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Forum

Field and Forage Crops

Value of Neonicotinoid Insecticide Seed Treatments in Mid-South Corn (*Zea mays*) Production Systems

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Abstract

Neonicotinoid seed treatments are one of several effective control options used in corn, *Zea mays* L., production in the Mid-South for early season insect pests. An analysis was performed on 91 insecticide seed treatment trials from Arkansas, Louisiana, Mississippi, and Tennessee to determine the value of neonicotinoids in corn production systems. The analysis compared neonicotinoid insecticide treated seed plus a fungicide to seed only with the same fungicide. When analyzed by state, corn yields were significantly higher when neonicotinoid seed treatments were used compared to fungicide only treated seed in Louisiana and Mississippi. Corn seed treated with neonicotinoid seed treatments yielded 111, 1,093, 416, and 140 kg/ha, higher than fungicide only treatments for Arkansas, Louisiana, Mississippi, and Tennessee, respectively. Across all states, neonicotinoid seed treatments resulted in a 700 kg/ha advantage compared to fungicide only treated corn seed. Net returns for corn treated with neonicotinoid seed treatment were $1,446/ha compared with $1,390/ha for fungicide only treated corn seed across the Mid-South. Economic returns for neonicotinoid seed treated corn were significantly greater than fungicide-only-treated corn seed in 8 out of 14 yr. When analyzed by state, economic returns for neonicotinoid seed treatments were significantly greater than fungicide-only-treated seed in Louisiana. In some areas, dependent on year, neonicotinoid seed treatments provide significant yield and economic benefits in Mid-South corn.

Key words: neonicotinoid, seed treatment, corn

Corn production in the Mid-South region of the United States has changed considerably in recent years. Higher yielding hybrids and favorable market prices have led to increased corn production (USDA-NASS 2015). Corn is typically the first major agronomic crop planted in the Mid-South region of the United States, beginning around early-March and extending through mid-April (Cartwright et al. 2003, Purcell et al. 2003). Advantages of planting corn early include minimal harvest conflict with other row crops during the growing season, reduced irrigation costs, reduced season-long exposure to insects and diseases, and timely harvest (Espinoza 2008). Corn seed and seedlings are more vulnerable to a number of early season pests at earlier planting dates compared to later planting dates due to cooler temperatures and slow growth rate. These insects can reduce plant densities and early season growth, thereby reducing overall yield potential (Higgins 1994). Therefore, many producers throughout the Mid-South have adopted at-planting insecticides to help manage early season pests of corn to reduce the risk of stand loss and replants.

Early season insect pests observed in Mid-South corn production include seedcorn maggot, *Delia platura* (Meigen); white grubs, *Phyllophaga* spp.; Japanese beetle, *Popillia japonica* (Newman); southern corn rootworm, *Diabrotica undecimpunctata* howardi (Barber); wireworms, *Melanotus* spp., and other spp.; lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller); corn root aphid, *Aphis middletoni* (Thomas); greenbug, *Schizaphis graminum* (Rondani); corn leaf aphid, *Rhopalosiphum maidis* (F.); bird cherry-oat aphid, *Rhopalosiphum padi* (L.); billbugs, *Sphenophorus* spp.; chinch bug, *Blissus leucopterus leucopterus* (Say); black cutworm, *Agrotis ipsilon* (Hufnagel); and sugarcane beetle, *Euetheola humilis rugiceps* (LeConte) (Steffey et al. 1999, Akin et al. 2012) . Wireworms and corn rootworms are key pests of corn seed and seedlings in many regions of the United States, feeding on the primary and secondary roots. Root tissue loss causes instability in the corn plant and can cause the plant to lodge (Higgins 1994). Also, damaged corn roots are less efficient for water and nutrient uptake resulting in stunted plant growth and yield losses. These are exacerbated in dry soil conditions and can be detrimental to corn yield potential across the United States (Jeschke et al. 2011).

