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Corn Response to POST-Applied HPPD-Inhibitor Based Premix Herbicides with In-Furrow and Foliar-Applied Insecticides

Lawrence E. Steckel, Scott D. Stewart, and Sandy Steckel*

In recent years injury has been reported in numerous Tennessee corn fields treated with an organophosphate (OP) insecticide and either a mesotrione- or tembotrione-based herbicide premix. Research was conducted with the objective to determine if corn treated with an in-furrow application of chlorpyrifos or a foliar application of chlorpyrifos or bifenthrin , or a combination of in-furrow and foliar treatment, would be more predisposed to injury when either a premix of *S*-metolachlor, mesotrione, and glyphosate (meso premix) or a premix of tembotrione plus thiencarbazone (tembo premix) was applied. The main effects of insecticide or herbicide, the two-way interaction of insecticide by herbicide, and the three-way interaction of herbicide by insecticide by application type of insecticide were all significant for injury as well as yield. When chlorpyrifos was used both in-furrow and foliarly on corn treated with the tembo premix, injury was increased to 56% and yield was reduced 58% compared with corn that had not been treated with that insecticide. This use pattern of chlorpyrifos utilized in-furrow followed by chlorpyrifos applied foliarly with the tembo premix essentially doubled the injury (29 to 56%) and increased yield loss from 41% where chlorpyrifos was only utilized foliarly to 49% when chlorpyrifos was applied in-furrow and foliarly. Corn injury was negligible (< 6%) and yield was similar where the meso premix was examined in combination of both types of insecticide applications. This study clearly demonstrated the phytotoxic interaction between these two herbicide premixes and the OP insecticide chlorpyrifos. Therefore, growers need to be mindful of which herbicides are utilized when OP insecticides are used for insect management.

Nomenclature: Bifenthrin; chlorpyrifos; mesotrione; mesotrione and glyphosate (meso premix); *S*-metolachlor, tembotrione; tembotrione plus thiencarbazone (tembo premix); corn, *Zea mays* L. 'DeKalb DKC 64–83 VT Triple Pro', DeKalb DKC 61–88 VT Triple Pro'.

Key words: Corn, herbicide and insecticide corn injury, herbicide and insecticide interaction.

En años recientes en Tennessee, han habido numerosos reportes de daño en maíz (*Zea mays*) tratado con un insecticida organophosphate (OP) y pre-mezclas con los herbicidas mesotrione o tembotrione. Se realizó una investigación con el objetivo de determinar si el maíz tratado con una aplicación de chlorpyrifos en el surco o una aplicación foliar de chlorpyrifos o bifenthrin, o una combinación de tratamientos en el surco y foliar, estarían más predispuestos al daño cuando se aplica una premezcla de *S*-metolachlor, mesotrione, y glyphosate (premezcla meso) o una premezcla de tembotrione más thiencarbazone (premezcla tembo). Los efectos principales de insecticida o herbicida, la interacción en dos direcciones de insecticida por herbicida, y la interacción en tres direcciones de herbicida por insecticida por tipo de aplicación del insecticida fueron todos significativos para daño y rendimiento. Cuando se usó chlorpyrifos en el surco y foliarmente en maíz tratado con la premezcla tembo, el daño incrementó a 56% y el rendimiento se redujo 58% al compararse con el maíz que no tuvo tratamiento con insecticidas. Este uso de chlorpyrifos utilizado en el surco seguido de chlorpyrifos aplicado foliarmente con la premezcla tembo esencialmente duplicó el daño (29 a 56%) e incrementó la pérdida de rendimiento de 41% donde se aplicó chlorpyrifos solamente foliarmente a 49% cuando se aplicó chlorpyrifos en el surco y foliarmente. El daño en el maíz fue casi no detectable (<6%) y el rendimiento fue similar donde se examinó la premezcla meso en combinación con ambos tipos de aplicación de insecticida. Este estudio demostró claramente la interacción fitotóxica entre estas dos premezclas de herbicidas y el insecticida OP chlorpyrifos. Por esta razón, los productores necesitan ser conscientes acerca de cuales herbicidas son utilizados cuando se usan insecticidas OP para el manejo de insectos.

