International Journal of

Agricultural Research

ISSN 1816-4897

Academic Journals Inc.

www.academicjournals.com

International Journal of Agricultural Research 9 (4): 200-209, 2014
ISSN 1816-4897 / DOI: 10.3923/ijar.2014.200.209

Localized Application of Insecticide Combined with Fertilizer on Corn Controls *Spodoptera frugiperda* (Smith) and Reduces Spray Drift

H.B.N. Campos, M.C. Ferreira, L.L. Costa, S.T. Decaro Júnior and O. Lasmar
Department of Phytosanitary, Sao Paulo State University, Jaboticabal/SP, Brazil

Corresponding Author: H.B.N. Campos, Department of Phytosanitary, Sao Paulo State University, P.O. Box 14884-900, Jaboticabal/SP, Brazil

ABSTRACT
Pesticides are important tools in agriculture for several decades, providing control of pest and diseases for an increasing demand of food by the growth of population. However, pesticides are often associated with contamination, both in food and environment. A change in application method makes spraying more safe and viable but the development of new techniques is a challenge. This study describes the evaluation of different strategies of insecticide application in the control of *Spodoptera frugiperda* (Smith) on corn. Techniques of insecticide application (localized application combined with nitrogenous (N) fertilizer and total area application); models of spray nozzles (pre-orifice and air induction) at different angles, flow rates, pressures and spray volumes (50, 100 and 150 L ha^{-1}) were evaluated on the fall armyworm control. The localized application combined with fertilizer were found possible, controls fall armyworm and reduces the amount of off-target insecticide exposure in total treated area. Appropriate techniques for the chemical control of *S. frugiperda* have been discussed. This new technique enables two operations within a single pass of the tractor and suggests a simple and low-cost installation that can be readily adopted by small family farms.

Key words: Application technology, spray nozzles, spray volumes, family farms, *Zea mays*

INTRODUCTION
The fall armyworm *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae) is an important insect pest that attacks corn, *Zea mays* L. which is grown in summer and winter crops (Farinelli and Filho, 2006). The fall armyworms feeds on all above ground plant structures and can significantly reduce crop yields (Buntin, 1986).

Although, transgenic corn hybrids from entomopathogenic bacterium *Bacillus thuringiensis* Berliner (Bt) increase resistance to predation by *S. frugiperda* (Kos *et al*., 2009), when populations of this insect adapts in Bt plants the insecticides are important for reducing damages to the crop (Waquil *et al*., 2002). But traditional application techniques (Dal Pogetto *et al*., 2012) are not well suited for these requirements wherein much of the chemical sprayed does not reach the target due to fact of caterpillars can remain protected by the whorl of the plants as well as to the incompatible positioning of the nozzles within the spray booms and the plant rows.

The efficiency of the spraying process is affected by the diameter of droplets produced by the spray nozzles (Ishfaque *et al*., 2005). Thus, to improve the spraying efficacy and reduce environmental contamination caused by pesticide drifts the development of spray nozzles with pre-orifice and air induction have been prompted (Derksen *et al*., 2007). However, studies on the use of these nozzles for the control of *S. frugiperda* on corn remain limited.

Another important factor affecting the efficacy of pesticide application is the adequacy of the spray volume because it limits the amount of spray that can provide maximal droplet coverage with minimal loss due to runoff (Matthews, 2000). There is a demand for low volumes due the increase in operational capacity of sprayers, reducing costs to the farmers (Yamauti *et al*., 2012).

Insecticides for controlling *S. frugiperda* are generally applied when nitrogenous (N) fertilizers are applied on the soil surface along plant rows which is predominantly to compensate for the lixiviation losses of N fertilizer applied at seed sowing time (Pottker and Wietholter, 2004). Hence, the hypothetical combined application of both insecticide and fertilizer warrants investigation.

In this study was evaluated the control of the *S. frugiperda* by the localized insecticide application combined with fertilizer on corn using specific nozzles and spray volumes.

