Management of southern corn rootworm and leafhoppers by treating seeds: field assessments in maize second crop in Southern Brazil

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Abstract
Maize productivity is highly affected by *Diabrotica speciosa* and *Dalbulus maidis* in the second crop seasons in southern Brazil. Thus, this study evaluated the effects of different systemic insecticides tested at recommended doses by seed treatment on the management of these two pest species and assessed the influence of these treatments on maize yield. For this purpose, we conducted a 2-year field experiments (2015/2016 and 2016/2017) at two locations (Chapecó and Guatambú) in Santa Catarina State, southern Brazil. The experiments were conducted under natural infestation of both pest species, with eight treatments [(Imidacloprid, thiamethoxam, imidacloprid+thiodicarb, fipronil, imidacloprid+bifenthrin, chlorantraniliprole, chlorantraniliprole+clothidian (standard used in industrial seed treatment), and a negative control (without insecticides)]. There were five replicates per treatment, totaling 40 experimental units. The results showed that seed treatment do not reduce population density of *D. maidis* after 21 days of plant emergence and injuries in the maize root system caused by *D. speciosa* larvae. In addition, insecticides via seed treatment do not affect productivity and crop yield components. Regardless of the location and year, root damage was positively correlated with diameter of the first internode and inversely correlated with grain yield. This research suggests that maize seed treatments not always provide economic benefits to farmers, such as pest reductions or yield improvements.

KeyWords *Zea mays, neonicotinoids, pyrazoles, Diabrotica speciosa, Dalbulus maidis, IPM*

Introduction

Maize (*Zea mays* L.) is an important cereal that has been largely used for animal feeding, human consumption and, more recently, to ethanol production (Ranun et al., 2014). The United States, China, and Brazil are the major maize producers in the world (FAO, 2017). In Brazil, genetically modified insect-resistant maize genotypes (e.g. *Bt* hybrids – a maize variant that has been genetically altered to express one or more proteins from the bacteria *Bacillus thuringiensis* Berliner (Eubacteriales: Baccilaceae)) have been widely used in the management of fall armyworm [*Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae)], which is considered the main pest species of maize crops in Latin America (Ribeiro et al., 2014; Burtet et al., 2017; Michelotto et al., 2017). However, non-target arthropod species gradually adapted to this condition and increased their populations [niche occupation (Virla et al., 2010)], constituting a challenge for stablished integrated pest management (IPM) programs.

The southern corn rootworm, *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae) and corn leafhopper, *Dalbulus maidis* (DeLong & Wolcott) (Hemiptera: Cicadellidae), are serious emerging pest problems of maize crops in Brazil (Ávila et al., 2013; Meneses et al., 2016; Costa et al., 2018). *D. speciosa* is a polyphagous herbivore that lives in the soil during the larval stage and is usually found in maize roots (Santos et al., 2014). *D. speciosa* feeds on corn roots and compromises the capacity of plants to absorb water and nutrients, making it less productive and more susceptible to root diseases and tipping (Capinera, 2008). On the other hand, *D. maidis* is a specialist pest species on *Zea* and relatives (Poaceae) (Bellota et al., 2018) and a vector of three maize pathogens: corn stunt spiroplasma, maize bushy stunt phytoplasma (both bacterial of the Class Mollicutes) and Maize rayado fino virus - MRFV (Oliveira et al., 2015). According to Waquil et al. (1999), yield losses caused by these diseases range from 9 to 90% depending on cultivar susceptibility and on pathogen involved.

Maize second crop in southern Brazil usually starts after early soybean or common bean crops and is characterized by intense pressures of *D. speciosa* and *D. maidis* populations, which reduce yield and compromise the economic viability of farms. In the maize second crop, the management of *D. speciosa* and *D. maidis* populations is mostly carried out by synthetic insecticides via seed treatment and sowing furrow as well as in post-emergence of the crop (adults control) (Wordell Filho et al., 2016). In seed treatment, insecticides should exhibit a residual effect between 6 and 10 weeks for an effective protection in the initial crop phase (Levine and Oloumi-Sadeghi, 1991), during the first occurrences of mollicutes and MRFV transmission (Massola Júnior et al., 1999) and more pronounced damage on maize roots by *D. speciosa* larvae (Ávila et al., 2013). However, constant changes of production systems, climatic conditions, and pest species behavior as well as the occurrence of insect-resistant populations have led to inconsistent results of this chemical control in cornfields (Tsai et al., 1990; Albuquerque et al., 2006; Cox et al., 2007; Oliveira et al., 2007; Martins et al., 2008; Oliveira et al., 2008; Santos et al., 2009).

