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Research Article

Water in maize whorl enhances the control of *Spodoptera frugiperda* with insecticides[1]

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ABSTRACT

The fall armyworm *Spodoptera frugiperda* is among the main insect-pests on maize crops, due to its damaging potential and control issues related to the larval habit of concealing itself within the plant whorl. This study aimed to evaluate the effect of water in the maize whorl, combined with insecticides and spray sets, on the damage caused by *S. frugiperda* and the grain yield. The experiments were carried out under field conditions, at two cropping seasons, both with *Bt*-maize hybrids, in a 2 × 2 × 5 + 1 factorial scheme, testing the presence or absence of water inside the plant whorl, two insecticides and five spray sets (combinations of spray volumes, nozzle types, pressures and spraying speed), plus a control without water and insecticide. The presence of water inside the whorl reduced the damage caused by *S. frugiperda* during the early growth stages, especially in the plants sprayed with the insecticide chlorantraniliprole. The spray sets with 200 L ha^{1}/20.3 psi or 250 L ha^{1}/33.4 psi provided the highest reductions in the percentage of damaged plants and damage scores, regardless of the insecticide. Therefore, the spraying of insecticides, when there is water from irrigation, dew or rainfall inside the maize whorl, improves the control of *S. frugiperda* in maize crops, especially in *Bt*-maize.

KEYWORDS: Chlorantraniliprole, chlorfenapyr, fall armyworm, pest management.

RESUMO

Água em cartucho de milho melhora o controle de *Spodoptera frugiperda* com inseticidas

A lagarta do cartucho *Spodoptera frugiperda* é uma das principais pragas do milho, pelos danos que ocasiona e pela dificuldade de controle com as lagartas abrigadas e protegidas no interior das folhas do cartucho. Objetivou-se avaliar a influência da água no cartucho de milho, em combinação com inseticidas e conjuntos de pulverização, sobre os danos causados por *S. frugiperda* e a produtividade de grãos. Os experimentos foram conduzidos em campo, sob duas épocas de cultivo, ambas com híbridos de milho-*Bt*, em esquema fatorial 2 × 2 × 5 + 1, testando presença ou ausência de água no cartucho, dois inseticidas e cinco conjuntos de pulverização (combinações de volumes de calda, tipos de bico, pressões e velocidade de aplicação), mais um controle sem água e inseticida. A presença de água no cartucho reduziu os danos de *S. frugiperda* nos estádios iniciais, especialmente nas plantas tratadas com o inseticida clorantraniliprole. Os conjuntos de aplicação com 200 L ha^{1}/20,3 psi ou 250 L ha^{1}/33,4 psi proporcionaram as maiores reduções no percentual de plantas atacadas e nas notas de dano, independentemente do inseticida. Portanto, a aplicação de inseticidas, quando há água no cartucho do milho procedente de irrigação, orvalho ou chuvas, melhora o controle de *S. frugiperda* em cultivos de milho, especialmente em milho-*Bt*.

PALAVRAS-CHAVE: Clorantraniliprole, clorfenapir, lagarta-do-cartucho, manejo de pragas.

INTRODUCTION

The fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) can reduce the maize grain yield up to 60 %, according to the sowing date, maize hybrid and plant growth stage at which the damage occurs (Cruz et al. 2008). The main control strategy for *S. frugiperda* is the use of genetically modified maize plants expressing the toxins *Cry* or *Vip* (i.e., *Bt*-maize). However, its control has become difficult, due to the increasing occurrence of populations resistant to some *Bt* toxins (Cruz et al. 2013, Farias et al. 2014), demanding insecticide sprays in maize plants that should be highly resistant to the *S. frugiperda* attack (Burtet et al. 2017).

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The control of *S. frugiperda* in maize plants using insecticide spraying presents serious downsides related to the feeding behavior of the larvae, which migrate into the plant whorl immediately after its emergence and remain sheltered during the whole larval phase (Busato et al. 2002). The whorl is a funnel-shaped structure formed by the growing leaves of the maize plant during its early development stages (Girardin 1992, Ritchie et al. 1993). *S. frugiperda* larvae stay lodged inside the maize whorl while feeding and producing excrements, which partially block the entrance of the funnel and afford protection from possible predators and insecticide sprays alike (Gassen 1996).