Numerous at planting insecticides are currently labeled for corn production. At planting insecticide options consist of neonicotinoid seed treatments and in-furrow or banded applications of organophosphate or pyrethroid insecticides. Early season insect management techniques have progressively changed within the past two decades. In 2008 for instance, in-furrow applications were already being replaced with the use of insecticide treated corn seed (Elbert et al. 2008). Nearly all corn seed is currently treated with a neonicotinoid insecticide (Haire 2014). Imidacloprid (Gaucho 600, Bayer CropScience, Research Triangle Park, NC), thiamethoxam (Cruiser 5FS, Syngenta Crop Protection, Greensboro, NC), and clothianidin (Poncho 600, Bayer CropScience) are the neonicotinoid seed treatments; however, clothianidin is most commonly applied to corn seed. Neonicotinoid insecticides are systemic and move through the plant when applied as a seed treatment to corn. This provides a high degree of efficacy on some early season insects feeding on seedling corn both below and above the soil surface (Hopwood et al. 2012). The use of insecticide seed treatments across the United States is higher in corn than other crops relative to the percentage of hectares treated. Over 18 million ha of corn were treated with a neonicotinoid insecticide seed treatment between 2009 and 2011 (Brassard 2012). Since 2011, around 80% of corn seed is coated with a neonicotinoid seed treatment in the United States (Douglas and Tooker 2015).

Longevity in the soil also plays a major role in the efficacy of these insecticides on the early season complex of corn pests (Maienfisch et al. 2001), and there are alternative at-planting insecticides for corn that are effective against early season pests. Bifenthrin (Capture LFR, FMC Corporation, Philadelphia, PA), chlorpyrifos (Lorsban 15G, Dow AgroSciences, Indianapolis, IN), and terbufos (Counter 15G, BASF Corporation, Research Triangle Park, NC) are the most common at-planting non-neonicotinoid insecticides used. Pyrethroids, organophosphates, and neonicotinoids provide similar control of the early season pest complex in corn (Pike et al. 1993, Sloderbeck et al. 1996, Wilde 1997, Tharp et al. 2000, Kuhar et al. 2003). However, most producers have opted to use the neonicotinoid seed treatments because they are almost universally preapplied by seed companies, they are generally effective and easy to use, and they pose less risk to pesticide handlers compared with organophosphates and pyrethroid alternatives.

The use of neonicotinoids and their potential association with declines in pollinator populations have raised questions about the future use of this class of chemistry (vanEngelsdorp et al. 2009, Spivak et al. 2011). While many trials have been previously conducted on neonicotinoid seed treatments in corn, there is a shortage of published data on the value of neonicotinoid insecticide seed treatments in corn production systems in the Mid-South. Therefore, an analysis of previous research with neonicotinoid insecticide seed treatments across the Mid-South region was conducted to determine their value to corn production systems in the region.

Methods and Materials

Data were requested from university cooperators at the University of Arkansas, Louisiana State University, Mississippi State University, and the University of Tennessee. These data were from small plot replicated trials conducted from 2001 to 2014 and were used to evaluate the impact of neonicotinoid insecticide seed treatments on corn yield.

All trials included a neonicotinoid seed treatment with a base fungicide package compared to seed treated with the same base fungicide package. The neonicotinoids were imidacloprid, thiamethoxam, or clothianidain. Neonicotinoid seed treatments were applied to corn seed at the currently labeled rates ranging from 0.13 to 1.34 mg ai/kernel. The other important criteria for including a study in the analysis were that they were planted within the recommended planting window for each region. All available unpublished data from university research and extension specialists within each state that met the above criteria were included in the analysis.

The experimental design for each individual trial was a randomized complete block design with four to six replications. Plot sizes ranged from 4 to 16 rows wide by 12.2–30.5 m long and planted on 76.2–101.6 cm centers. Measurements to evaluate insect control included but were not limited to actual insect counts, damage ratings, stand counts, plant height, plant vigor, etc. These measurements varied considerably based on insect species occurrence, corn growth stage, location, and year. Timings and methods of evaluation were not consistently recorded across trials and therefore are not included in this analysis. In most instances trials were infested with insect populations that consisted of a complex of multiple species occurring simultaneously or in sequence throughout seed and seedling growth. The most common insects observed included various soil insects, most commonly southern corn rootworm, *Diabrotica undecimpunctata howardi* (Barber). This species infests seedling corn after planting and prior scouting is not effective (Isley 1929). As a result, no thresholds have been established in the southern United States (Buntin et al. 1994). Other insects observed included billbug, lesser cornstalk borer, and chinch bug.