MATERIALS AND METHODS

General data-crop years 2010 and 2011: Two experiments were conducted in an experimental area of Sao Paulo State University-UNESP, Campus Jaboticabal-SP, Brazil, located at latitude of 21°15'22" S, longitude of 48°19'20" Wand an altitude of 575 m above sea level. Maize seeds of the transgenic hybrid 2B88 (Herculex I, TC 1507, maize Cry 1F) were used. Seeds for the 2010 cropping season experiment were planted on June 17, 2010 (winter) and the required water was provided via a sprinkling irrigation system. Seeds for the 2011 cropping season experiment were planted on December 20, 2011 (summer). At the time of sowing, an 8-20-20 NPK soil fertilizer was applied at a rate of 350 kg ha^{-1} and a side-dressing of urea was applied at a rate of 200 kg ha^{-1}. These amounts were based on the results of a soil chemical analysis performed on the experimental area. The distance between the plant rows was 0.9 m, with six seeds per meter of row. Each experimental unit was formed by four 15 m long lines for a total area of 54 m^2. In that area, two central lines (useful area of 27 m^2) were used for the experimental data.

In the field, the experimental units were distributed according to a randomized complete block design following a factorial arrangement (2×2×3+1), in four replicates. The factor levels were based on combinations of the modes of insecticide application (localized and total area application), the nozzle tips (DG and AI), the spray volumes (50, 100 and 150 L ha^{-1}) and a control treatment (without the application of insecticide).

After the emergence of the seedlings, the *S. frugiperda* infestation was monitored within the experimental area. Four plants were sampled at random from each plot, preserving the useful area, in order to evaluate the damage caused to the plant leaves by the caterpillar. The severity of damage was classified using a scale ranging from 0 (no visual damage) to 9 (plants with total leaf destruction) according to a procedure developed previously (Davis *et al*., 1992). The insecticide was applied to plants exhibiting a damage level of 4 (3 to 4 large (1.3-2.5 cm) lesions per plant).

We used a neonicotinoid-based connect insecticide (Bayer CropScience) in a concentrated suspension formulation consisting of a mixture of imidacloprid+beta-cyfluthrin (100+12.5 g L^{-1}) at a dosage rate of 0.8 L ha^{-1}, according to the manufacturer's recommended protocols.

Hydraulic spray nozzles made of a polymer with a stainless steel insert with pre-orifice (DG) and Air Induction (AI) were used at flow rates of 0.15, 0.2 and 0.3 American gallons per min. The EVS models which are equipped with a continual flat spray tip at a 95° angle were used for localized application and VS models equipped with a discontinuous flat spray tip at a 110° angle were used for total area application.

Table 1: A comparison of localized and total area insecticide application using models of spray nozzles, pressures and operating speeds in the control of fall armyworm

Localized application	Pressure (kPa)	T.S (km h^{-1})	Total area application	Pressure (km h^{-1})	T.S (km h^{-1})
DG 95015-50 L ha^{-1}	229.9	6.8	DG 110015-50 L ha^{-1}	130	7.8
DG 9502-100 L ha^{-1}	300.0	5.4	DG 11002-100 L ha^{-1}	140	6.8
DG 9503-150 L ha^{-1}	350.0	5.4	DG 11003-150 L ha^{-1}	170	6.8
AI 95015-50 L ha^{-1}	229.9	6.8	AI 110015-50 L ha^{-1}	200	7.8
AI 9502-100 L ha^{-1}	300.0	5.4	AI 11002-100 L ha^{-1}	200	7.8
AI 9503-150 L ha^{-1}	350.0	5.4	AI 11003-150 L ha^{-1}	200	7.8

Fixed dosage of 0.8 L ha^{-1} of the commercial product Connect® in both modes of application. T.S: Tractor speed

Table 2: Meteorological data during the applications of insecticide in the control of fall armyworm