Due to the concealed habit of the larvae, the control of *S. frugiperda* in maize plants is highly dependent on the spray volume. Silva (1999) obtained a higher larval mortality using 300 L ha^{-1} of spray volume, when compared to 150 L ha^{1}. Higher spray volumes cause the insecticide to drip inside the whorls, increasing the chances of direct contact with the larvae (Guedes & Maziero 2011). The addition of insecticides to sprinkler irrigation water has also been pointed out as an effective tool for pest control, due to the higher spray coverage and plant wetting resulted therein (Vieira & Silva 2006). Nonetheless, the propensity to minimize operational costs has led maize growers to reduce spray volumes (Bayer et al. 2011), potentially jeopardizing the control efficiency of *S. frugiperda.*

Besides providing shelter for armyworm larvae, maize leaves can also store water from rain, dew or overhead irrigation, due to their spatial arrangement in the whorl (Basantaet al. 2000). It is possible that the presence of water inside the whorl enhances the control efficiency of insecticides sprayed at this moment, targeting specifically at *S. frugiperda*, but such hypothesis remains untested. Therefore, this study aimed to evaluate the effect of water inside the maize whorl (simulating a moderate rain or irrigation), combined with insecticides and spray sets, on the damage caused by *S. frugiperda* and the grain yield of maize plants.

MATERIAL AND METHODS

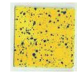
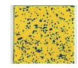
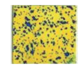
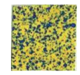
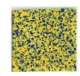
Two experiments were carried out under field conditions during two cropping seasons (first-crop and second-crop maize), in 2015/2016, in Santa Maria, Rio Grande do Sul state, Brazil (29º43’40”S, 53º33’43” W and 95 m of altitude). The climate of the region is classified as *Cfa* (i.e., humid subtropical with hot summers and without dry seasons) (Alvares et al. 2013). Both sowings were carried out with *Bt*-maize hybrids: November 29, 2015, with the 30F53YH hybrid (first crop); and January 4, 2016, with the 3161YH hybrid (second crop). The sowing density was 6.8 seeds m^{-2}.

The choice of the maize hybrids was based on recommendations for each sowing date and the fact that both express *Cry1F* and *Cry1AB* toxins. Fertilization at sowing comprised 350 kg ha^{-1} of the 05-20-20 fertilizer (% of N, P_2O_5 and K_2O, respectively), followed by surface fertilization with urea (45 % of N) at the growth stages V3 and V6 of the maize plants (Ritchie et al. 1993), at the doses of 45 kg ha^{-1} and 22.5 kg ha^{-1} of N, respectively. In both experiments, weeds were controlled at 15 days prior to sowing with the spraying of 1,200 g a.i. ha^{-1} of glyphosate (Zapp Qi® 620 SL), and in post-emergence at the growth stage V4 of the maize plants with 1,250 + 1,250 g a.i. ha^{-1} of atrazine + simazine (Primatop® 250 + 250 SC).

The experimental design for both trials was randomized complete blocks, with four replications, and treatments in a 2 × 2 × 5 + 1 factorial scheme, in 2 m × 5 m plots (four rows spaced 0.5 m per plot). The levels of treatment factors comprised the presence or absence of water inside the maize whorl (after overhead irrigation), two insecticides (chlorantraniliprole - Premio® 200 SC, 24 g a.i. ha^{-1}; chlorfenapyr - Pirate® 240 SC, 192 g a.i. ha^{-1}) and five spray sets resulting from combinations of spray volumes, nozzle types, pressures and spraying speed (Table 1). An additional treatment with no irrigation or insecticide spraying comprised the control.

Infestation by *S. frugiperda* occurred naturally, and damage was monitored and quantified using the scale proposed by Davis et al. (1992), which comprises the following scores: 0 = no damage; 1 = less than three small injuries; 2 = small round injuries; 3 = rectangular injuries smaller than 1.3 cm; 4 = injuries between 1.3 cm and 2.5 cm; 5 = four to seven injuries bigger than 2.5 cm; 6 = holes beginning to appear on expanded leaves; 7 = more than eight injuries on whorl leaves and small holes on expanded leaves; 8 = most whorl leaves injured and holes of every size on expanded leaves; 9 = whorl and expanded leaves virtually destroyed. Evaluations

Table 1. Spray sets assessed with the respective spray volumes, nozzles, pressures, speeds and coverages on water-sensitive paper.

Spray set	Volume (L ha^{-1})	Nozzle (model)	Pressure (psi)	Speed (km h^{-1})	Coverage
S1	50	ADGA 01	12.3	5.4	
S2	100	ADGA 015	14.5	5.4	
S3	150	ADGA 02	23.2	5.4	
S4	200	ADGA 03	20.3	5.4	
S5	250	ADGA 03	33.4	5.4	

were carried out every three days, beginning at the emergence of the maize plants.

Insecticides were sprayed when 20 % of the plants reached damage scores ≥ 3 (IRAC 2017). This control level was reached at the growth stage V4 of the maize plants for the first crop, and at the stage V1 for the second one. Additional sprayings were carried out fortnightly, or when the average of damaged plants surpassed 20 %.

Prior to the insecticide sprays, irrigation was carried out (4 mm of water depth) using impact sprinklers (model AJS-13®, 0.86 m^3 h^{-1}). In the plots that needed absence of water inside the whorl, the plants were covered with a plastic canvas atop metallic arcs of 2 m × 2 m (Figure 1). The insecticides were sprayed after irrigation, using a CO_2-pressurized backpack sprayer. The damage caused by *S. frugiperda* on the maize plants was evaluated every three days after spraying, until the growth stage V13, by sampling twenty plants of the two central rows of each plot and employing the scale proposed by Davis et al. (1992). The grain yield was assessed in each treatment by harvesting 2.0 m^2 of the central area per plot.