The effect of any management strategy on pest population levels must be studied and determinations need to be made regarding the strategy efficiency for control objectives (Furlan et al., 2006). Therefore, given the increasing impact to maize inflicted by *D. speciosa and D. maidis* in the second crop in southern Brazil, this study evaluated the effect of different registered systemic insecticides tested by seed treatment on the management of these two pest species and assessed the influence of treatments on maize productivity. For that purpose, we conducted a 2-year study (2015/2016 and 2016/2017) at two municipalities (Chapecó and Guatambu) under no-till conditions in Santa Catarina State, southern Brazil.

Materials and Methods

Field sites and crop management

The experiments were conducted in the maize second crop in Chapecó (27°05'19"S, 52°38'13"W; Elevation: 658 m) and in Guatambu (27°07'55"S; 52°45'38" W; Elevation: 570m), both in Santa Catarina State, Brazil, during the 2015/2016 and 2016/2017 crop years. The soil of both areas is classified as a dystroferric red latosol (Solos do Estado de Santa Catarina, 2004) under no-tillage with the following characteristics: Chapecó [clay = 61% (w v^{-1}); pH water (1: 1) = 6.0; P = 29.3 mg dm^{-3}; K = 226.1 mg dm^{-3}; organic matter = 2.9% (m v^{-1})] and Guatambu [clay = 63% (w v^{-1}); pH water (1: 1) = 5.2; P = 16.0 mg dm^{-3}; K = 1560 mg dm^{-3}; organic matter = 2.5% (w v^{-1})]. The climate in both sites is humid subtropical, with hot summers (cfa) (Pandolfo et al., 2002).

In both sites and crop years, common bean (*Phaseolus vulgaris* L.) was the predecessor crop. Thirty days before sowing, spontaneous plants were desiccated using the herbicide glyphosate (Roundup Original®, 480 g a.i. L^{-1}) and 2,4-dichlorophenoxy acetic acid (2,4-D Nortox®, 806 g a.i. L^{-1}), at 5 and 2 L ha^{-1}, respectively. Sowing was carried out in the second half of January using the hybrid P3340 VYH Liberty Link (Pioneer®), spacing 0.8 m between rows with average sowing density of 4.8 seeds per meter.

The basic fertilization consisted of 400 kg ha^{-1} of NPK 09-33-12, according to analysis of soil from both sites. In V3 and V8 stages, two applications of glufosinate-ammonium salt herbicide (Finale®, 200 g a.i. L^{-1}) + 0.25% of soybean oil methyl ester (Aureo®, 720 g a.i. L^{-1}) adjuvant were performed at the dosage of 1.5 L ha^{-1}, in a mixture volume of 150 L ha^{-1}. The application of N under cover was done in V5-V6 stages, using 250 kg ha^{-1} of urea (45% N). For disease control, two applications (V10-V11 and R2-R3) of the fungicide picoxystrobin (200 g a.i. L^{-1}) + ciproconazol (80 g a.i. L^{-1}) (Aproach Prima®, 400 mL ha^{-1}) added with mineral oil 0.5% (Assist®, 756 g a.i. L^{-1}) were performed using a Stihl® SR 430 atomizer and a mixture volume of 300 L ha^{-1}. The other cultural treatments followed the technical recommendations for maize production in Brazil (Rosa et al., 2017), except for application of insecticides which was not carried out during the entire crop cycle.

Treatments, experimental design and analyzed variables

Table 1 shows the insecticides used for seed treatment with the respective doses and manufacturer details. The experiments were conducted under a completely randomized design with 8 treatments and 5 replicates, totaling 40 experimental units. Each experimental unit was composed of 6 rows of 5 m each, making a useful area of 24 m^2. In all treatments, the fungicides composed by fludioxonil (25 g a.i. L^{-1}) + metalaxyl-M (10 g a.i. L^{-1}) (Maxim XL®) and carbendazim (150 g a.i. L^{-1}) + thiram (350 g a.i L^{-1}) (Derosal Plus®) were added at doses of 1.5 and 3 mL kg^{-1} of seeds, respectively.