	Temperature (C°)		R.U (%)		Time		W.S (km h^{-1})	
Parameters	2010	2011	2010	2011	2010	2011	2010	2011
Localized application								
DG-50 L ha^{-1}	27.9	35.8	37	41	9 h 10	8 h 10	3	3
DG-100 L ha^{-1}	27.9	34.8	37	49	9 h 35	8 h 35	3	4
DG-150 L ha^{-1}	28.1	34.2	37	50	9 h 58	8 h 57	3	4
AI-50 L ha^{-1}	29.7	35.8	32	41	10 h 22	9 h 20	3	3
AI-100 L ha^{-1}	29.7	34.8	32	49	10 h 50	9 h 42	3	4
AI-150 L ha^{-1}	29.9	34.2	32	50	11 h 13	10 h 05	3	4
Total area application								
DG-50 L ha^{-1}	29.3	36.2	30	41	11 h 36	10 h 28	3	2
DG-100 L ha^{-1}	29.6	34.1	30	58	14 h 50	10 h 55	3	2
DG-150 L ha^{-1}	29.3	34.2	30	57	15 h 15	11 h 18	3	2
AI-50 L ha^{-1}	27.7	36.2	35	41	15 h 37	14 h 30	2	2
AI-100 L ha^{-1}	27.2	34.1	39	58	16 h 00	14 h 53	2	2
AI-150 L ha^{-1}	24.7	34.2	45	57	16 h 26	15 h 17	2	2

Temperature: Air temperature, R.U: Relative Humidity, W.S: Wind Speed

Application volumes of 50, 100 and 150 L ha^{-1} were used. The calibration of these volumes was facilitated by adjusting the flow of the above-mentioned spray nozzles, the working pressure and the moving speed of the tractor-sprayer assembly, in order to maintain the modes of application of insecticide (Table 1). A Ford model 4610 tractor was used in the application of the insecticide which was pressurized by a CO_2 cylinder.

The localized application of the insecticide was accomplished using four spray nozzles adjusted to the spray boom. A distance of 0.9 m between nozzles, the same distance as between plant rows, was used. The spray boom was connected to the frontal part of the tractorand the jet was directed toward the leaf whorl. The distance between the nozzles and the plants was adjusted in 0.2 and 0.25 m increments. In an orchestrated manner, the fertilizer was applied using equipment that was placed at the rear of the tractor so as not to interfere with the insecticide application.

The application of the insecticide within the total area was accomplished using six nozzles on the spray boom. In addition, the spray boom was connected to the frontal part of the tractor. The distance between the nozzles of the spray boom was 0.5 m and the distance between the nozzles and the plants was adjusted in 0.50 and 0.55 m increments.

In crop year 2010, the insecticide was applied at 11 Days After seedling Emergence (DAE), when the plants were at growth stage V4. In 2011, the insecticide was applied at 26 DAE, when the plants were at growth stage V8. The meteorological conditions observed during the treatment applications are shown in Table 2.

Spectrum of droplets produced: The analysis of the spectrum of the droplets produced by the spray nozzles used during the treatments was performed on 06/27/2013. The parameters examined included the volume median diameter (Dv 0.5) (drop diameter such that 50% of the volume of sprayed liquid drops consists of larger or smaller sizes than this value), the coefficient of uniformity of droplet size and the percentage of volume droplets with diameters smaller than 100 µm.

The droplet diameter was determined by laser diffraction for the passage of the droplet through the sampling region of a particle size analyzer (Mastersizer, Malvern Instruments Limited) adjusted to measure droplets up to 1000 µm in diameter. The degree of diffraction that a light beam undergoes is inversely proportional to the particle size. The data were decoded using algorithms developed for the data and for the characterization of the droplet diameter by laser diffraction and were tabulated and processed directly using the program Mastersizer S®, version 2.19.

The DG and AI spray nozzles were installed on a radial conveyor positioned at 40 cm from the laser beam, consistent with FAO standards (FAO, 1998). We used three sample nozzle for analysis, with four replicates performed per jets sprayed, maintaining the pressures adopted in the field trial. The experimental design was completely randomized, as the operating conditions and weather between the replicates were standardized.

The coefficient of uniformity was obtained using the following equation:

$$\text{Coefficient of uniformity} = \frac{Dv_{0.9}-Dv_{0.1}}{Dv_{0.5}}$$

in which, $Dv_{0.1}$ and $Dv_{0.9}$ refer to the droplet diameter, such that 10 and 90%, respectively, of the volume is composed of smaller sprayed droplets diameter.

Control evaluations: On the 3rd, 6th and 10th Days After Spraying (DAS), we evaluated the extent of fall armyworm control. We randomly sampled four plants outside of the useful area of each plot and counted the number of living caterpillars. Among the caterpillars counted, first (3 mm) and fourth (between 11 and 15 mm) instar specimens were found.