Data were submitted to the Shapiro-Wilk normality test, undergoing the transformation of a$\sqrt{(x+0.5)}$. Afterwards, analysis of variance was performed, followed by mean comparisons by the Tukey test (or the Scheffé test for the mean contrasts between the control and each other treatments), all at 5 % of significance. For these analyses, the softwares Action (Equipe Estatcamp 2014), SOC (Embrapa 1997) and Sisvar 5.6 (Ferreira 2008) were used.

RESULTS AND DISCUSSION

The damage caused by *S. frugiperda* in maize plants was significantly reduced ($p < 0.01$) by the presence of water inside the whorls at both experiments, especially at the early growth stages of the plants (Figure 2). The number of damaged plants was 17 % lower when chlorantraniliprole was sprayed with water inside the whorls (Figures 2A and 2C). This effect was observed until the growth stage V8

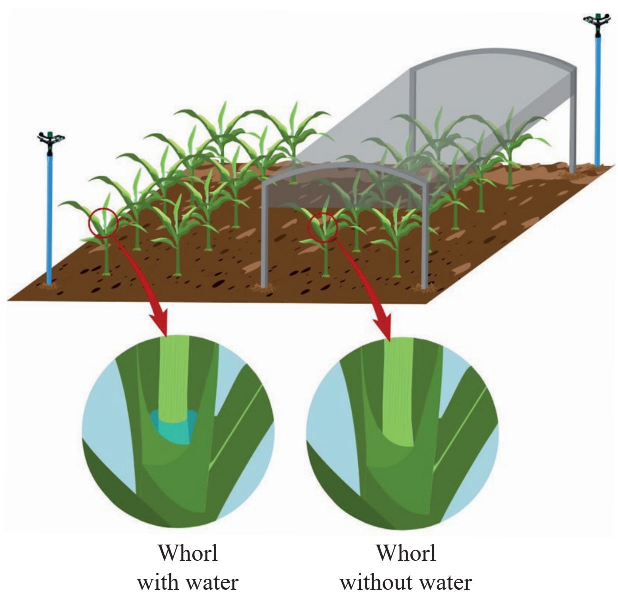


Figure 1. Depiction of the plots that received overhead irrigation (left) or remained sheltered by a plastic canvas (right). In detail, the storage of water inside the maize whorl after irrigation (4 mm).

