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Corn Response to Mesotrione as Affected by Soil Insecticide, Application Method, and Rate

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Abstract

Mesotrione is a selective herbicide used for preemergence and postemergence weed control in corn. A better understanding of the interactions between mesotrione and soil insecticides is needed to avoid risk of serious corn injury. Field trials were conducted to examine corn injury from mesotrione applied postemergence as affected by insecticide type, application method, and application rate. Corn injury from mesotrione applied postemergence at 0.19 lb ai/acre was 34, 19, and 13% in corn treated with terbufos, chlorpyrifos, and tefluthrin, respectively. In a separate study, corn injury was greater in corn treated with terbufos than clorpyrifos. Injury from mesotrione increased when terbufos was applied at two times the typical rate. Corn injury was higher when terbufos was applied in-furrow versus T-band. In each study, corn recovered rapidly from mesotrione injury with no reduction in corn yield. The extent of corn injury observed in these trials indicate that the combination of foliar-applied mesotrione following soil-applied terbufos should be avoided.

Introduction

Herbicide-insecticide interactions have the potential to cause corn (*Zea mays* L.) injury and yield loss. For example, the use of organophosphate (OP) soil insecticides in combination with sulfonylurea herbicides results in corn injury and yield losses up to 54% (2,5,6,8,9,10). OP insecticides reduce the rate at which the cytochrome P450 enzyme metabolizes sulfonylurea herbicides, resulting in a higher concentration of the herbicide remaining in the plant longer than if no insecticide was used (1,4).

The type of soil insecticide, as well as the application method, affects the extent of corn injury from sulfonylurea herbicides. Previous research indicated that soil-applied terbufos followed by a postemergence (POST) application of a sulfonylurea herbicide *caused* more severe corn injury than other soil-applied OP insecticides followed by a POST application of a sulfonylurea (2,3). In-furrow applications of terbufos resulted in more severe corn injury from sulfonylurea herbicides than band applications of terbufos (2,10). Uptake and translocation of the insecticide within corn by plants may be the primary factor contributing to injury from the interaction of an OP insecticide and sulfonylurea herbicide. The availability of soil-applied terbufos for uptake by corn is influenced by soil pH, type, organic matter, and moisture (8,9).

Mesotrione was registered in 2001 for preemergence (PRE) and POST weed control in corn. It is a member of the benzoylcyclohexane-1,3-dione herbicide family. Mesotrione is a chemical derivative of the herbicidal phytotoxin leptospermone, produced naturally by the bottle brush plant (*Callistemon citrinus*) in Australia (7). Mesotrione competitively inhibits the enzyme P-hydroxyphenyl pyruvate dioxygenase (HPPD) (12). Corn is tolerant to both sulfonylurea herbicides and mesotrione as a consequence of selective metabolism involving the cytochrome P450 enzyme (7,13). An understanding of the potential interaction between mesotrione and soil-applied OP insecticides is needed to avoid risk of serious corn injury.

The objectives of this research were: (i) to characterize the interaction of mesotrione and soil-applied insecticides in the field; and (ii) to determine the effect of insecticide, application method, and application rate on corn injury from mesotrione.

General Procedures for Two Field Trials in Two Years

Field experiments were conducted in 2002 and 2003 in East Lansing, MI. Experiments were conducted as a randomized complete block design with four replications. Individual plots were 3-ft wide and 35-ft long, consisting of four rows spaced at 30 inches. Corn was planted with a White 5100 Seed Boss (Agco Corp., Duluth, GA) four-row, forced-air planter with attached granular soil insecticide applicators. Insecticides were applied at the time of corn planting, either in-furrow or in a 7-inch T-band ahead of the press wheel. Herbicides were applied with a tractor-mounted, compressed air sprayer. The sprayer was equipped with 8003 flat-fan nozzles spaced 30 inch apart and delivered 20 gal/acre at 30 psi with a ground speed of 3.5 mph. Boom height was set at 18 inch above the soil surface or plant canopy. POST mesotrione treatments were applied in a water carrier with crop oil concentrate and 28% liquid nitrogen fertilizer at 1 and 2.5% (v/v), respectively, at the 4- to 5-leaf corn stage. Since the goal of the study was to evaluate crop injury, the experimental area was kept free of weeds through the use of PRE and POST herbicides. In 2002, atrazine and mesotrione were applied PRE over the entire study area at 1.5 lb ai/acre and 0.19 lb ai/acre, respectively. The study also received a POST application of glyphosate at 0.38 lb ai/acre and ammonium sulfate at 2% w/w /ha. In 2003, one study (study 1) was also treated with a POST application of bentazon + atrazine (0.75 + 0.75 lb ai/acre) and crop oil concentrate (1% v/v) to control escaping broadleaf weeds. In 2003, atrazine was applied PRE at 1.5 lb ai/acre over both study sites. Root ratings for corn rootworm (*Diabrotica virgifera virgifera* LeConte) damage were not taken in the trials because the studies were conducted in rotated fields, in an area lacking the rotation-resistant variant.