In addition, plant dry matter was measured at 10 DAS. We randomly sampled four whole plants from the useful area within each plot and placed them inside paper bags that were subsequently subjected to pre-drying in an air-forced oven at a temperature of 52°C for 72 h. After that, the plants were weighedand the weights of the dry matter obtained are shown as grams per plot.

We also determined grain yield at the end of the crop cycle. Considering a grain humidity between 18 and 20% and six standing plants per meter, we manually harvested ears of corn within 5 m within the useful area of each plot. The ears of corn were packed in labeled bags and then mechanically threshed. The grain samples were weighed and the values obtained are shown as kilograms per plot.

Finally, using the number of live caterpillars prior to the application and at 3, 6 and 10 DAS, the efficiency of the applied insecticide was calculated using the formula proposed previously by Henderson and Tilton (1955), who indicated that efficacies lower than 80% are considered low, whereas efficacies between 80 and 90% are favorable and those exceeding 90% are considered high efficacy.

Statistical analysis: The experimental data were first subjected to an analysis of variance (ANOVA) by F testand the treatment means were compared at the 5% level of probability by Tukey's test. Statistical analysis performed using the AgroEstat program, version 1.1.0.0694. The experimental data were Log x-transformed to comply with the normality and homogeneity assumptions of the ANOVA.

RESULTS

Calculated the efficiency percentage of control of *S. frugiperda* were found that the applications of insecticide on the crop rows yielded high control efficacy (higher than 90%) in the first experiment and favorable efficiency (higher than 80%) in the repetition. In contrast, the insecticide applications over the total area resulted in a low control efficacy (lower than 80%) in both crop years.

With respect to statistical analysis, we found at 3, 6 and 10 DAS that the localized application was effective in controlling *S. frugiperda*, with total larval mortality in the first experiment. In contrast, the total area applications did not achieve the same level of control. However, the localized and total area applications did not exhibit statistically significant differences at 3 and 10 DAS in terms of fall armyworm control in the repetition (Table 3).

In both crop years, the spray nozzles with pre-orifice DG and air induction AI, at different angles, flow rates and pressures, elicited similar effects at 3, 6 and 10 DAS in controlling the *S. frugiperda* (Table 3). However, we observed differences between the DG and AI nozzles in our

Table 3: Average No. of fall armyworm in experimental plots at 3, 6 and 10 Days After Spraying (DAS) with localized and total area application using the DG and AI nozzles and spray volumes of 50, 100 and 150 L ha^{-1}

	3 DAS		6 DAS		10 DAS	
Parameters	2010	2011	2010	2011	2010	2011
Modes of application (M.A)						
Localized application	0.0^{a}	0.72^{a}	0.0^{a}	0.70^{a}	0.0^{a}	0.70^{a}
Total area application	0.33^{b}	0.70^{a}	0.25^{b}	0.71^{b}	0.45^{b}	0.69^{a}
Nozzles (N)						
DG	0.16^{a}	0.72^{a}	0.16^{a}	0.71^{a}	0.25^{a}	0.70^{a}
AI	0.16^{a}	0.70^{a}	0.08^{a}	0.70^{a}	0.20^{a}	0.69^{a}
Spray volumes (S.V)						
50 L ha^{-1}	0.12^{a}	0.71^{a}	0.06^{a}	0.70^{a}	0.31^{a}	0.70^{a}
100 L ha^{-1}	0.18^{a}	0.70^{a}	0.18^{a}	0.71^{a}	0.18^{a}	0.69^{a}
150 L ha^{-1}	0.18^{a}	0.72^{a}	0.12^{a}	0.70^{a}	0.18^{a}	0.70^{a}
F-test						
M.A.	10.73**	3.62ns	7.46**	4.26*	18.93**	2.28ns
N	0.00ns	3.62ns	0.83ns	0.17ns	0.16ns	2.28ns
S.V	0.17ns	1.30ns	0.62ns	0.19ns	0.63ns	0.57ns
M.A×N	0.00ns	0.36ns	0.83ns	0.17ns	0.16ns	2.28ns
M.A×S.V	0.17ns	0.27ns	0.62ns	2.21ns	0.63ns	0.57ns
N×S.V	0.50ns	0.27ns	0.21ns	1.19ns	0.63ns	0.57ns
M.A×N×S.V	0.50ns	0.09ns	0.21ns	0.17ns	0.63ns	0.57ns
Factorial×Control treatment	20.63**	5.58*	28.10**	11.02*	16.48**	0.18ns
C.V (%)	3.89	4.88	3.51	3.87	4.0	2.15