Field corn growers in Tennessee are commonly using premixes of HPPD-(4-hydroxyphenylpyruvate dioxygenase inhibitor)inhibiting herbicides in corn (L. Steckel personal experience). The two most commonly used premixes are the combination of *S*-

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metolachlor, mesotrione, and glyphosate under the trade name of Halex GT®, and the premix of tembotrione plus thiencarbanzone methyl sold under the trade name Capreno® (L. Steckel personal experience) (Anonymous 2014a,b).

Weed and insect pest infestations in corn are common in Tennessee (S. Stewart and L. Steckel personal experience). Despite the use of insecticide seed treatments, sporadic but damaging insect infestations from seed and seedling pests may still occur in corn. A good example is the sugarcane beetle [*Euetheola rugiceps* (LeConte)] (Coleoptera: Scarabaeidae). Adult sugarcane beetles emerge with warmer spring temperatures and may attack seedling corn. They damage corn by boring into the outer walls of the stalk just below the soil surface making a large, ragged wound that destroys tender tissue and may extend more than halfway through the stalk (Henderson et al. 1958; Phillips and Fox 1933). Young plants are typically more susceptible to plant mortality from feeding injury than older plants. Severe infestations often reduce crop stands to the point where replanting is necessary. Currently, some commercial seed treatments provide protection against sugarcane beetles but are only satisfactory when higher than typical rates are used (Stewart and McClure 2014).

In parts of the Midwest, populations of western corn rootworm, (*Diabrotica virgifera virgifera* LeConte) (Coleoptera: Chrysomelidae), have developed resistance to some *Bacillus thuringiensis* (Bt) corn proteins (Gassmann et al. 2011), and insecticide seed treatments may not adequately control this pest (e.g., Cox et al. 2007). Foliar sprays have very limited efficacy against seed and seedling pests such as sugarcane beetles or corn rootworms because these insects are found underground. One recommendation is the use of in-furrow granular or liquid insecticides at planting, such as the OP insecticide chlorpyrifos (Stewart and McClure 2014).

However, there have been a number of studies that documented crop injury from the interaction between herbicides and insecticides in the 1990s, most notably, the sulfonylurea (SU) herbicides with OP insecticides. Morton et al. (1993) explored interactions between the SU herbicide nicosulfuron applied POST and terbufos insecticide applied in-furrow to field and sweet corn, *Zea mays* L. var. *saccharata* Sturtev. L. H. Bailey. They found that nicosulfuron applied alone did not injure either type of corn but when corn was previously treated in-furrow with terbufos, yield was reduced. Kwon and Penner (1995) observed a reduction in corn plant height and grain yield in two field corn hybrids treated with either nicosulfuron or primisulfuron (SU herbicides) and terbufos applied in-furrow. In a study of the effect of insecticides applied in-furrow or as a T band or surface band, it was found that all the insecticides tested (terbufos, phorate, fonofos, chlorpyrifos, chloerethoxyfos, tefluthrin, andcarbofuran) increased corn injury of nicosulfuron (Morton et al. 1994). Rahman and James (1993) and Kwon and Penner (1995) also found that terbufos, the more commonly used corn rootworm insecticide, enhanced injury from nicosulfuron more than other insecticides. The basis for the injury from terbufos and primisulfuron was reported to be reduced metabolism of the SU herbicide in the corn plants previously exposed to terbufos (Frazier et al. 1993). One study reported injury from the HPPD-inhibiting herbicide mesotrione with OP insecticides. In that study it was revealed that corn treated with mesotrione after in-furrow or T-band application of terbufos and chlorpyrifos resulted in 34 and 19% corn injury, respectively, but that this injury did not result in yield loss (Jewett et al. 2008).