Data from the experiments were subjected to analysis of variance and means were separated using Fisher's protected LSD test (a = 0.05).

Interactions of Mesotrione and Soil-applied Insecticides

2002 field study. An initial screen was conducted to determine if there was crop injury when mesotrione was combined with two commonly used OP soil insecticides. The study was conducted at the Agronomy Farm at Michigan State University (MSU) on a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualf) with 2.8% OM and a pH of 6.1. The study was planted on 7 May with the glyphosate resistant hybrid 'Dekalb 44-46' at 72,900 seeds/ha at a depth of 2 inches. The soil insecticide treatments were: chlorpyrifos (Lorsban 15G, OP) (Dow AgroSciences LLC, Indianapolis, IN) t-banded (1.31 lb/acre, a 1× rate); terbufos (Counter 20CR, OP) (BASF AG, Global Engineering, Ludwigshafen, Germany) t-banded (1.30 lb/acre, a 1× rate); and terbufos in-furrow (1.30 or 3.90 lb ai/acre, a 1× or 3× rate), respectively. Soil insecticide was applied only to the third and fourth row of each plot. Mesotrione was applied POST (0.10 lb ai/acre) to all four rows of these four treatments on 7 June. A fifth treatment had terbufos applied at 3.90 lb ai/acre to the third and fourth rows of each plot with no post application of mesotrione, allowing for an evaluation of possible injury from a high rate of soil insecticide alone. Prior to the POST application of mesotrione, corn injury was evaluated visually on 6 June for injury from the PRE application of mesotrione. Corn injury was then evaluated visually at 3, 5, and 14 days after the POST (DAPO) application on a scale of 0% (no injury) to 100% (complete death). Corn injury symptoms on the plant included chlorosis (whitening of tissue) and some stunting. Injury symptoms became less apparant with new corn growth (Fig. 1). Corn was harvested on 10 October with a small-plot combine in row 2 for post-mesotrione injury and in row 3 for post-mesotrione plus insecticide injury.

Fig. 1. Corn injury from a 2× rate of terbufos (2.60 lb ai/acre) applied in-furrow at planting followed by a 1× rate of mesotrione (0.10 lb/acre) applied POST (2003).

Injury from mesotrione interactions with soil insecticides. No injury was observed from a 3× rate of terbufos alone, without mesotrione. Also, no injury was observed from the PRE application of mesotrione to insecticide-treated rows of any treatment. Minimal (5%) corn injury was observed 3 and 5 DAPO to rows treated with mesotrione alone applied POST. This injury declined to 0% by 14 DAPO. The decline in corn injury was related primarily to the emergence of new leaves exhibiting no injury symptoms. There was little additional injury when mesotrione was applied POST to corn treated with chlorpyrifos showing 6 to 7% injury through 14 days of rating (Table 1). However, the POST application of mesotrione in combination with terbufos in-furrow resulted in statistically significant injury within 3 DAPO. Mesotrione injury to corn with a labeled rate of terbufos (1.30 lb ai/acre) in-furrow was significantly greater than injury to corn with a T-band application. This difference was evident until at least 5 DAPO. Corn injury was greatest with mesotrione POST following a 3× rate of terbufos in furrow (3.90 lb/acre), reaching 49% at 5 DAPO.

Table 1. Crop injury 3, 5, and 14 days after a POST (DAPO) application of mesotrione[w] to corn previously treated with different OP soil insecticide rates and application placement, 2002.