Mean values of the original data and letters of transformed (Log×+5). Mean values in the same column followed by the same lower case letter are not significantly different at the 5% level of probability according to the Tukey's test. According to the F-test: *,**Significant at 5 and 1% level of probability, respectively, ns: Non-significant, C.V (%): Coefficient of variation

Table 4: Analysis of variance and mean tests for volume median diameters ($Vmd_{0.5}$) percentage of droplets smaller than 100 microns (%<100 μm) and coefficient of uniformity (Coef. Unif.) by the spray nozzles DG and AI (localized applications) maintaining the pressures adopted in the field trial

	Localized application					
	DG	AI	DG	AI	DG	AI
Parameters	Vmd$_{0.5}$ (μm)		%<100 μm		Coef. Unif.	
Flow rates						
15	221.82$^{B\ a}$	790.05$^{A\ a}$	9.49$^{B\ a}$	1.06$^{B\ a}$	1.57$^{B\ a}$	1.67$^{A\ a}$
20	229.29$^{B\ a}$	566.72$^{A\ b}$	9.78$^{B\ a}$	2.68$^{B\ b}$	2.61$^{B\ b}$	1.56$^{A\ a}$
30	224.14$^{B\ a}$	547.86$^{A\ b}$	10.58$^{B\ a}$	2.95$^{B\ b}$	2.59$^{B\ b}$	1.51$^{A\ a}$
F-test						
Nozzle (N)		3303.6771**		530.1316**		16.9539**
Flow rate (F)		114.4419**		6.7549**		3.3352*
N x F		123.7615**		1.3394ns		5.5849**
CV (%)		7.03		23.35		36.44
MDS N (5%)		24.6637		1.1598		0.5694
MDS F (5%)		29.6251		1.3931		0.684

Mean values in the same column followed by the same lowercase letter and in the same line by the same uppercase letter are not significantly different at the 5% level of probability According to the Tukey's test. According to the F-test: *,**Significant at 5 and 1% level of probability, respectively, ns: Not significant, MDS: Minimum distance significantly, C.V (%): Coefficient of variation

Table 5: Analysis of variance and mean test for volume median diameters ($Vmd_{0.5}$). percentage of droplets smaller than 100 microns (%<100 μm) and coefficient of uniformity (Coef. Unif.) by the spray nozzles DG and AI (total area applications) maintaining the pressures adopted in the field trial

	Total area application					
	DG	AI	DG	AI	DG	AI
Parameters	Vmd$_{0.5}$ (μm)		%<100 μm		Coef. Unif.	
Flow rates						
15	328.04$^{B\ b}$	892.56$^{A\ a}$	5.65$^{B\ b}$	0.72$^{A\ a}$	2.04$^{B\ ab}$	1.55$^{A\ a}$
20	374.36$^{B\ a}$	777.61$^{A\ b}$	4.18$^{B\ a}$	1.32$^{A\ b}$	1.88$^{B\ a}$	1.43$^{A\ a}$
30	334.91$^{B\ b}$	765.37$^{A\ b}$	5.27$^{B\ b}$	1.47$^{A\ b}$	2.32$^{B\ b}$	1.42$^{A\ a}$
F-test						
Nozzle (N)		6394,6455**		564,4228**		65,9040**
Flow rate (F)		35,7505**		5,0877**		2,6868ns
N×F		73,1361**		13,4815**		3,7677*
CV (%)		4.27		22.25		18.12
DMS N (5%)		20,1624		0.5627		0.2621
DMS F (5%)		24,2183		0.6759		0.3148

Mean values in the same column followed by the same lower case letter and in the same line by the same upper case letter are not significantly different at the 5% level of probability according to the Tukey's test. According to the F-test: *,**Significant at 5 and 1% level of probability, respectively, ns: Not significant, MDS: Minimum distance significantly, C.V (%): Coefficient of variation

analysis of the spectrum of droplets produced under the same pressure in the field assay (Table 4 and 5). The volume median diameters ($Vmd_{0,5}$) of the droplets formed by the DG nozzles were significantly reduced compared to those produced by the AI nozzles. The coefficient of uniformity (Coef. Unif.) was significantly lower for the AI spray nozzles, reflecting the production of more uniform droplets (the closer to zero that the coefficient of uniformity is, the more homogeneous spectrum of droplets is produced).