In recent years corn injury has been reported in Tennessee from numerous fields treated with an insecticide applied to control sugarcane beetle and either a mesotrione- or tembotrione-based herbicide premix (L. Steckel and S. Stewart). There has been some documentation of the SU herbicides nicosulfuron and primisulfuron interacting with OP insecticides to cause corn injury and one study documenting mesotrione interacting with OP insecticides causing corn injury. However, there has been no documentation of crop injury from the interaction of the newer generation of corn herbicide premixes that contain HPPD-inhibiting tembotrione or mesotrione as one of their components with insecticides. Hence, research was conducted with an objective to determine if corn treated with an in-furrow application of chlorpyrifos or a foliar application of chlorpyrifos or bifenthrin, or a combination of these treatments, would be more predisposed to injury when either a premix of *S*-metolachlor, mesotrione, and glyphosate (meso

Table 1. Pesticide-formulated products and application.

Herbicide	Formulated product name	Application
		g ai ha^{-1}
Chlorpyrifos[a]	Lorsban	1,120
Bifenthrin[b]	Brigade	105
(Tembotrione + thiencarbazone) + glyphosate[c]	Capreno + Roundup PowerMax	(725) + 867[e]
Mesotrione + *S*-metolachlor + glyphosate[d]	Halex GT	2,215

[a] Dow AgroSciences LLC, Indianapolis, IN, www.dowagro.com; [b] FMC Corporation, Philadelphia, PA, www.fmc.com; [c] Bayer Crop Sciences, Research Park, NC, www.cropscience.bayer.com; [d] Syngenta Crop Protection, Inc., Greensboro, NC, www.syngentacropprotection.com; [e] Glyphosate rate in acid equivalent.

premix) or a premix of tembotrione plus thiencarbazone (tembo premix) was applied.

Materials and Methods

Field experiments were conducted in 2011 and 2012 at the West Tennessee Research and Education Center in Jackson, TN (35.37181°N, 88.51179°W). On May 19, 2011, a genetically modified corn hybrid, 'DeKalb DKC 64–83 VT Triple Pro' (Monsanto Co., St. Louis, MO) containing insecticide toxins Cry1A.105, Cry2Ab2, and Cry3Bb1 was planted on a Lexington silt loam soil (fine-silty, mixed, thermic, Typic Paleudalfs) with organic matter of 1.0% and pH of 6.2. On May 22, 2012, DeKalb DKC 61–88 VT Triple Pro (Monsanto) with similar Bt traits was planted on a similar soil. These are Bt transgenic hybrids that provide excellent control of tunneling caterpillars such as southwestern corn borer (*Diatraea grandiosella* Dyar) and European corn borer (*Ostrinia nubilalis* Hübner) (Lepidoptera: Crambidae), respectively (Abel et al. 2000; Buntin et al., 2004; Castro et al., 2004). This technology also has good activity on corn earworm [*Helicoverpa zea* (Boddie)], (Lepidoptera: Noctuidae), fall armyworm [*Spodoptera frugiperda* (J. E. Smith)], (Lepidoptera: Noctuidae), and western corn rootworm (Buntin et al. 2004; Hardke et al. 2010; Huang et al. 2006; Vaughn et al. 2005). The use of these hybrids and seed with a base treatment of clothianidin (Poncho® 250, 0.25 mg aiseed^{-1}, Bayer CropScience, Research Triangle Park, NC) reduced potential confounding effects of insect injury.

In each year of the study, corn was planted no-till into soybean stubble from the previous year. Plots were planted with a John Deere 7000 (Deere and Co., Moline, IL) planter with a seeding rate of 69,000 seed ha^{-1} at a planting depth of 3.8 cm. Row spacing was 76 cm and plots were two rows by 12.2 m long in 2011 and 2 rows by 9.1 m long in 2012. According to the University of Tennessee recommendations, the soil at the sites was fertilized with 200 kg N ha^{-1} with a grain yield target of 10,000 kg ha^{-1} (McClure 2010).