Twenty-one days after emergence (DAE), visual counting of adults of *D. speciosa* and *D. maidis* were counted visually on pre-stablished plants (5th, 10th, 15th and 20th plant of lines 3 and 4 of each plot). Plant height (distance between soil and the last expanded leaf) and the number of emerged plants in each plot were also registered. In R1 stage (flowering), pre-stablished plants (5th, 10th and 15th plants of lines 2 and 5) were collected to evaluate the damage caused by corn rootworms, using the scale proposed by Oleson et al.,

Table 1. Information on insecticides[1] used in maize seed treatment for protection against southern corn rootworm (*Diabrotica speciosa*) and corn leafhopper (*Dalbulus maidis*).

Active ingredient	Commercial brand	Dose	Manufacturer
Imidacloprid (600 g L^{-1})	Gaucho® FS	800 mL 100 kg^{-1} of seeds	Bayer S.A.
Thiamethoxam (350 g L^{-1})	Cruiser® 350 FS	120 mL 60 $thousand^{-1}$ seeds	Syngenta Proteção de Cultivos Ltda.
Imidacloprid (150 g L^{-1})+ thiodicarb (450 g L^{-1})	CropStar®	350 mL $hectare^{-1}$	Bayer S.A.
Fipronil (250 g L^{-1})	Shelter®	100 mL $hectare^{-1}$	Adama Brasil S.A.
Imidacloprid (135 g L^{-1}) + bifenthrin (165 g L^{-1})	Rocks®	1.5 L 100 kg^{-1} of seeds	FMC Química do Brasil Ltda.
Chlorantraniliprole (625 g L^{-1})	Dermacor®	72 mL 60 $thousand^{-1}$ seeds	DuPont do Brasil S.A.
Chlorantraniliprole (625 g L^{-1}) + clothianidin (600 g L^{-1})	Dermacor® + Poncho®*	48 mL 60 $thousand^{-1}$ seeds + 350 mL 100 kg^{-1} of seeds	DuPont + Bayer

[1] The insecticides were tested according to the highest dose recommended for seed maize treatment in Brazil (Agrofit, 2018);
* Standard used in the industrial seed treatment by some seed companies in Brazil.

(2005). In addition, the diameter of the first internode of each plant was measured with a digital caliper. Due to the stem elliptical shape, two measurements were made on the stem opposite sides and then the mean of the two measurements was calculated. At physiological maturation, the 2 central lines of each plot (lines 3 and 4) were collected manually to count the average number of cobs per plant and the final population of plants, and measure yield (with 13% of moisture content) and weight of one thousand seeds (WTS).

Statistical analysis

For the data analysis, firstly, we performed a pre-adjustment of model with normal distribution to the data and, afterwards, we tested the normality of residues in the Shapiro-Wilk test (Shapiro and Wilk, 1965) and the homogeneity of variances in the Bartlett test (Bartlett, 1937). When the data did not show normality and/or homoscedasticity, we proceeded to a transformation based on the method of maximum power of Box-Cox (Box and Cox, 1964). When assumptions were satisfied, the data were submitted to analysis of variance by the F test (p <0.05). When there was a significant difference between the treatments, the means were compared by the Tukey test (p <0.05). The correlation between the variables analyzed was determined using the Pearson correlation (p = 0.05).

All the analyses were carried out using the statistical software "R", version 3.4.3 (R Core Team 2017).

Results and discussion

We did not perform a joint analysis of the experiments in the different sites of cultivation and crops because the assumption of homogeneity of variances between experiments was not attained (Pimentel-Gomes, 2000). Thus, the analyses were conducted independently by site and crop year.

Regardless of the cultivation site and crop year, the insecticides tested through seed treatment did not show any influence on the crop initial population (initial stand) and average number of *D. speciosa* and *D. maidis* per plant as well as on the height of plants 21 days after maize emergence (Table 2). Despite the high natural incidence of corn leafhoppers, which varies according to the year and site, no incidence of the diseases transmitted by *D. maidis* was observed, possibly due to the low frequency of pathogens in the insect population, temporal and spatial isolation of areas in relation to other cornfields and resistance of the hybrid used.