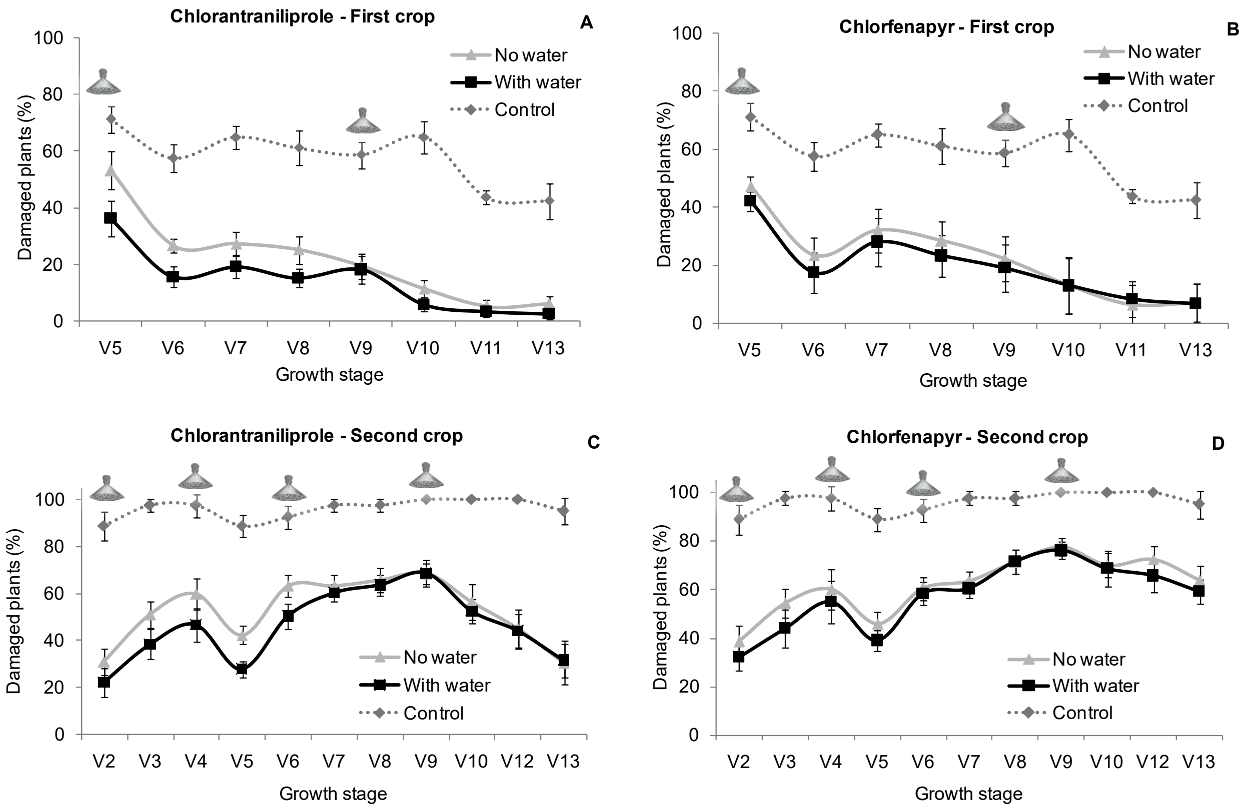


Figure 2. Number (mean ± standard error) of maize plants damaged by *Spodoptera frugiperda* after spraying with chlorantraniliprole and chlorfenapyr, in the first (A, B) or second (C, D) crop, respectively. Lines represent damages associated to the treatments with no water inside the maize whorls, water inside the maize whorls and the untreated control; and spray jets over the lines indicate the moments of insecticide spray.

in the first crop, and until the stage V6 in the second. No significant reduction ($p > 0.05$) was obtained with the combination of chlorfenapyr and water inside the maize whorls, regardless of the plant growth stage and sowing date (Figures 2B and 2D).

The infestation by *S. frugiperda* was lower in the first crop, demanding only two insecticide sprays, against four in the second crop (at the growth stages V1, V4, V7 and V9, respectively). The occurrence of *S. frugiperda* in the Rio Grande do Sul state is higher in second-crop maize, demanding a high number of sprays to prevent economic damage in most maize hybrids (Farias 2014, Burtet et al. 2017). In this study, insecticide sprays were carried out fortnightly, or when the average of plant damage surpassed 20 %.

The damage caused by *S. frugiperda* has two distinct phases: significant difference between presence and absence of water during the early growth stages, and no significant difference during the late stages (Figure 2). Thus, data were grouped and analysed as *early stages* (V5 to V8) and *late stages* (V9 to V13) in the first crop, as well as *early stages* (V2 to V6) and *late stages* (V7 to V13) in the second crop. The factors spray set, insecticide and presence of water in the whorls differed significantly for the variables damaged plants and damage score at both experiments ($p < 0.05$) (Table 2), except for the variable damaged plants under presence of water inside the whorl in the second crop ($p = 0.056$). In both experiments, there was no interaction among water inside the whorls, insecticides and spray sets; however, the "water × insecticide" interaction showed a significant effect for damaged plants and damage score at the early stages of both crops, as well as the "insecticide × spray set" interaction for the late stage (Table 2).

The presence of water inside the maize whorls combined with chlorantraniliprole spray reduced significantly ($p < 0.05$) the percentage of damaged plants and the damage scores of *S. frugiperda* at the early stage of both crops, regardless of spray set (Figure 3). In the first crop, the averages of

Table 2. Summary of analyses of variance (p-values) for three variables[1], as a function of the treatment factors (water inside the maize whorls, insecticides and spray sets), and their respective interactions, at two cropping seasons (different trials) and two development plant stages.

Source of variation[2]	DF	First crop					Second crop				
		Early stages		Late stages		Y	Early stages		Late stages		Y
		PD	D	PD	D		PD	D	PD	D	
Water (W)	1	< 0.001	< 0.001	0.006	0.018	0.816	< 0.001	< 0.001	0.056	< 0.001	0.257
Insecticide (I)	1	< 0.001	< 0.001	< 0.001	< 0.001	0.893	< 0.001	< 0.001	< 0.001	< 0.001	0.015
Spray set (S)	4	< 0.001	< 0.001	< 0.001	< 0.001	0.146	< 0.001	< 0.001	< 0.001	< 0.001	0.369
W * I	1	0.001	0.038	0.045	0.053	0.960	0.001	0.012	0.430	0.608	0.713
W * S	4	0.873	0.633	0.479	0.140	0.653	0.548	0.958	0.307	0.143	0.714
I * S	4	0.996	0.839	0.001	0.004	0.903	0.369	0.833	< 0.001	< 0.001	0.626
W * I * S	4	0.428	0.928	0.863	0.811	0.244	0.687	0.817	0.195	0.481	0.799
UC *vs*. Factorial	1	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CV (%)	-	7.611	7.393	14.386	9.177	8.357	4.929	5.637	3.846	3.995	8.347