The study consisted of two POST herbicides, and two in-furrow and two foliar insecticide treatments. Herbicide treatments included a premix of mesotrione plus *S*-metolachlor plus glyphosate (Halex GT®, Syngenta Crop Protection, Inc., Greensboro, NC); and a premix of tembotrione plus thiencarbazone (Capreno, Bayer CropScience) tank-mixed with glyphosate (Roundup PowerMax®, Monsanto). In-furrow insecticide treatments included no in-furrow insecticide and granulated chlorpyrifos (Lorsban® 15G, Dow AgroSciences LLC, Indianapolis, IN). Herbicide and insecticide use rates are provided in Table 1. Treatments were arranged in a two by two by two factorial design with herbicide treatments as main plots and in-furrow insecticide and foliar insecticide treatments as subplots. In-furrow insecticide treatments were applied with insecticide boxes calibrated to deliver 730 g ha^{-1} of granulated chlorpyrifos. POST herbicides were applied over the top of corn treated with or without granular chlorpyrifos at the V3 corn stage(3rd leaf collar visible). On the same day of POST herbicide application, foliar-applied insecticides (chlorpyrifos or bifenthrin) were applied according to the treatment plan. The mesotrione-based premix was applied with a nonionic surfactant (Tennessee Farmers Co-Op, 200 Waldron Road, Box 243, LaVergne, TN) at 0.25% v/v. The tembo-based tank mix was applied with crop oil concentrate (Tennessee Farmers Co-Op) at 1.25% v/v. Both tank mixtures were applied with a spray grade ammonium sulfate at a rate of 10 g L^{-1} of water.

Herbicides were applied with a tractor-mounted PTO (power takeoff)-driven sprayer calibrated to deliver 103 L ha^{-1} at a pressure of 276 kPa using 80015VS flat fan nozzles (Spraying Systems Co.,

Table 2. The main effects and two-way interaction between herbicide and in-furrow insecticide and foliar-applied insecticides.

	Injury 30 DAA[a,b]		Grain yield	
Herbicide				
Pr > F	0.0296		0.0001	
Soil-applied				
Pr > F	0.0259		0.0001	
Foliar-applied				
Pr > F	0.0048		0.0001	
	In-furrow insecticide			
	None	Chlorpyrifos	None	Chlorpyrifos
Herbicide				
Pr > F	0.0001		0.0848	
	Foliar-applied insecticide			
	Bifenthrin	Chlorpyrifos	Bifenthrin	Chlorpyrifos
Herbicide				
Pr > F	0.0001		0.0001	

[a] Visual determination of corn biomass reduction in treated plot compared with a nontreated control.

[b] Abbreviations: DAA, days after application; Pr>F, probability of a greater F value.

North Avenue, Wheaton, IL) spaced 48 cm apart. Foliar insecticides were applied with a CO_2-charged backpack sprayer calibrated to deliver 164 L ha^{-1} at a pressure of 276 kPa using 80015VS flat fan nozzles (Spraying Systems) spaced 48 cm apart.

Corn injury was visually evaluated and rated on a 0 to 100 scale (0 being no injury and 100 being complete death of all plants). The visual injury was assessed by noting the difference in chlorosis and growth reduction between treatments. Visual evaluations were made 14 and 30 d after application (DAA) of foliar treatments. The total number of living plants was counted in the two rows of each plot for the length of the plot at 15 DAA. Data were analyzed using Proc Mixed procedure in SAS (version 9.1, SAS, Cary, NC).

The experimental design was a randomized complete block design with four replications. Each year was considered a different environment that was sampled at random (Carmer et al. 1989). Assigning year as a random effect will determine if treatment means are different over a collection of environments. Years, blocks (nested within years), and effects associated with these factors were considered random in the model. Treatments were selected as fixed effects. Fisher's protected LSD was used to detect treatment differences at the $P < 0.05$ level.

Results and Discussion

Results were not different across years ($P = 0.5367$). Therefore, data were pooled across years. Corn injury assessed 30 DAA was different between the main effect of the two herbicide premixes when averaged across either the soil- or foliar-applied insecticide applications ($P = 0.0296$) (Table 2). This injury was reflected in corn yield ($P < 0.0001$). The main effect of chlorpyrifos applied in-furrow compared to no in-furrow treatment averaged over herbicide premix and foliar-applied insecticide was different ($P = 0.0259$). This injury was also reflected in corn yield ($P < 0.0001$). The main effect of the foliar-applied bifenthrin vs chlorpyrifos insecticide averaged across in-furrow insecticide and herbicide premix was different ($P = 0.0048$). This corn injury was carried out to yield where the chlorpyrifos treatment reduced yield ($P < 0.0001$). The interaction effect between in-furrow insecticide and herbicide treatments on corn injury and grain yields were significant ($P < 0.0001$). None of the observed corn injury in this two-way interaction resulted in yield loss ($P = 0.0848$).