Soil insecticide	**Rate** (lb ai/acre)	**Application placement**[x]	**Percent Crop Injury**[z], **DAPO**		
			3	**5**	**14**
chlorpyrifos	1.31	T	7 a	6 a	7 a
terbufos	1.30	T	15 b	19 b	18 b
terbufos	1.30	IF	24 c	34 c	21 b
terbufos	3.90	IF	31 d	49 d	27 c

[w] Mesotrione applied POST at 0.10 lb/acre with crop oil concentrate and 28% liquid nitrogen fertilizer at 1 and 2.5% (v/v), respectively. Entire study area treated with atrazine plus mesotrione PRE at 1.5 lb/acre and 0.19 lb/acre, respectively.

[x] Soil insecticides were applied at planting in-furrow (IF) or T-banded (T).

[z] Crop injury rated visually on a 0 to 100% scale. Within each column, numbers followed by different letters indicate significant differences at $P < 0.05$.

Injury from mesotrione alone POST was no longer evident by 14 DAPO, while corn treated with mesotrione POST following OP soil insecticides showed significant injury 14 DAPO (Table 1). In general, injury symptoms decreased over time, but were still up to 27% at 14 DAPO. Despite the crop injury, yield did not differ significantly among treatments (*data not shown*).

Effects of Insecticide, Rate, & Application Method on Mesotrione Corn Injury

2003 field study. After injury was confirmed in 2002, studies were expanded in 2003 to assess the impact of mesotrione rate (Study 1) and insecticide product, rate, and application method (Study 2) on corn injury. Both were planted with 'Dekalb 44-46' at 31,000 seeds/acre at a depth of 2 inches.

Study 1 was conducted on the MSU Crop and Soil Science Farm on an Aubbeenaubbee-Capac sandy loam (fine loamy, mixed, mesic Aeric Ochraqualf) with 1.8% organic matter (OM) and a pH of 5.7. The study was planted on 21 May. The study consisted of nine treatments evaluating combinations of three soil insecticides and three mesotrione rates in a factorial arrangement. The soil insecticide treatments were chlorpyrifos (1.31 lb ai/acre), terbufos (1.30lb ai/acre), and tefluthrin (Force 3G, pyrethroid) (Bayer Crop Science, Research Triangle Park, NC) (0.17 lb ai/acre). As in 2002, insecticide was applied in-furrow only to two rows of each four-row plot. The three mesotrione treatments were 0.0, 0.10, and 0.20 lb ai/acre, applied POST on 16 June to all four rows in each plot. Corn injury was evaluated visually at 7, 14, and 28 DAPO, on a scale of 0% (no injury) to 100% (complete death). Yield was taken on 9 October with a small-plot combine on rows 2 and 3.

Study 2 was conducted on the MSU Entomology Farm on a Capac loam (fine loamy, mixed, mesic Aeric Ochraqualf) with 2.2% OM and a pH of 6.6. The study was planted on 22 May. The study consisted of ten treatments evaluating mesotrione injury as affected by OP soil insecticide rate and application method. Treatments consisted of mesotrione (0.10 lb ai/ acre) applied POST on 17 June to plots treated with either terbufos (1.30 and 2.60 lb ai/acre) or chlorpyrifos (1.31 and 2.61 lb ai/acre). Each insecticide was applied either in-furrow or T-band, to give a total of 8 treatments. All four rows in each plot were treated with mesotrione and soil insecticide. The two final treatments were mesotrione alone (POST at 1×), and an untreated weed-free check. Corn injury was evaluated visually at 6, 13, and 21 DAPO. Yield was taken on 18 October with a small-plot combine on rows 2 and 3.

Factors affecting mesotrione injury to corn. In Study 1 in 2003, no crop injury was observed in plots with soil insecticide alone. When mesotrione was applied POST on corn without soil insecticide, injury was observed with a 1× rate within 7 DAPO. However, this injury was barely detectable by 14 DAPO.

