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Evaluating Postemergence Herbicides, Safener, and Tolerant Hybrids for Corn Response

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Crop safety is one of the many considerations when deciding which POST herbicide to use. This research examined relative corn injury as a result of POST herbicides and the effect of including the safener isoxadifen, the choice of a sensitive or tolerant hybrid, or both. The herbicides included commercial combinations of dicamba, diflufenzopyr, nicosulfuron, rimsulfuron, and thifensulfuron, all at twice the labeled rate. Isoxadifen reduced twisting from dicamba plus diflufenzopyr but not with dicamba plus rimsulfuron. Isoxadifen had negligible effect on chlorosis. In general, rimsulfuron plus thifensulfuron caused the most corn stunting, whereas including isoxadifen or using a tolerant hybrid often reduced corn injury. In two of the four years, treatments with rimsulfuron plus thifensulfuron resulted in yield reductions. Although using products with isoxadifen or selecting tolerant hybrids may influence injury, herbicide selection will have the greatest effect on corn injury.
Nomenclature: Dicamba; diflufenzopyr; nicosulfuron; rimsulfuron; thifensulfuron; isoxadifen; corn, *Zea mays* L.
Key words: Area under the curve, cumulative stunting.

La seguridad en el cultivo es una de las muchas consideraciones cuando se decide cuáles herbicidas POST y a qué dosis se usarán estos. Esta investigación examinó el daño relativo del maíz como resultado de herbicidas POST y el efecto de incluir isoxadifen como antídoto, el efecto de la selección de híbridos sensibles o tolerantes, y la combinación de estos dos factores. Los herbicidas incluyeron combinaciones comerciales de dicamba, diflufenzopyr, nicosulfuron, rimsulfuron, y thifensulfuron, todos al doble de las dosis de etiqueta. Isoxadifen redujo el enrollamiento causado por dicamba más diflufenzopyr, pero no con dicamba más rimsulfuron. Isoxadifen tuvo un efecto mínimo sobre la clorosis. En general, rimsulfuron más thifensulfuron causaron el mayor retraso en el crecimiento del maíz, mientras que el incluir isoxadifen o usar un híbrido tolerante frecuentemente redujo el daño al maíz. En dos de los cuatro años, los tratamientos con rimsulfuron más thifensulfuron resultaron en reducciones en el rendimiento. Aunque el usar productos con isoxadifen o seleccionar híbridos tolerantes podría influenciar el nivel daño, la selección de los herbicidas tendrá el mayor efecto en el daño que sufrirá el maíz.

Weed competition can reduce corn yields (Gower et al. 2003; Myers et al. 2005; Soltani et al. 2016). Growers have relied on various weed control methods to reduce or eliminate weed competition in the pursuit of maximizing their yields, with herbicides currently being the most widely used method. Although most growers attempt to control weeds with a herbicide application at or near planting time, many fields are treated with a POST herbicide. Many factors go into the decision on when and which POST herbicide(s) to use, with crop safety being an important consideration. Farmers and crop advisors need information to make informed decisions on balancing weed control with crop safety. Most herbicide trials focus on weed control, and although crop injury is routinely rated in these trials, the effect of crop injury on corn yield is often confounded by the presence of weeds (Nurse et al. 2007).

A few research trials have examined hybrid corn response to POST herbicides in the absence of weeds, but they evaluated only one or two active ingredients, or grain yield was not one of the parameters measured (Bunting et al. 2004a; Doohan et al. 1998; Green 1998; Green and Ulrich 1993). As a result, there is lack of information comparing multiple herbicides, herbicide combinations, or both on corn safety and yield.

Safeners, sometimes called antidotes or protectants, are products included as a portion of the formulated herbicide to improve crop safety. Isoxadifen has improved corn safety for acetolactate

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synthase (ALS)–inhibiting herbicides and 4-hydroxy-phenyl-pyruvatedioxygenase (HPPD)–inhibiting herbicides (Bunting et al. 2004a; Williams and Pataky 2010). Isoxadifen is also used with plant growth regulator herbicides.