However, overarching all the significant main effects and two-way interactions, corn injury ($P = 0.0114$) and yield ($P = 0.0198$) were affected by the three-way interaction (Table 3) where the herbicide premix was examined in combination with or without in-furrow chlorpyrifos and either bifenthrin or chlorpyrifos foliar-applied. Only results of the three-way interaction will be discussed as the results of the main effects and two-way interactions are affected by all three variables (Le and Johnson 2008).

Corn injury was negligible (< 6%) and yield was similar where the meso premix was examined in combination with both types of insecticide applications. The level of injury was less than what was reported (19%) by Jewett et al. (2008), where chlorpyrifos applied in-furrow was followed by mesotrione POST. However, our study agrees with the results of Jewett et al. (2008) where the injured corn recovered and no yield loss was recorded. These results support the Halex GT label and showed that the premix of *S*-metolachlor, mesotrione, and glyphosate is safe to use with bifenthrin. However, this study as well as Jewett et al. (2008) would suggest that the Halex GT label is conservative with respect to using that herbicide with chlorpyrifos applied in-furrow as it does injure corn but yield loss is not likely.

Table 3. The effects of herbicide by soil-applied by foliar-applied insecticide interactions on crop injury and grain yield.

Insecticide	Injury 30 DAA[a,b]				Grain yield			
In-furrow	None		Chlorpyrifos		None		Chlorpyrifos	
Foliar	Bifenthrin	Chlorpyrifos	Bifenthrin	Chlorpyrifos	Bifenthrin	Chlorpyrifos	Bifenthrin	Chlorpyrifos
Herbicide	%				kg ha^{-1}			
Mesotrione + *S*-metolachlor + glyphosate	6 a	5 a	6 a	3 a	9,450 bc	9,700 c	9,770 c	9,260 bc
Tembotrione + thiencarbazone	3 a	29 c	18 b	56 d	9,830 c	6,670 b	7,700 b	4,100 a
Pr > F	0.0114				0.0198			

[a] Visual determination of corn injury.

[b] Abbreviations: DAA, days after application; Pr > F, probability of a greater F value.

The tembo premix was evaluated in combination with or without in-furrow and foliar insecticide. Corn injury was increased when chlorpyrifos was utilized, regardless of application type. When chlorpyrifos was used both in-furrow and foliarly on corn treated with the tembo premix, injury was increased to 56% and yield was reduced 58% compared to corn that had not been treated with that insecticide. This use pattern of chlorpyrifos utilized in-furrow followed by chlorpyrifos applied foliarly with the tembo premix essentially doubled the injury (29 to 56%) and increased yield loss from 41% when chlorpyrifos was only utilized foliarly to 49% when chlorpyrifos was applied in-furrow and foliarly.

These results illuminate, with the severe corn injury and yield loss, the reason why the Capreno label states that chlorpyrifos should not be used with it in the same season. These data also document the reports from growers who have experienced severe injury where the tembo premix was used in combination with chlorpyrifos.

This research would suggest that the findings of some previous studies on corn injury from combinations of herbicides and OP insecticides also apply to the more recently developed HPPD-inhibitor–based herbicide premixes widely used in Tennessee today. Our results clearly demonstrated the phytotoxic interaction between these two herbicide premixes and the OP insecticide chlorpyrifos. Corn has been grown on more acres in the southern United States in recent years to the point that hard-to-control seedling corn insects may be a more frequent issue. The data generated by this research suggest that growers need to be mindful of which herbicides are utilized when OP insecticides are used for insect management. Future research should examine which herbicide or herbicides in this premix are the cause for the injury.

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