When mesotrione was applied POST at a 2× rate on corn treated with the pyrethroid tefluthrin, there was minimal injury within 7 DAPO, which further declined by 14 DAPO (Table 2). These results are consistent with data reported by (2) who observed no interaction between tefluthrin and the sulfonylurea herbicide nicosulfuron. When mesotrione was applied POST following chlorpyrifos, there was a slight, but statistically significant increase in injury with a 1× rate of mesotrione at 14 DAPO, and with a 2× rate of mesotrione at both 7 and 14 DAPO. By 28 DAPO, however, injury declined to 2%, even with a 2× rate of mesotrione. When mesotrione was applied POST on rows treated with terbufos, injury increased significantly (Table 2). Given an equivalent mesotrione rate, at 7 DAPO, injury was 2.5 times greater on rows treated with mesotrione following terbufos (18% and 34%, respectively), compared to mesotrione following tefluthrin (5% and 13%, respectively), respectively. AT 14 DAPO, injury remained significantly greater with mesotrione plus terbufos and by 28 DAPO, injury was still elevated with a 2× rate of mesotrione following terbufos, although the injury had diminished greatly from 7 DAPO (Table 2). Injury with mesotrione plus terbufos was significantly higher than with mesotrione following chlorpyrifos or tefluthrin, given the same mesotrione rate, through 28 DAPO. When the mesotrione rate was doubled (0.20 lb/acre), crop injury increased following OP soil insecticides (19% and 34% injury with chlorpyrifos and terbufos, respectively) compared to tefluthrin (13%). As in 2001, injury symptoms decreased over time and were barely visible at 28 DAPO. As in 2002, despite the crop injury, there were no significant differences in yield among the treatments (*data not shown*).

Table 2. Crop injury 7, 14, and 28 days after a POST (DAPO) application of various rates of mesotrione[x] (M) to corn previously treated with different OP soil insecticides (I), 2003.

Soil insecticide	Insecticide rate (lb ai/acre)	Mesotrione rate (lb ai/acre)	Percent Crop Injury[y] DAPO		
			7	14	28
tefluthrin	0.17	0	0 a	0 a	0 a
		0.10	5 b	0 a	0 a
		0.20	13 c	7 b	3 b
chlorpyrifos	1.31	0	0 a	0 a	0 a
		0.10	7 b	4 b	1 a
		0.20	19 d	10 c	2 b
terbufos	1.30	0	0 a	0 a	0 a
		0.10	18 d	10 c	2 b
		0.20	34 e	21 d	4 c

[x] Mesotrione applied POST with crop oil concentrate and 28% liquid nitrogen fertilizer at 1 and 2.5% (v/v) respectively.

[y] Crop injury rated visually on a 0 to 100% scale. Within each column, numbers followed by different letters indicate significant differences at $P < 0.05$.

In study 2 in 2003, background injury from mesotrione alone was 8%, 6 DAPO, dropping to 1% or less 13 DAPO (Table 3). When mesotrione was applied to plots treated with chlorpyrifos, injury was two times greater compared to background mesotrione injury 6 DAPO. However, this injury declined from 3 to 7% at 13 DAPO, and 2% at 21 DAPO. Neither application method nor rate of chlorpyrifos significantly changed injury among any of the rating timings. When mesotrione was applied to plots treated with terbufos, at 6 DAPO injury was 3 to 5 times greater compared to background mesotrione injury (8%). Injury dropped over time, however by 21 DAPO injury in 3 of the 4 mesotrione plus terbufos treatments (8 to 11%) was still significantly greater than injury in plots treated with mesotrione plus chlorpyrifos (2%). Terbufos application method and rate of chlorpyrifos did impact injury. In-furrow applications and 2× rates often caused greater injury than T-Band applications or a 1× rate. Despite the injury noted in the study, yields did not differ significantly among any of the treatments (*data not shown*).

Table 3. Crop injury 6, 13, and 21 days after POST (DAPO) resulting from a POST application of mesotrione[w] to corn treated with OP soil insecticide using two methods and two rates, 2003.

Pesticide	Rate (lb ai/acre)	Application method[x]	DAPO 6	DAPO 13	DAPO 21
			Crop Injury[x] (%)		
Weed-free check[y]	—	—	0 a	0 a	0 a
mesotrione[z]	—	—	8 b	1 ab	0 a
chlorpyrifos	1.31	IF	14 bc	3 abc	2 a
	1.31	T	14 bc	3 abc	2 a
	2.61	IF	15 c	5 bcd	2 a
	2.61	T	18 cd	7 cd	2 a
terbufos	1.30	IF	25 de	12 ef	9 cd
	1.30	T	23 de	8 de	6 ab
	2.60	IF	38 f	18 g	11 d
	2.60	T	30 e	14 fg	8 bc

[w] Mesotrione applied POST at 0.10 lb ai/ acre with crop oil concentrate and 28% liquid nitrogen fertilizer 1 and 2.5% (v/v), respectively.

[x] Crop injury rated visually on a 0 to 100% scale. Within each column, numbers followed by different letters indicate significant differences at $P < 0.05$.