In terms of spray volumes, 50, 100 and 150 L ha^{-1} elicited the same effect against *S. frugiperda* at 3, 6 and 10 DAS in both crop years (Table 3), despite the fact that the application of 50 L ha^{-1} is three times less in volume than the application of 150 L ha^{-1}.

The application of imidacloprid+beta-cyfluthrin reduced the population of *S. frugiperda* compared to the treatment without the application of insecticide in all assays. Also the combined technologies evaluated were effective in controlling the fall armyworm compared to the control treatment in both crop years (Table 3).

Regarding the production of dry matter and grain in the first experiment, the modes of insecticide application were significantly different. Localized and total area applications produced 86.13 and 64.13 grams of dry matter per plot and 3.36 and 2.22 kg of grain per plot, respectively. In the repetition essay, no differences were observed in terms of the dry matter and grain produced between the localized and total area applications.

DISCUSSION

Mainly because of high chemical demands, a method of precision band spraying is needed. Localized insecticide application increased the accuracy of targeted distribution. Consistent spacing between the nozzles on the spray boom and the crop rows enabled jet spraying directly into the whorls of corn plants, increasing the proportion of on-target droplet deposition compared to the total area application. Consequently, we observed increased exposure of the fall armyworms to the effects of the pesticide.

Despite eliciting similar effects between the modes of application on fall armyworm control in repetition essay, we found localized application to be more favorable due this strategy does not require the overlap of spray jet-producing nozzles which decreases the amount of product applied directly to the soil compared to the total area application. The impact of localized application of insecticides to control *S. frugiperda* in the environment has not been investigated. Nevertheless Hong *et al*. (2012) describes the advantages in use localized application. According to the authors, new application techniques are needed in order to reduce chemical usage in agriculture, once non-target pesticides poisoning has been identified as the cause of fish kills, reproductive failure in birds and illness in humans (Rao *et al*., 1993).

Regarding the spray nozzles, with smaller droplet diameter DG nozzle produced an increased percentage of spray volume of droplets with a diameter less than 100 μm. For safe applications that are more tolerant of drift, 15% of the spray volume is recommended to contain droplets with diameters less than 100 μm (Cunha *et al*., 2003). However, the observed weather conditions during the applications (Table 3) indicated favorable wind speeds (3 km h^{-1}) which might have contributed the lack of significant differences between the DG and AI nozzles in terms of fall armyworm control, regardless of the mode of insecticide application.

Chechetto *et al*. (2013) evaluated the influence of spray nozzles DG 8003 VS and AI 8003 VS in reducing potential drift in a wind tunnel with air flow rate maintained at 2 m sec^{-1} (7.2 km h^{-1}). These authors concluded that nozzles with pre-orifice and air induction reduce the drift potential by producing droplets of larger diameters. Thus, during the favorable wind conditions observed in this study, the DG and AI nozzles facilitated the optimal on-target deposition of product.

According to our statistical analyses, the spray volumes of 50, 100 and 150 L ha^{-1} showed the same effect in controlling *S. frugiperda*. Therefore the smaller volume of 50 L ha^{-1} was appropriate, once reduced volumes can improve the operational capacity of sprayers and directly minimize losses by runoff (De Souza *et al*., 2012).

In contrast, the opposite result was previously observed by Gimenes *et al.* (2012). The authors evaluated the effect of spray volumes of 100 and 200 L ha^{-1} in controlling *S. frugiperda* on corn plants and achieved more favorable results in terms of insect control with increasing the spray volume. However, were found more suitable results using the higher volume (200 L ha^{-1}) when combined with air induction nozzles.