All trials included in this analysis were harvested at physiological maturity. Grain weight and moisture content were recorded and all yields were corrected to 15% moisture and converted to kilograms of grain per hectare. Yield was the only dependent variable that was recorded in a consistent manner across all trials. Trials were conducted at multiple locations within each state. Eight trials were conducted at two locations in Arkansas, including the Northeast Research and Extension Center (Keiser, AR) and Southeast Research and Extension Center (Rowher, AR). Forty-nine trials were conducted in Louisiana at the LSU AgCenter Macon Ridge Research Station (Winnsboro, LA). Twenty-four trials were conducted in Mississippi at multiple locations including the R.R. Foil Plant Science Research Center (Starkville, MS), the Delta Research and Extension Center (Stoneville, MS), the Brown Loam Experiment Station (Raymond, MS), as well as several producer fields throughout the state. Ten trials were conducted in Tennessee at the West Tennessee Research and Education Center (Jackson, TN) and at the Milan Research and Education Center (Milan, TN).

Yield and economic data were analyzed with a mixed model analysis of variance (SAS Institute 2015). Year, location, and replication nested within year and location were considered random effects, and treatments were considered fixed effects for overall analysis. Analysis was also performed on yield and economic data by year and state. Residual plots and normal distribution plots were generated to verify that data met ANOVA assumptions. Means were separated using Fisher's protected LSD procedure at the 0.05 level of significance. Insecticide seed treatment prices were obtained through personal correspondence from Bayer CropScience. The costs of the insecticide seed treatments were accounted for during economic analyses (Table 1) and based on a plant population of 79,040 plants/ha. Economic data were determined using yield for each treatment and the price of corn seed (harvested grain) in that particular year and state based on data from the National Agricultural Statistics Service (Table 2, USDA-NASS 2015). To calculate gross economic returns, the yield of each treatment was multiplied by the average price received (Table 2) for the state and year of that trial. The cost of the seed treatment was then subtracted from the gross economic return to give the net economic return for each treatment.

Results and Discussion

In total, 91 trials were conducted over 14 yr in Arkansas, Louisiana, Mississippi, and Tennessee. There were significant differences in mean corn yields among treatments where a neonicotinoid seed treatment was applied (F= 32.95; df = 3, 672; P < 0.01). Imidacloprid, thiamethoxam, and clothianidin seed treatments resulted in significantly greater yields compared to fungicide only treatment but did not differ significantly from each other. Corn yields of plots planted with imidacloprid, thiamethoxam, or clothianidin treated seed averaged 9,406, 9,137, and 9,245 kg/ha, respectively, compared with 8,528 kg/ha for plots that received the fungicide-only treatment. Because no differences were observed between imidacloprid, thiamethoxam, or clothianidin, a separate analysis was conducted where data for imidacloprid, thiamethoxam, and clothianidin seed treatments were pooled and comparisons were made between corn with a neonicotinoid seed treatment and corn without a neonicotinoid seed treatment. Averaged across all trials, corn yields of plots that received a neonicotinoid seed treatment were significantly greater than that of plots where a neonicotinoid seed treatment was not used (F = 95.55; df = 1, 670; P < 0.01; Table 3), with a mean yield difference of 700 kg/ha. There were also significant differences in mean net economic returns between treatments (F = 19.82; df = 1, 662; P < 0.01; Table 3). The neonicotinoid seed treatment resulted in a $56/ha return higher compared with corn seed where no insecticide seed treatment was used.

When analyzed by state for the years 2001 to 2014, there were significant differences in mean corn yields among treatments for Louisiana (F = 219.6; df = 1, 315; P < 0.01) and Mississippi (F = 5.71; df = 1, 190; P < 0.01). In those states, corn planted with a neonicotinoid seed treatment produced higher yields than corn planted with no insecticide seed treatment (Table 4). The use of a neonicotinoid seed treatment resulted in 1,094 and 401 kg/ha more yield in Louisiana and Mississippi, respectively, compared where one was not used. Significant differences in net economic returns were observed between corn that received a neonicotinoid seed treatment and corn with no insecticide seed treatment only in Louisiana (F = 104.02; df = 1, 302; P < 0.01; Table 4). No differences in mean net economic returns between treatments were observed in Arkansas (F = 0.94; df = 1, 91.1; P = 0.33), Mississippi (F = 1.85; df = 1, 189; P = 0.17), or Tennessee (F = 0.01; df = 1, 74.6; P = 0.92). When analyzed by year, there was a significant difference in yields between seed treated with a neonicotinoid and those only treated with fungicide in 8 out of 14 yr (Table 5). Corn yield in 2001, 2002, 2004, 2005, 2006, 2007, 2008, and 2014 was significantly greater where a neonicotinoid seed treatment was used compared with where no