[1] PD: percentage of damaged maize plants by *Spodoptera frugiperda*; D: damage scores (Davis' scale); Y: grain yield. [2] UC: untreated control (here in contrast with the other treatments, in a factorial scheme); CV: coefficient of variation; DF: degrees of freedom.

damaged plants and damage scores fell from 33.2 % to 21.6 % and from 0.6 to 0.4, respectively; whereas, in the second crop, the reductions were of 49.4 % to 37.0 % and 2.6 to 1.9. The most likely explanation for this control enhancement is that the presence of water inside the maize whorls (especially during the early growth stages of the crop; see Figure 1) forces the armyworm larvae to come out to perform a gas exchange through its spiracles, as observed during the conduction of the experiment. This behavior results in an increased exposure of the larvae to contamination with insecticide sprays, as well as to predation by natural enemies (e.g., insects, birds and pathogens).

As for the late stages, the water storage inside the maize whorls did not affect significantly the percentage of damaged plants. The *S. frugiperda* damage at late stages was lower in the first crop and higher in the second one (Figures 3 and 4). At this point of the crop cycle, armyworm larvae are well developed and protected by their excrements inside the maize whorls, hindering the control by chlorantraniliprole, even when combined with previous irrigation. Insecticide sprays during the early growth stages of the maize plants, on the other hand, may also lose the control efficiency due to the lower leaf area (Ceccon et al. 2004).

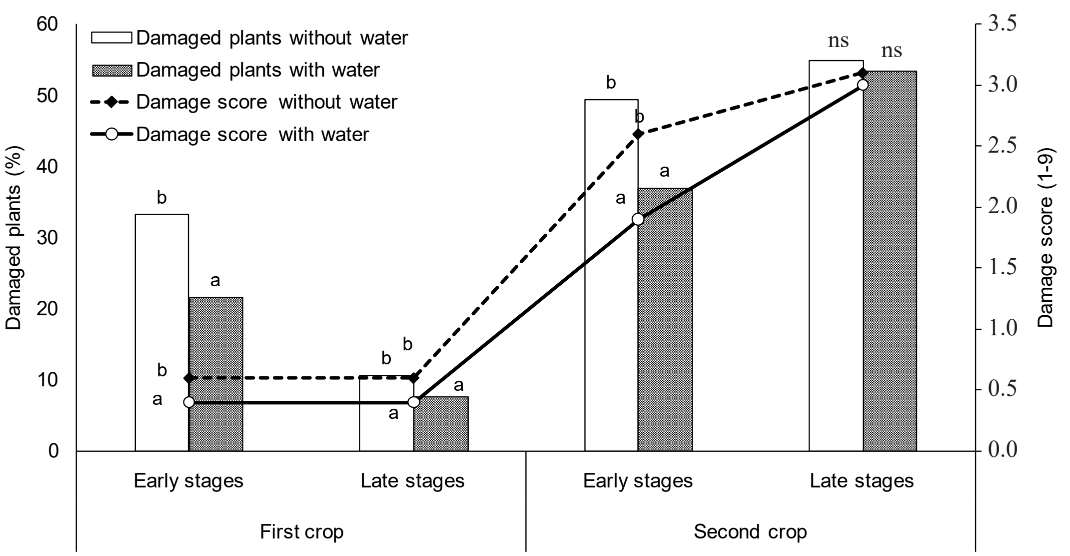


Figure 3. Effect of the water presence inside the maize whorls for the incidence and damage score of *Spodoptera frugiperda* on maize plants sprayed with chlorantraniliprole at two growing crops and two growth stages. Means followed by different letters in the columns are different by the F-test at 5 % of probability; ns: non-significant.