In this study, the control of fall armyworm obtained with 50 L ha^{-1} was attributed to the use of specific spray nozzles that reduced the drift effect. Smaller volumes combined with drops of larger diameter which are less susceptible to drift, might represent a more sustainable modality of phytosanitary intervention, given the concepts of efficacy, economy and respect for the environment.

The application of insecticide reduces the *S. frugiperda* population even when used on Bt corn plants, demonstrating the importance of investigating new technologies for pesticide application in pest management. Cruz *et al.* (2013) explained that the advent of transgenic modalities has set precedence for the potential and significant reduction of fall armyworm-associated problems in maize cultivation without the use of insecticides. However, these authors postulate that any technology, when used without considering other control tactics, can become inefficient.

According to our results, in the first experiment the most significant amount of dry matter and grain was produced when the insecticide was applied in the crop row compared to the total area. In agreement Cunha and Silva (2010) noted a positive relationship between effective control and productivity. When authors evaluated spray volumes and nozzles used in the chemical control of *S. frugiperda* on sorghum crops were found that better controls resulted in greater crop yields. In other hand, in the repetition experiment, no differences were observed in terms of the amounts of dry matter and grain produced using either mode of application. But Taiz and Zeiger (2006) explain that the damage caused by *S. frugiperda* in the whorl leaves can negatively affect the metabolic processes in corn plants which exhibit intense photosynthetic activity in young leaves. Further, according to Balardin *et al.* (2005), when the photosynthetically active areas are maintained, plants can produce more photoassimilates that can be stored as grains, thus ensuring increased subsequent productivity. Thus, corn yield is directly related to the effectiveness of the armyworm control methods.

The hypothesis that the optimized alignment of spray nozzles with the plant rows facilitated the more accurate deposition of product for the control of *S. frugiperda*. The suggested technique represents a simple and low-cost installation that can be readily adopted by small family farms. Furthermore, this technique can be incorporated by agricultural machine manufacturers for integration into current machinery.

CONCLUSION

Based on the results found in this study, the combined localized application of pesticide with fertilizer enables two operations within a single pass of the tractor decreasing the amount of product lost off-target compared to traditional application, maintaining effective in controlling fall armyworm. Of the models of spray nozzles combined with the spray volumes, the uses of the DG and AI at 50 L ha^{-1} showed control of *S. frugiperda*. This study indicates that a change in application method enables a sustainable modality of phytosanitary intervention in maize crops.

ACKNOWLEDGEMENTS

The authors would like to thank the Fundação de Amparo à Pesquisa do Estado de São Paulo-FAPESP for funding (Process 2010/13092-2).

REFERENCES

Balardin, R.S., F.C. Juliatti, A.C. Polizel and F.X.R. Vale, 2005. [Soybean rust: Epidemiology and management for a re-emerging disease]. Annu. Rev. Plant Pathol., 13: 351-395.

Buntin, G.D., 1986. A review of plant response to fall armyworm, *Spodoptera frugiperda* (JE Smith), injury in selected field and forage crops. Florida Entomol., 69: 549-559.

Chechetto, R.G., U.R. Antuniassi, A.A.B. Mota, F.K. Carvalho, A.C. Arruda e Silva and C.M. Vilela, 2013. Influencia de pontas de pulverizacao e adjuvantes no potencial de reducao de deriva em tunel de vento [Influence of spray nozzles and adjuvants in the reduction potential drift in the wind tunnel]. Semina: Ciencias Agrarias, 34: 37-46.

Cruz, I., F.H. Valicente, P.A. Viana and S.M. Mendes, 2013. Risco potencial das pragas de milho e de sorgo no Brasil [Pest risk potential of corn and sorghum in Brazil]. Documentos 150, EMBRAPA, CNPMS, Brazil, pp: 1-42.

Cunha, J.P.A.R. and A.D. Silva Jr., 2010. [Spray volume and spray nozzle effects on chemical control of *Spodoptera frugiperda* in fodder sorghum]. Engenharia Agricola, 30: 692-699 (In Brazilian).

Cunha, J.P.A.R., M.M. Teixeira, J.R. Coury and L.R. Ferreira, 2003. [Evaluation of strategies to reduce pesticide spray drift]. Planta Daninha, 21: 325-332 (In Brazilian).