Table 1. Neonicotinoid insecticide seed treatment price used to calculate net return (Bayer CropScience)

Insecticide rate (mg ai per seed)	Insecticide seed treatment price/ha
0.125	$8.40
0.13	$8.72
0.16	$10.74
0.22	$14.77
0.25	$16.80
0.32	$21.49
0.34	$22.82
0.35	$23.51
0.45	$30.23
0.50	$33.59
0.60	$40.31
0.64	$42.98
1.05	$43.97
1.125	$47.13
1.25	$52.36
1.34	$56.12

Insecticide seed treatment price used to calculate net return based on 79,040 corn plants/ha.

Table 2. Values used to calculate the net economic returns of using an insecticide seed treatment within each year and state

Year	Arkansas		Louisiana		Mississippi		Tennessee	
	$/kg[a]	kg/ha[b]	$/kg[a]	kg/ha[b]	$/kg[a]	kg/ha[b]	$/kg[a]	kg/ha[b]
2001	0.08	9,101	0.09	9,289	0.08	8,160	0.08	8,285
2002	0.10	8,411	0.09	7,595	0.09	7,532	0.10	6,716
2003	0.09	8,787	0.09	8,411	0.09	8,348	0.09	8,222
2004	0.09	8,787	0.10	8,473	0.10	8,348	0.09	8,787
2005	0.08	8,222	0.09	8,536	0.09	7,909	0.08	8,160
2006	0.11	9,164	0.11	8,787	0.11	6,716	0.12	7,846
2007	0.15	10,608	0.15	10,231	0.14	9,289	0.15	6,653
2008	0.17	9,540	0.18	9,038	0.18	8,787	0.18	7,406
2009	0.15	9,289	0.14	8,285	0.15	8,034	0.14	9,289
2010	0.18	9,415	0.19	8,787	0.17	8,536	0.19	7,344
2011	0.25	8,850	0.24	8,473	0.25	8,034	0.26	8,222
2012	0.27	11,172	0.27	10,859	0.27	10,356	0.29	5,335
2013	0.20	11,675	0.20	10,859	0.20	11,047	0.19	9,792
2014	0.16	11,737	0.16	11,486	0.17	11,612	0.15	10,545

[a]Average price received for corn seed within each year and state (USDA-NASS 2001–2014).
[b]Average corn yields within each year and state (USDA-NASS 2001–2014).

insecticide seed treatment was used (Table 6). Also, significant economic returns were observed in the same years, where there was a significantly greater corn yield (Table 6).

Numerous experiments have investigated the impact of neonicotinoid seed treatments on corn yield in the United States (Wilde et al. 2004, Mullin et al. 2005, Kabaluk and Ericsson 2007). In general, those studies showed reduced insect numbers and improved yields with a neonicotinoid seed treatment in corn. For instance, Wilde et al. (2004) showed that systemic seed treatments resulted in reduced early season infestations of seedling insect pests and higher yields. Mullin et al. (2005) found that imidacloprid, thiamethoxam, and clothianidin at rates used commercially provided 90% mortality of corn rootworm within 1 d in laboratory bioassays. Also, Kabaluk and Ericsson (2007) found increases in stand density and seedling growth where clothianidin was present. These data indicate that an insecticide/fungicide seed treatment can, in fact, provide control of early season insect pests feeding on corn seedlings throughout different regions of the United States.

Out of the 91 trials conducted across the Mid-South, 82% displayed a numerically positive yield response when a neonicotinoid seed treatment was used from 2001 to 2014. The overall average corn yield response to neonicotinoid seed treatments was 700 kg/ha. When net economic returns were calculated across the Mid-South

Table 3. Mean yields (SEM) and net economic returns (SEM) of corn treated with a neonicotinoid seed treatment compared with those not treated with insecticide across the Mid-South Region from 2001 to 2014

Treatment	Yield (kg/ha)	Net return ($/ha)
Untreated[a]	8,528 b (140.8)	1,390 b (32.3)
Neonicotinoid[b]	9,228 a (103.9)	1,446 a (23.5)
$P > F$	<0.01	<0.01

Means within a column and treatment followed by the same letter are not significantly different, $P < 0.05$.