The maize seed treatment did not show any influence on root damage (assessed by damage note scale) caused by corn rootworms and on the diameter of the first internode when assessed in full bloom of maize plants, except for Chapecó (2015/2016), where most treatments (thiametoxan, imidacloprid+thiodicarb, fipronil, imidacloprid+bifenthrin, chlorantraniliprole, chlorantraniliprole+clothianidin, all at registered doses) caused a small reduction in the diameter of the first internode (Table 3). Regardless of the site, crop year and treatment, root damage was positively correlated with diameter of the first internode (r = 0.5974; df = 158; p<0.0001) and inversely correlated with grain yield (r = -0.4490; df = 158; p<0.0001).

At physiological maturation, the tested insecticides via seed treatment did not affect the final stand (plants/hectare) and the assessed yield components (number of cobs $plant^{-1}$ and weight of one thousand seeds) as well as grain yield, regardless of the cultivation site

Table 2. Effect of different insecticides[1] via seed treatment on both initial stand and average number of *Diabrotica speciosa* plant^{-1} and *Dalbulus maydis* plant^{-1} as well as on plant height after 21 days of maize emergence

Assessment 21 days after emergence				
Treatments	**Initial stand (plants hectare^{-1})**	**No. of *D. speciosa* plant^{-1}**	**No. of *D. maidis* plant^{-1}**	**Plant height (cm)**
Chapecó 2015/2016				
Imidacloprid	56750±1015.50	0.37±0.08	0.77±0.15	81.83±1.54
Thiamethoxam	57750±2069.12	0.45±0.14	0.98±0.05	82.39±1.01
Imidacloprid+ thiodicarb	61250±1976.42	0.55±0.09	0.72±0.11	81.77±1.48
Fipronil	59000±1551.21	0.57±0.11	0.77±0.05	82.58±2.00
Imidacloprid+bifenthrin	58500±1785.36	0.22±0.07	0.92±0.13	80.66±1.97
Chlorantraniliprole	59000±1870.53	0.40±0.07	0.70±0.14	81.61±2.69
Chlorantraniliprole+clothianidin*	60250±1992.17	0.40±0.10	0.67±0.11	84.58±3.62
Control (deionized water)	59000±1075.29	0.35±0.10	0.67±0.18	83.70±1.58
F	0.657 ns	1.197 ns	0.887 ns	0.341 ns
p value	0.706	0.332	0.528	0.929
Chapecó 2016/2017				
Imidacloprid	58000±935.41	1.22±0.19	2.15±0.40	89.47±1.99
Thiamethoxam	58250±1346.29	0.70±0.15	2.60±0.70	88.81±2.02
Imidacloprid+thiodicarb	59000±918.56	0.67±0.09	1.70±0.28	85.27±1.83
Fipronil	57000±1286.95	0.87±0.19	2.52±0.23	89.12±1.72
Imidacloprid+bifenthrin	60250±1075.29	1.02±0.12	1.50±0.38	88.01±2.08
Chlorantraniliprole	57500±559.01	1.10±0.22	3.12±0.32	93.02±0.81
Chlorantraniliprole+clothianidin*	57750±1391.94	1.02±0.12	2.20±0.54	91.90±0.94
Control (deionized water)	59250±1286.95	1.10±0.06	1.67±0.45	87.01±1.72
F	0.878 ns	1.693 ns	1.587 ns	2.15 ns
p value	0.534	0.146	0.175	0.0663
Guatambu 2015/2016				
Imidacloprid	62750±728.87	0.22±0.07	0.35±0.14	82.59±3.58
Thiamethoxam	61250±883.89	0.17±0.05	0.35±0.11	81.06±5.40
Imidacloprid+ thiodicarb	62000±1159.20	0.25±0.08	0.50±0.20	80.92±2.10
Fipronil	62250±1274.75	0.30±0.10	0.62±.016	84.99±5.20
Imidacloprid+bifenthrin	60000±684.65	0.17±0.03	0.55±0.23	80.54±3.83
Chlorantraniliprole	62750±918.66	0.25±0.08	0.60±0.10	83.10±3.86
Chlorantraniliprole+clothianidin*	63000±637.38	0.20±0.06	0.67±0.22	88.96±1.97
Control (deionized water)	59750±1274.75	0.27±0.07	0.32±0.21	77.93±2.72
F	1.676 ns	0.41 ns	0.61 ns	0.776 ns
p value	0.151	0.889	0.743	0.612
Guatambu 2016/2017				
Imidacloprid	58750±1425.21	1.52±0.27	0.42±0.10	92.45±2.86
Thiamethoxam	56750±1750.00	1.65±0.45	0.62±0.14	92.30±0.94
Imidacloprid+ thiodicarb	59250±1015.50	0.95±0.23	0.60±0.06	90.70±2.07
Fipronil	56750±500.00	1.60±0.26	0.42±0.11	94.30±2.22
Imidacloprid+bifenthrin	59250±935.41	1.37±0.23	0.65±0.13	94.27±1.43
Chlorantraniliprole	60500±935.41	1.65±0.33	0.62±0.10	93.60±3.26
Chlorantraniliprole+clothianidin*	59250±935.41	1.40±0.14	0.50±0.21	96.37±1.55
Control (deionized water)	60750±1089.72	1.62±0.20	0.45±0.08	90.32±3.54
F	1.752 ns	0.609 ns	0.926 ns	0.704 ns
p value	0.132	0.744	0.50	0.668