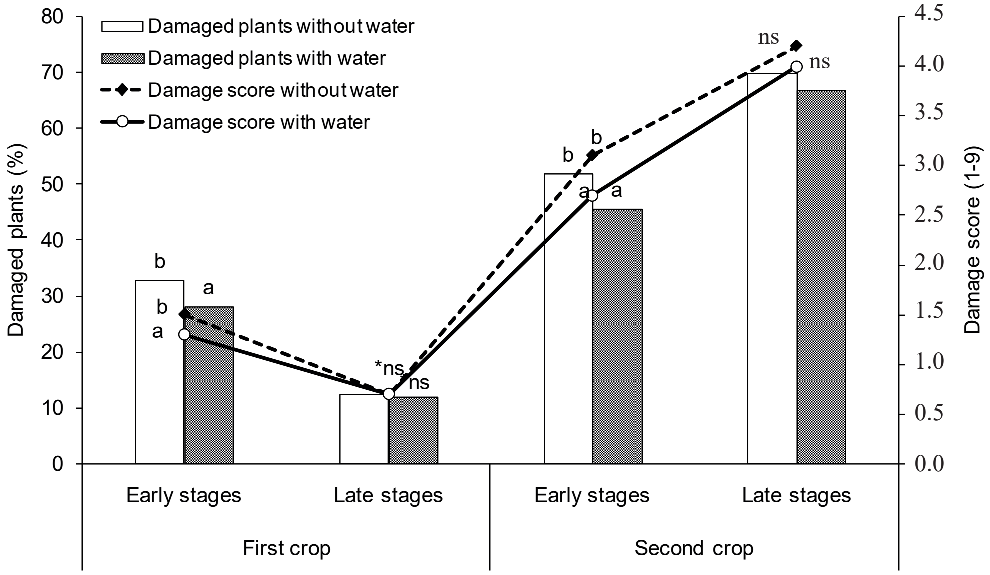


Figure 4. Effect of the water presence inside the maize whorls for the incidence and damage score of *Spodoptera frugiperda* on maize plants sprayed with chlorfenapyr at two growing crops and two growth stages. Means followed by different letters in the columns are different by the F-test at 5 % of probability; ns: non-significant.

These results indicate that the water inside the maize whorls combined with chlorantraniliprole reduces in more than 10 % the number of plants damaged by *S. frugiperda* during the early growth stages, regardless of spray set. Chlorantraniliprole is a ryanodine receptor modulator (IRAC 2019) widely regarded as highly efficient in the control of lepidopteran pests (Cordova et al. 2007). While control failures of *S. frugiperda* due to the selection of resistant strains have already been reported for many insecticides, in Brazil (e.g. spinosad, lambda-cyhalothrin and lufenuron; see Diez-Rodríguez & Omoto 2001, Okuma 2015 and Nascimento et al. 2016, respectively), the frequency of resistance alleles for chlorantraniliprole inside *S. frugiperda* populations seems to remain considerably low (Ribeiro 2014).

Increases in the spray volume, combined with the respective changes in the spray nozzle and pressure, enhanced the control of *S. frugiperda* with chlorantraniliprole in both crops. The spray set S4 (200 L ha^{-1}; 20.3 psi) provided the lowest percentage of damaged plants and damage score, regardless of presence or absence of water inside the maize whorls (Table 3). The spray sets S1 (50 L ha^{-1}; 12.3 psi) and S2 (100 L ha^{-1}; 14.1 psi) resulted in the highest damages, corroborating Silva (1999), which states low-volume sprays as one of the main factors leading to control failures of *S. frugiperda* in maize crops. The water inside the maize whorls significantly reduced the percentage of damaged plants at early stages (from 39.1 % to 22.2 %), when combined with the spray sets S2, S3 and S4 (100 L ha^{-1}, 150 L ha^{-1} and 200 L ha^{-1}, respectively) in the first crop, and S3, S4 and S5 (150 L ha^{-1}, 200 L ha^{-1} and 250 L ha^{-1}, respectively) in the second crop. However, no significant effect was observed at the late stages of both crops, since, at this development stages, the maize whorl has grown and can no longer store water inside.

During the early stages of the second crop and with absence of water inside the maize whorls, the percentage of damaged plants decreased to 41 %, when the spray volume was raised to 200 L ha^{-1} (S4); after irrigation, however, the same percentage was obtained with half that volume (Table 3). Similar results were obtained at the early stages of the first crop. Thus, the presence of water inside the maize whorls at the early growth stages of the crop, whether from artificial irrigation or natural precipitation (e.g., rainfall, mist and dew), allows a reduction in the spray volume of chlorantraniliprole targeting at *S. frugiperda*. Lower spray volumes increase the operational efficiency by allowing the spraying of a bigger area in less time (Souza et al. 2012); however, the volume of reduction must be carefully pondered, in order to avoid control failures.

The damage by *S. frugiperda* was significantly reduced by chlorfenapyr, when combined with the

Table 3. Means[1] of damaged maize plants (%) and damage scores (1 to 9) by *Spodoptera frugiperda*, at early and late plant growth stages, for combinations of the treatment factors water inside the maize whorls (no or with) and spray sets (S1 to S5) to the chlorantraniliprole insecticide.