[a]Untreated seed did not have an insecticide seed treatment but were treated with fungicides.

[b]Neonicotinoid treated seed were treated with imidacloprid, thiamethoxam, or clothianidin plus the same fungicides used in the untreated treatment.

Table 4. Mean (SEM) yields and net economic returns (SEM) of corn treated with a neonicotinoid seed treatment compared with those not treated with insecticide within each state in the Mid-South from 2001 to 2014

Year	Treatment	kg/ha	$/ha
Arkansas	Untreated[a]	8,990 a (386.0)	1,732 a (117.1)
	Neonicotinoid[b]	9,101 a (266.1)	1,669 a (64.6)
Louisiana	Untreated[a]	7,845 b (161.7)	1,088 b (32.6)
	Neonicotinoid[b]	8,939 a (128.2)	1,188 a (26.2)
Mississippi	Untreated[a]	9,035 b (271.1)	1,678 a (56.4)
	Neonicotinoid[b]	9,451 a (197.7)	1,719 a (40.8)
Tennessee	Untreated[a]	10,263 a (532.2)	1,905 a (85.8)
	Neonicotinoid[b]	10,403 a (367.1)	1,903 a (65.7)

Means within a column and state followed by the same letter are not significantly different, $P < 0.05$.

[a]Untreated seed did not have an insecticide seed treatment but were treated with fungicides.

[b]Neonicotinoid treated seed were treated with either midacloprid, thiamethoxam, or clothianidin plus the same fungicides used in the untreated treatment.

Table 5. ANOVA table for corn yields and net economic returns across the Mid-South for each year (2001–2014)

Year	*F*-value; df; *P*-value	
	Yield	Returns
2001	50.21; 1, 7; 0.01	23.99; 1, 7; 0.01
2002	36.45; 1, 11; 0.01	30.67; 1, 11; 0.01
2003	3.26; 1, 17.4; 0.08	1.27; 1, 17.3; 0.27
2004	48.41; 1, 65.8; 0.01	28.95; 1, 65.7; 0.01
2005	52.28; 1, 29.4; 0.01	18.57; 1, 27.3; 0.01
2006	48.49; 1, 65; 0.01	32.20; 1, 65; 0.01
2007	70.45; 1, 53.2; 0.01	38.84; 1, 53.2; 0.01
2008	25.44; 1, 85.4; 0.01	16.07; 1, 85.6; 0.01
2009	0.08; 1, 52.3; 0.77	0.04; 1, 52.3, 0.83
2010	0.75; 1, 76.2; 0.38	0.02; 1, 76.1; 0.87
2011	0.72; 1, 64.4; 0.40	1.64; 1, 64.3; 0.20
2012	1.69; 1, 56.4; 0.19	0.05; 1, 56.4; 0.81
2013	2.27; 1, 43; 0.13	0.40; 1, 43; 0.52
2014	14.18; 1, 39.4; 0.01	6.51; 1, 39.4; 0.01

Table 6. Mean (SEM) yields and net economic returns (SEM) of corn treated with a neonicotinoid seed treatment compared with those not treated with insecticide for each year across the Mid-South region from 2001 to 2014

