall armyworm injury when its infestations occur in advanced growth stages (Costa *et al*., 2005). In this case, the leaves number quantification was done at silking growth stage (advanced growth stage), what can explain the low injury in the sprayed treatments.

Regarding Leaves Number (LN), the spray volume was essential to provide differences between the treatments independent of spray nozzles, where the values ranged from 11.85 to 14.21. There was better performance for spray volumes of 200 L ha^{-1}, which they promoted approximately two more leaves per plant, as showed in Table 5. The fall armyworm can completely destroy younger leaves, especially in high infestations. Therefore, this interference in the leaves number reflects the ineffectiveness of the treatments affected (100 L ha^{-1} and treatment control).

About the use of solar radiation, the leaf surface photosynthetically active in relation to the unit area of ground is called Leaf Area Index (LAI). This parameter is used to estimate the stage growth of plants potential their interception potential of radiant energy. The LAI values ranged between 3.46 and 4.82 (Table 5). Again there was superiority of treatment with spray volume of 200 L ha^{-1} in relation to the others. The LAI is directly proportional with leaf surface, which is influenced by number of leaves. There was, therefore, a correlation between these two variables, since they showed the same trend in the experiment.

For the phenological character of stem diameter, there were no significant variations by the treatments, ranging from 2.11 to 2.79 cm (Table 5). However, there was interference in the mass of thousand grains, where the treatment control showed the lowest value (299.85 g) and the treatment with spray volume of 200 L ha^{-1} combined with AXI 11002 resulted in the highest value (336.73 g) (Table 5).

The corn grain productivity according with different technologies is represented by Fig. 2. The treatments whose spray volume was 200 L ha^{-1} stood out, being more productive than others. When there was any insecticide spraying (treatment control), the fall armyworm infestation caused reduction of 19% in the final grain productivity.

The leaves number reduction can cause decrease in grain productivity due the small photosynthetically active area of plants (Casa *et al.*, 2007). The best quality of soil and climatic condition where the culture is submitted during the cycle promote higher growth rate of individual grain and, consequently, higher productivity (Khoramivafa *et al.*, 2006). In this case, in addition of fewer leaves number per plants (Table 5), the losses in the grain productivity where there was no effective control of fall armyworm may have been intensified, probably due the adverse weather conditions (lack of rain) where the corn was exposed during the silking growth state (Table 1).

Figure 3 correlates the corn productivity of maize according with fall armyworm control efficiency. The correlation was significantly expressed by the equation Y = 0.0207x+8.0586, with a determination coefficient of 0.93. The productivity has always been increased was increased in the extent that higher efficiencies were obtained, since fall armyworm control can promote greater green leaf area remaining, with subsequent maintenance of productive potential. Figueiredo *et al.* (2006) evaluating the insecticides effects on *S. frugiperda* suppression in corn plants and Samarbakhsh *et al.* (2009) investigating the pesticides efficiency on corn plants also found a positive correlation between control efficiency and productivity, where better controls resulted in higher grain productivity.

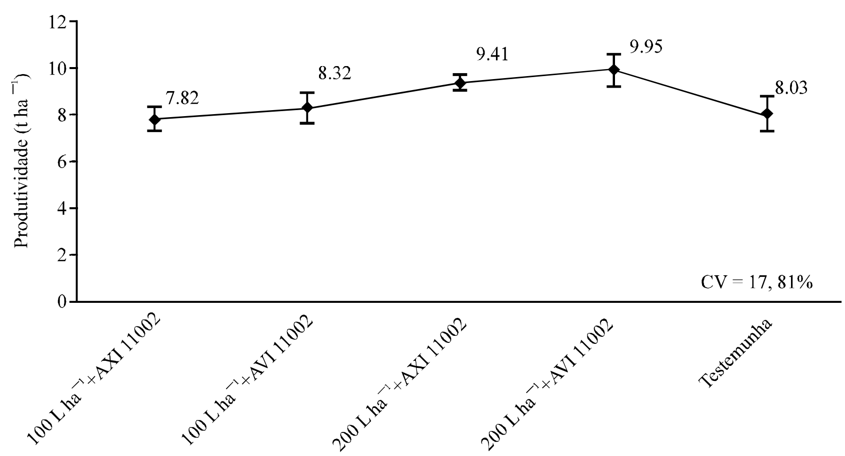

Fig. 2: Corn productivity (t ha^{-1}) according different spray nozzles and spray volume

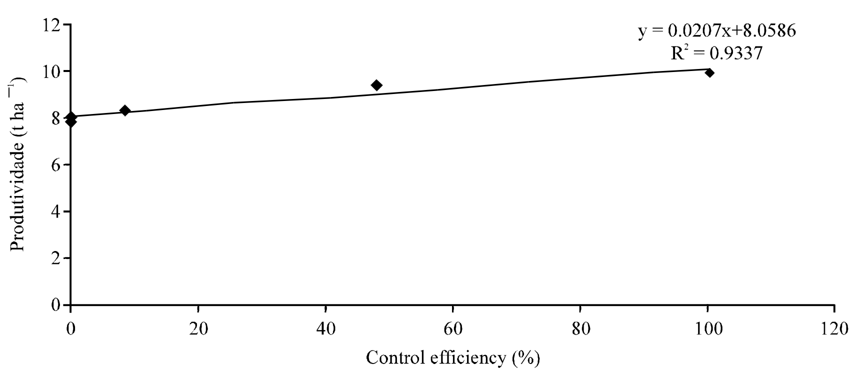

Fig. 3: Relation between corn productivity (t ha^{-1}) and control efficiency (%) of fall armyworm

CONCLUSIONS

According with experimental conditions, it is possible to conclude that: the spray deposition on corn plants (hybrid 2 B 707), cultivated in the narrow row system was influenced by air assistance and spray nozzles; air assistance and spray volume of 200 L ha^{-1} promoted satisfactory levels of *S. frugiperda* control in corn plants, hybrid 2 B 707, at narrow row cropping system; phytosanitary treatments, with spraying in total area, reduced injury levels of fall armyworm on corn plants, hybrid B 2 707 in narrow row cropping system; the corn productivity of hybrids B 2 707 is directly influenced by control efficiency of fall armyworm, where greater efficiencies provide higher grain productivities; these results can assist the implementation of integrated pest management of *S. frugiperda* in narrow row corn crop, by the prediction of appropriate pesticides spraying technologies to fall armyworm control, as well as the injury of this pest on the corn plants.

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