Treatments	Early stages					Late stages				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
					First crop - damaged plants (%)					
No water	38.1 A	39.1 Ab	32.2 Ab	27.8 Ab	28.8 A	13.1 AB	15.6 B	6.6 A	6.9 A	10.9 AB
With water	29.4 B	22.2 Aba	21.9 Aba	15.6 Aa	19.1 AB	12.2 B	8.4 AB	4.4 A	5.6 AB	7.2 AB
Mean	33.8 C	30.6 BC	27.0 ABC	21.7 A	23.9 AB	17.0 B	12.0 B	5.5 A	6.3 A	9.1 AB
Control			63.8					52.5		
					First crop - damage scores (1-9)					
No water	1.8^{ns}	1.7 b	1.3	1.1	1.3	0.8 CB	1.0 Cb	0.3 A	0.4 AB	0.6 ABC
With water	1.3 B	1.0 Aba	0.8 AB	0.6 A	0.9 AB	0.7 B	0.5 ABa	0.2 A	0.3 A	0.4 AB
Mean	1.5 C	1.4 BC	1.1 AB	0.9 A	1.1 AB	0.8 C	0.7 C	0.3 A	0.3 A	0.5 AB
Control			3.5					3.4		
					Second crop - damaged plants (%)					
No water	62.0 B	51.5 AB	47.8 Ab	41.0 Ab	44.8 Ab	71.3 D	62.1 CD	54.0 BC	44.6 AB	42.7 A
With water	52.3 C	41.5 BC	32.5 ABa	28.3 Aa	30.3 Aa	62.3 B	60.0 B	51.0 AB	48.3 A	45.2 A
Mean	57.1 C	46.5 B	40.1 AB	34.6 A	37.5 A	66.8 C	61.0 BC	52.5 B	46.5 A	44.0 A
Control			93.0					98.3		
					Second crop - damage scores (1-9)					
No water	3.5 B	2.8 AB	2.5 ABb	2.1 Ab	2.3 Ab	4.2 C	3.7 BC	3.0 AB	2.5 A	2.4 A
With water	2.8 B	2.1 AB	1.7 Aa	1.5 Aa	1.5 Aa	3.5 B	3.4 B	2.8 AB	2.7 A	2.5 A
Mean	3.1 C	2.5 B	2.1AB	1.8 A	1.9 A	3.8 C	3.5 BC	2.9 AB	2.6 AB	2.5 A
Control			6.3					7.2		

[1] Means followed by the same lowercase letter in the column and uppercase letter in the row are not significantly different by the Tukey test ($p < 0.05$).

presence of water inside the maize whorls, at the early stages of both crops (Figures 2 and 4). The percentage of damaged plants decreased from 32.8 % to 28.1 % in the first crop and from 51.8 % to 45.6 % in the second one, showing that chlorfenapyr provides a lower control efficiency than chlorantraniliprole in these conditions. Similarly to the previous insecticide, the damage caused by *S. frugiperda* was not significantly affected during the late stages of the crop, regardless of water presence (Figure 4).

The low control efficiency provided by chlorfenapyr may be linked to intrinsic features of the product and the difficulty in reaching the target (i.e., *S. frugiperda*); however, the main reason is probably its low residual effect due to a rapid degradation in the environment (three to four days of half-life; Ditya et al. 2010). Chlorfenapyr is a pyrrole insecticide with a broad spectrum of action, activated by oxidative processes in metabolic enzymes of the insects (P450s, GSTs and COE) and functioning as an uncoupler of oxidative phosphorylation by disruption of the proton gradient (Hunt & Treacy 1998, Feyereisen 2012). Considering that this insecticide is highly efficient in managing defoliating caterpillars of hard control (e.g., *Chrysodeixis includens*; Perini et al. 2019), the low control obtained for *S. frugiperda* in maize plants is likely related to the short availability of active ingredient for larvae contamination.

The presence of water inside the maize whorls did not significantly affect the results obtained for each spray set. The lowest means for damaged plants and damage scores were obtained with the spray sets S4 (200 L ha^{-1}; 20.3 psi) and S5 (250 L ha^{-1}; 33.4 psi), regardless of sowing date and growth stage of the crop (Table 4). As observed for chlorantraniliprole, the spray sets with the lowest volumes (S1 and S2, with 50 L ha^{-1} and 100 L ha^{-1}, respectively) resulted in the highest damages by *S. frugiperda* on maize plants.

The maize grain yield differed significantly ($p < 0.01$) between the untreated control and the treated groups for all factors (water inside the whorls, insecticides and spray sets) (Table 2). The yield reduction due to *S. frugiperda* attack in the control was estimated in more than 2,000 kg ha^{-1}, when compared with some of the treatments in the second crop (Table 5). The insecticide effect was significant ($p = 0.015$) only for the second growing crop (Table 2), when the spraying with chlorantraniliprole resulted in an increase of 814.1 kg ha^{-1}, if compared to those with chlorfenapyr. For the conditions under which the

Table 4. Means[1] of damaged maize plants (%) and damage scores (1 to 9) by *Spodoptera frugiperda*, at early and late plant growth stages, for combinations of the treatment factors water inside the maize whorls (no or with) and spray sets (S1 to S5) to the chlorfenapyr insecticide.