POST herbicides have been extensively evaluated in the mid-Atlantic region of the United States, and they have consistently provided commercially acceptable weed control. These herbicides are safe when used at labeled rates under good growing conditions (Isaacs et al. 2002; Ritter and Menbere 2001; Whaley et al. 2006; Whaley and VanGessel 2002). To better understand relative crop safety and to evaluate the potential interactions with safeners and corn hybrid sensitivity, higher than label rates are often used (Bernards et al. 2006; Nelson and Penner 2006).

Corn hybrids can differ in their response to various herbicides, exhibiting a range of sensitivity (Bunting et al. 2004b; Doohan et al. 1998; Green 1998; Green and Ulrich 1993). Some of the corn seed companies identify hybrid sensitivity to herbicides in their technical bulletins. This information is designed to provide guidance on herbicide selection. Many factors, such as growing conditions and use of other herbicides or pesticides, can affect crop safety (Bunting et al. 2004a).

To provide better recommendations for POST herbicide application, this study was conducted to evaluate relative corn safety of POST herbicides when applied with and without isoxadifen. The effect of hybrid sensitivity to these products was also examined. Finally, the effect of POST herbicide injury on corn yield was investigated.

Materials and Methods

Trials were conducted from 2009 to 2012 at the University of Delaware's Research and Education Center located near Georgetown, DE (38.64°N, 75.46°W). The experimental sites were conventionally tilled with chisel plowing, discing, and field cultivation in the spring. Whole plots were 7.6 m long and 3 m wide with four rows, 76 cm apart. The soil was Rosedale loamy sand (loamy, siliceous, mesic Arenic Hapludults), with a pH range of 5.9 to 6.6 and organic matter ranging from 1.2 to 1.5%. Sites had access to irrigation to supplement rainfall. Starter fertilizer was used and tefluthrin {(2,3,5,6-tetrafluoro-4-methylphenyl)methyl 3-[(*Z*)-2-chloro-3,3,3-trifluoroprop-1-enyl]-2,2-dimethylcyclopropane-1-carboxylate} at 0.18 kg ai ha^{-1} was applied in-furrow. Supplemental nitrogen at 195 to 220 kg ha^{-1} was applied to V7 to V8 corn (70 to 85 cm in height). To eliminate weed competition, the entire trial was treated with *S*-metolachlor at 1.1 kg ai ha^{-1} plus 1.3 kg ai ha^{-1} atrazine within 48 h of planting. Additionally, approximately 1 wk after treatments were applied, glyphosate was applied at 0.9 kg ae ha^{-1} to all plots.

The study was a three-factor factorial, arranged as a strip plot. Whole plots were a factorial arrangement of herbicide and isoxadifen, and corn hybrid sensitivity was the subplot. Whole-plot herbicide treatments were dicamba plus diflufenzopyr, nicosulfuron, rimsulfuron plus dicamba, rimsulfuron plus nicosulfuron, and rimsulfuron plus thifensulfuron. Commercial formulations of these herbicides preformulated with isoxadifen were used, as well treatments without isoxadifen as commercial prepackaged mixtures or the appropriate amount of a single active ingredients selected to maintain the same rates of active ingredients and similar formulations. Additionally, a nontreated check was included. Herbicides were applied at twice the labeled rates, but adjuvants were at recommended rates. Herbicides, rates, and adjuvants are presented in Table 1. Using commercially formulated herbicides prevented the use of the same rimsulfuron or dicamba rates in all treatments.

Herbicides were applied to 38-cm corn at the five-collar stage in 2009, 36-cm corn at the six-collar stage in 2010, 30-cm corn at the six-collar stage in 2011, and 38-cm corn at the six-collar stage in 2012. Treatments were applied with a tractor-mounted compressed air sprayer, traveling 4.8 km h^{-1}, calibrated to deliver 187 L ha^{-1} at 276 kPa using Greenleaf AirMix 11002 nozzles (Greenleaf Technologies, P.O. Box 1767, Covington, LA 70434).