[y] Weed free check had neither mesotrione applied POST or soil insecticide applied to treatment.

[z] Mesotrione applied POST; no soil insecticide applied to treatment.

Conclusions

Corn injury was minimal from POST-applied mesotrione in the absence of soil-applied insecticide. A POST application of mesotrione to corn treated with chlorpyrifos resulted in significant corn injury in two of three studies. Mesotrione applied POST to corn treated with terbufos resulted in severe corn injury in all studies regardless of insecticide rate or application method. Injury was significantly greater with an increased rate of either mesotrione or terbufos. Injury 21 DAPO also was significantly greater when terbufos was applied in-furrow, rather than T-band. Similar results have been reported with sulfonylurea herbicide interactions with insecticides (2,3,10). As with sulfonylurea herbicides, inhibition of the cytochrome P450 enzyme by OP insecticides is likely the physiological basis for the observed interaction with mesotrione.

Data indicate the risk of severe corn injury for POST-applied mesotrione following soil-applied terbufos is very high. In our trials, corn was able to recover sufficiently to avoid statistically significant yield loss. However, experience with corn injury from other herbicides suggest that the level of corn injury observed in these studies may result in yield losses under certain environmental conditions. Mesotrione has the same site of action as isoxaflutole, inhibiting the HPPD enzyme. In another study, isoxaflutole injury caused 14% corn yield loss from 39% injury and 33% yield loss from 72% injury (11). Soil-applied chlorpyrifos followed by a POST application of mesotrione increased corn injury temporarily but did not cause severe, persistent injury.

Literature Cited

1. Baerg, R. J., Barrett, M., and Polge, N. D. 1996. Insecticide and insecticide metabolite interaction with cytochrome P450 mediated activities in maize. Pestic. Biochem. Physiol. 55:10-20.
2. Bailey, J. A., and Kapusta, G. 1994. Soil insecticide and placement influence corn (*Zea mays*) tolerance to nicosulfuron. Weed Technol. 8:598-606.
3. Biediger, D. L., Baumann, P. A., Weaver, D. N., Chandler, J. M., and Merkle, M. G. 1992. Interaction between primisulfuron and selected soil-applied insecticides in corn (*Zea mays*). Weed Technol. 6:807-812.

4. Diehl, K. E., Stoller, E. W., and Barrett, M. 1995. In vivo and in vitro inhibition of nicosulfuron metabolism by terbufos metabolites in maize. Pestic. Biochem. Physiol. 51:137-149.
5. Frazier, T. L., Nissen, S. J., Mortensen, D. A., and Meinke, L. J. 1993. The influence of terbufos on primisulfuron adsorption and fate in corn (*Zea mays*). Weed Sci. 41:664-668.
6. Kapusta, G., and Krausz, R. F. 1992. Interaction of terbufos and nicosulfuron on corn (*Zea mays*). Weed Technol. 6:999-1003.
7. Mitchell, G., Bartlett, D. W., Faser, T. E. M., Hawkes, T. R., Holt, D. C., Townson, J. K., and Wichert, R. A. 2001. Mesotrione: A new selective herbicide for use in maize. Pest Manag. Sci. 57:120-128.
8. Morton, C. A., Harvey, R. G., Kells, J. J., Lueschen, W. E., and Fritz, V. A. 1991. Effect of DPX-V9360 and terbufos on field and sweet corn (*Zea mays*) under three environments. Weed Technol. 5:130-136.
9. Morton, C. A., Harvey, R. G., Kells, J. J., Landis, D. A., Lueschen, W. E., and Fritz, V. A. 1993. In-furrow terbufos reduces field and sweet corn (*Zea mays*) tolerance to nicosulfuron. Weed Technol. 7:934-939.
10. Rahman, A. R., and James, T. K. 1993. Enhanced activity of nicosulfuron in combination with soil-applied insecticides in corn (*Zea mays*). Weed Technol. 7:824-829.
11. Sprague, C. L., Penner, D., and Kells, J. J. 1999. Weed control and *Zea mays* tolerance as affected by timing of RP-201772 application. Weed Sci. 47:375-382.
12. Sutton, P., Richards, C., Buren, L., and Glasgow, L. 2002. Activity of mesotrione on resistant weeds in maize. Pest Manag. Sci. 58:981-984.
13. Vencill, W. K., ed. 2002. Herbicide Handbook, 8th Edn. Weed Science Society of America, Lawrence, KS.