Dal Pogetto, M.H.F.A., E.P. Prado, M.J. Gimenes, R.S. Christovam and D.T. Rezende *et al.*, 2012. Corn yield with reduction of insecticidal sprayings against fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae). J. Agron., 11: 17-21.

Davis, F.M., S.S. Ng and W.P. Williams, 1992. Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. Technical Bulletin No. 186, Agricultural and Forest Experiment Station, Mississippi, USA., pp: 1-9.

De Souza, L.A., J.P.R.A. Cunha and L.A. Pavanin, 2012. [Weed deposition of 2,4-D Amine herbicide applied with different spray volumes and nozzles]. Revista Ciencia Agronomica, 43: 78-85 (In Brazilian).

Derksen, R.C., H. Zhu, R.D. Fox, R.D. Brazee and C.R. Krause, 2007. Coverage and drift produced by air induction and conventional hydraulic nozzles used for orchard applications. Trans. ASABE, 50: 1493-1501.

FAO, 1998. Agricultural Pesticide Sprayers, Volume 2: FAO Technical Standards: Sprayer Specifications and Test Procedures. Food and Agriculture Organization of the United Nations, Rome, Italy, ISBN-13: 9789251041192, Pages: 63.

Farinelli, R. and D.F. Filho, 2006. [Assessment of damage of *Spodoptera frugiperda* (JE Smith, 1797) (Lepidoptera: Noctuidae) in corn plants]. Cientifica Jaboticabal, 34: 197-202 (In Brazilian).

Gimenes, M.J., C.G. Raetano, M.H.F.A. Dal Pogetto, E.P. Prado, D.T. Rezende and R.S. Christovam, 2012. Effects of spray nozzles and spray volume on *Spodoptera frugiperda* management and narrow row corn performance. Int. J. Agric. Res., 7: 134-143.

Henderson, C.F. and E.W. Tilton, 1955. Tests with acaricides against the brow wheat mite. J. Econ. Entomol., 48: 157-161.

Hong, S., L. Minzan and Q. Zhang, 2012. Detection system of smart sprayers: Status, challenges and perspectives. Int. J. Agric. Biol. Eng., 5: 10-23.

Ishfaque, M., M. Ashfaq and A.H. Sayyed, 2005. Effect of power on droplet size by hand held spinning disc sprayer. Pak. J. Biol. Sci., 8: 567-570.

Kos, M., J.J. van Loon, M. Dicke and L.E. Vet, 2009. Transgenic plants as vital components of integrated pest management. Trends Biotechnol., 27: 621-627.

Matthews, G.A., 2000. Pesticide Application Methods. 3rd Edn., Wiley-Blackwell, New York, pp: 448.

Pottker, D. and S. Wietholter, 2004. [Timing and methods of nitrogen application for corn under no-tillage]. Ciencia Rural, 34: 1015-1020 (In Brazilian).

Rao, P.S.C., C.A. Bellin and M.L. Brusseau, 1993. Coupling Biodegradation of Organic Chemicals to Sorption and Transport in Soils and Aquifers: Paradigms and Paradoxes. In: Sorption and Degradation of Pesticides and Organic Chemicals in Soil, Linn, D.M. (Ed.). Chapter 1, Soil Science Society of America, Madison, WI., USA., ISBN-13: 9780891188032, pp: 1-26.

Taiz, L. and E. Zeiger, 2006. Plant Physiology. 4th Edn., Sinauer Associates Inc., New York, USA.

Waquil, J.M., F.M.F. Vilella and J.E. Foster, 2002. Resistencia do milho (*Zea mays* L.) transgenico (Bt.) a lagarta-do-cartucho, *Spodoptera frugiperda* (SMITH) (Lepidoptera: Noctuidae) [Resistance Of corn (*Zea mays* L.) transgenic (Bt) for *Spodoptera* cartridge, *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)]. Braz. J. Maize Sorghum, 1: 1-11.

Yamauti, M.S., P.R.F. Giancotti, B.N. Lodo, L.L. de Lima and M.C. Ferreira, 2012. [*Ipomoea hederifolia* control with low volume using adjuvant spray liquid with spray rotary nozzle]. Revista Brasileira Herbicidas, 11: 49-61 (In Brazilian).