Year	Treatment	kg/ha	$/ha
2001	Untreated[a]	6,091 b (282.1)	528 b (24.4)
	Neonicotinoid[b]	7,698 a (228.8)	624 a (19.8)
2002	Untreated[a]	4,081 b (378.3)	386 b (35.7)
	Neonicotinoid[b]	6,055 a (184.6)	541 a (16.2)
2003	Untreated[a]	7,315 a (331.4)	691 a (31.3)
	Neonicotinoid[b]	7,988 a (241.1)	729 a (21.8)
2004	Untreated[a]	8,474 b (246.4)	814 b (23.2)
	Neonicotinoid[b]	9,695 a (138.5)	904 a (12.5)
2005	Untreated[a]	7,774 b (269.9)	689 b (23.9)
	Neonicotinoid[b]	8,983 a (150.4)	754 a (15.5)
2006	Untreated[a]	8,006 b (518.2)	893 b (59.8)
	Neonicotinoid[b]	9,483 a (329.6)	1,022 a (38.3)
2007	Untreated[a]	11,104 b (264.8)	1,661 b (39.6)
	Neonicotinoid[b]	12,150 a (191.2)	1,778 a (28.5)
2008	Untreated[a]	7,106 b (184.4)	1,258 b (33.5)
	Neonicotinoid[b]	8,014 a (132.2)	1,387 a (23.7)
2009	Untreated[a]	9,348 a (657.8)	1,355 a (95.2)
	Neonicotinoid[b]	9,466 a (485.3)	1,343 a (70.3)
2010	Untreated[a]	8,352 a (490.2)	1,511 a (89.5)
	Neonicotinoid[b]	8,569 a (370.0)	1,518 a (68.1)
2011	Untreated[a]	8,821 a (389.5)	2,190 a (157.0)
	Neonicotinoid[b]	8,524 a (287.7)	2,079 a (152.4)
2012	Untreated[a]	6,458 a (364.8)	1,769 a (179.7)
	Neonicotinoid[b]	6,666 a (257.8)	1,780 a (178.3)
2013	Untreated[a]	11,290 a (430.0)	2,228 a (156.7)
	Neonicotinoid[b]	11,670 a (309.1)	2,260 a (154.1)
2014	Untreated[a]	10,686 b (419.6)	1,799 b (136.4)
	Neonicotinoid[b]	11,412 a (294.9)	1,883 a (135.5)

Means within a column and year followed by the same letter are not significantly different, $P < 0.05$.

[a]Untreated seed did not have an insecticide seed treatment but were treated with fungicides.

[b]Neonicotinoid treated seed were treated with imidacloprid, thiamethoxam, or clothianidin plus the same fungicides used in the untreated treatment.

region; 79% of the locations had a numerically positive return from using neonicotinoid seed treatments. Our analysis was conducted with the goal of determining the value of neonicotinoid insecticides as a seed treatment in corn. These 91 trials were analyzed from the production years of 2001 to 2014 and data indicate that neonicotinoid seed treatments provided a yield and economic benefit in corn production systems throughout the Mid-South region a majority of the time. However, significant differences in net economic returns were only observed in Louisiana when analyzed by state for 8 out of 14 yr when analyzed by year. Neonicotinoid seed treatments are currently used almost universally on corn hectares planted in the Mid-South. This high adoption rate can be attributed to better stand establishment, more vigorous seedling growth, yield advantages, risk management, and unavailability of untreated corn seed. Although no insect or plant growth parameters are reported, a complex of insect pests were observed in these studies that included southern corn rootworm, various other soil insects, billbug, lesser cornstalk borer, sugarcane beetle, and chinch bug. Field corn does not have the ability to compensate as well from early season stand loss compared to cotton and soybeans, making early season insect control a necessity (Bailey and Pedigo 1986). Sampling below ground insects prior to planting is difficult and not always predictive of risk in the Mid-South region. Also, there are no rescue treatments available in corn to manage soil insect pests that may occur after the crop has been planted. Because corn is planted early and often in cool soils, initial emergence and growth can be slow. Above ground symptoms of seed or root damage from the soil insect complex is often not immediately visible and may not be observed until several weeks after emergence. Research has shown yield losses associated with delayed planting of as much as 103.0 kg/ha/d after optimal planting dates (Pendleton and Egli 1969). Even timely replants can result in substantial losses in yield for producers. For these reasons, most producers utilize at planting insecticides or seed treatments to protect against stand loss and promote early season growth and vigor throughout the Mid-South region. Recent increases of cover crops in Mid-South production systems have led to a new approach in early season insect management in various crops. This increase of cover crop hectares is largely motivated to reduce water runoff and soil erosion, and when combined with a no-till practice, it significantly reduces runoff and soil erosion (Langdale 1983, Hartwig 1988). Also, cover crops can prevent weed species emergence that can become a problem in no-till corn (Hartwig 1977, 1989). However, increase in below ground pests will likely be associated with the use of cover crops. At-planting insecticides are recommended for control of early season insect corn pests in situations where living vegetation persists within a few weeks of planting (Catchot et al. 2017).

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