Treatments	Early stages					Late stages				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
					First crop - damaged plants (%)					
No water	41.9 B	35.3 AB	32.5 AB	25.3 A	29.1 A	21.9 B	14.1 AB	10.3 A	7.5 A	7.6 A
With water	34.4 B	32.8 AB	27.2 AB	21.9 A	24.4 AB	21.9 B	12.8 AB	10.0 A	7.2 A	7.4 A
Mean	38.1 C	34.1 BC	29.8 AB	23.6 A	26.7 AB	21.9 C	13.4 B	10.2 AB	7.3 A	7.5 A
Control			63.8					52.5		
					First crop - damage scores (1-9)					
No water	2.0 B	1.8 AB	1.4 AB	1.2 A	1.3 AB	1.2 B	0.9 AB	0.6 A	0.4 A	0.5 A
With water	1.7[ns]	1.3	1.2	1.1	1.0	1.4 B	0.7 A	0.6 A	0.4 A	0.5 A
Mean	1.9 C	1.5 BC	1.3 AB	1.1 A	1.2 AB	1.3 C	0.8 B	0.6 AB	0.4 A	0.5 A
Control			3.5					3.4		
					Second crop - damaged plants (%)					
No water	67.0 C	55.8 BC	49.5 AB	45.3 AB	41.3 A	80.8 B	69.6 AB	67.7 AB	61.7 A	69.2 AB
With water	60.8 C	49.5 BC	43.8 AB	37.8 A	36.3 A	80.0 B	66.3 A	62.3 A	60.2 A	65.2 A
Mean	63.9 D	52.6 C	46.6 BC	41.5 AB	38.8 A	80.4 B	67.9 A	65.0 A	60.9 A	67.2 A
Control			93.0					98.3		
					Second crop - damage scores (1-9)					
No water	4.2 B	3.3 AB	2.9 A	2.7 A	2.4 A	5.1 B	4.2 AB	4.0 AB	3.6 A	4.2 A
With water	3.6 B	2.9 AB	2.5 A	2.2 A	2.1 A	4.8 B	3.8 AB	3.7 A	3.6 A	3.9 A
Mean	3.9 C	3.1 B	2.7 AB	2.5 A	2.2 A	4.9 C	4.0 B	3.8 AB	3.6 A	4.1 A
Control			6.3					7.2		

[1] Means followed by the same lowercase letter in the column and uppercase letter in the row are not significantly different by the Tukey test ($p < 0.05$).

Table 5. Means[1] of maize grain yield (kg ha[1]) in response to combinations of the treatment factors water inside the whorls (no or with), spray sets (S1 to S5) and insecticide (chlorantraniliprole or chlorfenapyr) used for the damage control of *Spodoptera frugiperda*.

Treatments	First crop					Second crop				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
					Chlorantraniliprole					
No water	4,007.3	3,701.2	4,378.5	4,107.6	4,354.1	4,858.6	5,155.3	5,558.5	5,426.1	5,711.9
With water	4,140.1	4,703.7	4,608.8	4,400.2	4,760.6	5,319.9	5,049.8	5,889.0	5,697.6	5,855.8
Mean	4,073.7	4,202.4	4,493.7	4,253.9	4,557.4	5,089.3	5,102.5	5,723.8	5,561.9	5,783.8
Control			3,300.2					3,389.5		
					Chlorfenapyr					
No water	4,115.7	4,183.4	4,568.2	4,310.8	4,649.5	4,619.6	4,908.1	4,490.1	5,237.4	5,018.0
With water	4,072.4	4,486.9	4,741.6	4,619.7	4,497.7	4,710.0	5,416.3	5,132.9	5,187.1	5,037.0
Mean	4,094.0	4,335.2	4,654.9	4,465.2	4,573.6	4,664.8	5,162.2	4,811.5	5,212.3	5,027.5
Control			3,300.2					3,389.5		

[1] Means of treatments "with water" and "no water" for each spray set are non-significant ($p > 0.05$) by the Tukey test.

experiments were carried out, the means obtained for all treatments stayed below the average maize yield of the Rio Grande do Sul state (6,164 kg ha^{-1}; Conab 2016). These results are probably associated with a period of low rainfall, which coincided with the reproductive phase of the plants, the most vulnerable stage of the maize development cycle (Magalhães & Durães 2006).

Overall, the increased control rates obtained in both experiments do not justify the costs of irrigating the crop prior to insecticide spraying, solely to that end. However, when the plant demand for water coincides with the need for insecticide application, the two operations can be combined without further costs to increase the control of *S. frugiperda*. Additionally, when natural water accumulates inside the maize whorls (from rainfall or dew), the control can be increased by simply adjusting the timing of spray (moving it to early morning, for instance), or optimizing the workflow by reducing the spray volume. This alternative is especially relevant if considering that many maize growers in southern Brazil are smallholder farmers who cannot afford irrigation systems.

CONCLUSION

Insecticide sprays combined with water inside the maize whorls reduce the damages caused by *S. frugiperda* at early plant growth stages. This effect is more effective for chlorantraniliprole, in comparison with chlorfenapyr. The spray sets with 200 L ha^{-1}/20.3 psi or 250 L ha^{-1}/33.4 psi result in low damages by *S. frupiperda* in maize plants. The presence of water inside the maize whorls, whether from irrigation, dew or rainfall, enhances the control efficiency of chlorantraniliprole and chlorfenapyr to *S. frugiperda* in maize crops, especially for the *Bt*-maize studied here.

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