[1] The insecticides were tested according to the highest dose recommended for seed maize treatment in Brazil (Agrofit, 2018);
* Standard used in the industrial seed treatment by some seed companies in Brazil.

and crop year (Table 3). In general, the 2016/2017 crop year had higher yields than the 2015/2016 harvest (Table 3), due to better climatic conditions (data not shown).

The use of seed treatment is a highly sophisticated strategy that has evolved into a valuable, effective, and environmentally friendly component of agricultural production practices (Munkvold et al., 2014). Despite

Table 3. Effect of different insecticides tested via seed treatment on diameter of the first internode and root damage caused by corn rootworm (assessed at full bloom) and some crop yield components evaluated at physiological maturation.

Treatments	Full bloom assessment		Physiological maturation assessment			
	Diameter of first internode (mm)	Root damage note*	Final stand (plants hectare^{-1})	Number of cobs plant^{-1}	Productivity (kg hectare^{-1})	WTS (g)**
Chapecó 2015/2016						
Imidacloprid	21.59±0.54	0.78±0.08	57750±1695.58	1.00±0.03	5844.19±624.63	257.47±5.40
Thiamethoxam	22.40±0.42	0.73±0.16	58500±2806.04	0.97±0.01	6050.35±202.63	261.16±2.80
Imidacloprid+ thiodicarb	22.23±0.47	0.57±0.07	60250±728.87	0.96±0.01	5933.49±332.79	240.20±8.92
Fipronil	21.21±0.56	0.71±0.13	57500±1311.01	0.99±0.02	5808.67±129.64	261.59±2.98
Imidacloprid+bifenthrin	22.54±0.29	0.63±0.12	59000±2031.01	0.99±0.01	6324.47±316.34	254.22±7.81
Chlorantraniliprole	22.09±0.67	0.62±0.22	59500±847.79	0.97±0.02	5791.39±260.82	260.35±4.27
Chlorantraniliprole+clothianidin	21.29±0.37	0.93±0.11	60250±1334.63	1.01±0.03	6941.68±304.22	263.57±7.24
Control (deionized water)	22.43±0.40	0.62±0.10	59500±1510.38	0.98±0.03	5866.59±230.99	250.02±6.18
F	1.231 ^{ns}	0.67 ^{ns}	0.401 ^{ns}	0.398 ^{ns}	0.398 ^{ns}	1.796 ^{ns}
p value	0.315	0.696	0.895	0.896	0.896	0.122
Chapecó 2016/2017						
Imidacloprid	22.19±0.53 a	0.40±0.11	56500±1145.64	1.02± 0.01	8915.60±342.75	296.17±8.69
Thiamethoxam	21.37±0.16 b	0.37±0.09	57500±1045.82	1.05±0.01	8945.29±114.15	288.34±3.01
Imidacloprid+ thiodicarb	21.30±0.42 b	0.20±0.01	58000±935.41	1.03±0.01	8780.64±148.85	287.83±6.17
Fipronil	21.32±0.37 b	0.38±0.08	58000±1224.74	1.04±0.01	8723.04±116.34	286.92±5.10
Imidacloprid+bifenthrin	21.42±0.19 b	0.53±0.09	58750±1530.93	1.04±0.02	8812.72±272.36	293.03±8.77
Chlorantraniliprole	21.57±0.28 b	0.38±0.06	57250±1075.29	1.04±0.02	9191.37±235.84	293.07±5.04
Chlorantraniliprole+clothianidin	21.31±0.31 b	0.29±0.07	58000±935.41	1.01± 0.02	8417.66±532.12	290.24±9.58
Control (deionized water)	22.97±0.30 a	0.33±0.04	57750±728.87	0.99± 0.03	8862.15±271.77	298.20±8.71
F	3.089	1.369 ^{ns}	0.36 ^{ns}	0.552 ^{ns}	0.613 ^{ns}	0.32 ^{ns}
p value	0.0133	0.252	0.918	0.513	0.741	0.939
Guatambu 2015/2016						
Imidacloprid	20.12±0.35	0.72±0.05	61000±918.55	1.02±0.01	6826.25±324.79	239.94±5.63
Thiamethoxam	20.02±0.49	0.66±0.09	60500±1089.72	0.93±0.02	6006.25±209.83	237.58±8.38
Imidacloprid+ thiodicarb	18.70±0.35	0.64±0.12	61500±1211.92	0.95±0.03	6053.75±191.22	230.88±2.93
Fipronil	20.32±0.68	0.63±0.07	61250±1185.85	0.95±0.02	6208.75±227.51	234.05±5.54
Imidacloprid+bifenthrin	19.71±0.81	0.57±0.12	58000±847.79	0.94±0.02	5718.75±241.72	225.83±4.89
Chlorantraniliprole	19.34±1.47	0.53±0.12	61500±1551.21	0.96±0.02	6098.75±571.73	237.96±3.21
Chlorantraniliprole+clothianidin	20.03±0.58	0.71±0.16	62750±728.87	0.95±0.03	6671.25±247.85	236.60±5.46
Control (deionized water)	19.69±0.45	0.62±0.09	61000±1211.92	0.96±0.02	6387.50±423.59	238.47±3.61
F	0.995 ^{ns}	0.334 ^{ns}	1.463 ^{ns}	1.577 ^{ns}	1.606 ^{ns}	0.818 ^{ns}
p value	0.453	0.927	0.216	0.178	0,171	0.579
Guatambu 2016/2017						
Imidacloprid	20.24±0.47	0.25±0.08	57500±2091.65	1.02±0.02	8119.61±175.58	277.90±3.82
Thiamethoxam	19.19±0.42	0.33±0.07	58500±1274.75	1.08±0.05	8000.76±382.72	274.91±3.35
Imidacloprid+ thiodicarb	20.67±0.23	0.15±0.05	58000±935.41	1.01±0.01	8177.62±264.60	277.24±6.92
Fipronil	19.98±0.88	0.29±0.09	56000±612.37	0.99±0.03	7665.89±286.29	279.42±4.22
Imidacloprid+bifenthrin	19.55±0.47	0.35±0.03	60000±1767.77	1.04±0.03	8872.74±134.80	278.32±5.18
Chlorantraniliprole	20.12±0.46	0.24±0.12	59500±1457.73	1.05±0.03	8387.31±792.29	277.65±2.10
Chlorantraniliprole+clothianidin	19.50±0.80	0.23±0.03	57000±1837.12	1.06±0.03	8363.10±267.96	286.83±4.42
Control (deionized water)	19.57±0.51	0.32±0.05	60500±1658.31	1.00±0.02	7947.03±307.20	276.02±1.86
F	0.724 ^{ns}	2.334 ^{ns}	1.035 ^{ns}	0.779 ^{ns}	1.166 ^{ns}	0.721 ^{ns}
p value	0.653	0.052	0.426	0.61	0.35	0.655

Means followed by different letters in the columns containing site and year crops indicate significant differences between treatments (Tukey test, p<0.05);
^{ns} Not significant (p>0.05);
* Root damage assessed using the scale proposed by Oleson et al (2005);
** WTS: weight of one thousand seeds;
Note: All treatments included fungicides Fludioxonil (25 g a.i. L^{-1} + Metalaxyl-M 10 g a.i. L^{-1} (Maxim XL®) and Carbendazim (150 g a.i. L^{-1}) + Thiram (350 g a.i. L^{-1}) (Derosal Plus®) at doses 1.5 and 3 mL kg of seed^{-1}, respectively.

the clear environmental and agronomic benefits of seed treatment, some factors can influence its efficacy in cornfields (Rozen and Ester, 2010), such as differences in target rootworm species, active properties and formulation of ingredients, level of insecticide solubility, insecticide placement, climate, date of planting, date of rootworm hatch, among others (Boriani et al., 2006). Our results showed that maize seed treatments did not provide economic benefits to farmers through pest reductions or yield improvements in areas where southern corn rootworm and leafhoppers are the main phytosanitary problems (mainly in Bt maize crops).

Studies carried out in the United States and Europe, where western corn rootworm [*Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae)] is the main pest species of maize, indicated that insecticide seed coatings and soil insecticides applied in-furrow may provide protection against economic damage to roots without affecting insect populations (Széll et al., 2005; Furlan et al., 2006, Wilde et al., 2007). In Serbia, Inđić et al (2014) showed that imidacloprid provides efficient protection of maize roots from *D. v. virgifera* larvae, even at half of the rate (0.36 L 100 kg^{-1} seeds) used in our study against *D. speciosa* (0.8 L 100 kg^{-1} seeds). Despite differences in pest species tolerance, soil characteristics, such as organic matter, pH, clay content and rainfall regime, have variable effects on insecticide persistence at cornfields (Levine and Oloumi-Sade, 1991) and should explain the differences observed. Moreover, a delay in the oviposition of *D. speciosa* females during the corn cycle may favor the occurrence and development of larvae as well as the persistence period of insecticides used in seed treatment. In general, the critical period of incidence of southern corn rootworm occurs between 30 and 70 d after plant emergence (Gassen, 1996).

In the management of *D. maidis*, Oliveira et al. (2008) reported that imidacloprid and thiamethoxan were the most effective insecticides to control corn leafhoppers, providing a control efficiency of *D. maidis* adults equal to or greater than 70% until the 30^{th} day of evaluation, after 4-24 h of leafhoppers confining. In a greenhouse bioassay, imidacloprid and thiamethoxan controlled adults of *D. maidis* up to 50%, until the 30^{th} day, and reduced disease incidence and damage to growth and grain production of the infected plants exposed to infective leafhoppers 2 d after emergence (Oliveira et al., 2007). On the other hand, only treatments with thiamethoxam (42 g a.i. ha^{-1}) applied to seeds, along with thiamethoxam (21.15; 28.20 or 35.25 mL ha^{-1}) + lambdacyhalothrin (15.90; 21.20 or 26.50 g a.i. ha^{-1}) applied by foliar spraying, presented a minimum efficiency of 80% in the control of all assessed pests (Albuquerque et al., 2006). Conversely, our 2-year field experiments in two sites showed no effect of different seed treatments against leafhoppers 21 d after maize emergence.

Therefore, integrated strategies should be designed for *D. speciosa* management including maize crop rotation with other non-host crops, soil application of insecticides at planting, use of Bt rootworm transgenics, and foliar insecticide treatments. Management strategies for *D. maidis* should include the synchronism of the planting date, use of cultivars/hybrids resistant to transmittable diseases (corn stunt, maize bushy stunt and maize rayado fino virus), chemical control of insect vector in crop post-emergence and elimination of maize volunteer plants during offseason and alternative hosts (Oliveira et al., 2013). Notwithstanding, more accurate information is necessary for a safer recommendation of these strategies within an integrated pest management program and crop management.

Conclusions

In maize second crop in southern Brazil, the use of insecticides in seed treatment does not reduce the population density of *D. maidis* after 21 days of plant emergence and the injury caused by *D. speciosa* larvae to the maize root system. In addition, the use of insecticides via seed treatment does not affect yield and crop yield components.

Acknowledgements

This study was possible due to the technical support of the Cepaf Maize Group (Epagri/Cepaf), offered by Claudis Martha Horbach, Elias José Pinto, Leandro Zanchetta, Luiz Dalcin, Marcelo Rigo, Roque José Sulzbacher and Valter Augostinho Scussiato. We also thank the Brazilian National Counsel of Technological and Scientific Development (CNPq, Process number 445518/2014-6) for financial support and José Carlos Madalóz (Pionner® Brazil) for seed supply.

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