Subplots consisted of Dekalb's 'DKC61-69' or 'DKC63-42' planted in 2009 and 2010, and Hubner's 'H5707' or 'H5753' were planted in 2011 and 2012. Planting dates were May 12, 2009, April 23, 2010, May 12, 2011, and April 19, 2012, seeded at 69,000 seeds ha^{-1} in all years. Company literature lists DKC63-42 as acceptable for plant growth regulator herbicides (group 4) and warning (should not be used) for ALS inhibitor herbicides (group 2) (Anonymous 2010). H5707 is listed as

Table 1. Herbicides and isoxadifen rates for herbicide treatments.

Herbicide	Rate[a]	Isoxadifen rate	Adjuvant[b], rate	Commercial mixtures	Manufacturer, city, website
	——g ai ha^{-1}——		% v/v		
Dicamba + diflufenzopyr	420 + 168	0	NIS, 0.25 UAN, 1.25	Distinct®	BASF Corporation, Research Triangle Park, NC, http://agproducts.basf.us/
Dicamba + diflufenzopyr	420 + 168	53	NIS, 0.25 UAN, 1.25	Status®	BASF Corporation, Research Triangle Park, NC, http://agproducts.basf.us/
Nicosulfuron	57	0	COC, 1.0 UAN, 2.0	Accent®	E.I. DuPont de Nemours and Company, Wilmington, DE, http://cropprotection.dupont.com/
Nicosulfuron	57	16	COC, 1.0 UAN, 2.0	Accent Q®	E.I. DuPont de Nemours and Company, Wilmington, DE, http://cropprotection.dupont.com/
Rimsulfuron + dicamba	35 + 269	0	COC, 1.0 UAN, 2.0	Resolve® + dicamba 70WG[c]	E.I. DuPont de Nemours and Company, Wilmington, DE, http://cropprotection.dupont.com/
Rimsulfuron + dicamba	35 + 269	16	COC, 1.0 UAN, 2.0	Require Q®	E.I. DuPont de Nemours and Company, Wilmington, DE, http://cropprotection.dupont.com/
Rimsulfuron + nicosulfuron	26 + 52	0	COC, 1.0 UAN, 2.0	Steadfast®	E.I. DuPont de Nemours and Company, Wilmington, DE, http://cropprotection.dupont.com/
Rimsulfuron + nicosulfuron	26 + 52	16	COC, 1.0 UAN, 2.0	Steadfast Q®	E.I. DuPont de Nemours and Company, Wilmington, DE, http://cropprotection.dupont.com/
Rimsulfuron + thifensulfuron	32 + 7	0	COC, 1.0 UAN, 2.0	Resolve + Harmony GT®	E.I. DuPont de Nemours and Company, Wilmington, DE, http://cropprotection.dupont.com/
Rimsulfuron + thifensulfuron	32 + 7	14	COC, 1.0 UAN, 2.0	Resolve Q®	E.I. DuPont de Nemours and Company, Wilmington, DE, http://cropprotection.dupont.com/

[a] Dicamba rates presented as g ae ha^{-1}.

[b] Abbreviations: COC, crop oil concentrate; UAN, urea ammonium nitrate, 30% solution; NIS, non-ionic surfactant.

[c] Dicamba 70WG is not available as a commercial product.

sensitive to both plant growth regulator and ALS inhibitors (Anonymous 2011a). DKC61-69 and H5753 are listed as acceptable for both groups of herbicides (Anonymous 2011b; Anonymous 2012). Using a four-row planter, the left two rows were planted with one hybrid and the right two rows with the other hybrid.

Corn response was visually estimated at 3, 7, 21, and 28 d after treatment (DAT). Response variables included percentage of tissue with chlorosis or whitening based on a scale of 0 (no whitening or chlorosis) to 100 (all tissue white or chlorotic), amount of twisted or leaning corn based on a scale of 0 (all plants growing upright) to 100 (corn is growing horizontally), and amount of corn stunting based on 0 (no injury) to 100 (complete plant death). Corn was harvested with a combine at physiological maturity. Yield was determined by harvesting one row of each subplot using conventional harvesting equipment. Yields were adjusted to 15.5% moisture content before analysis.

Cumulative corn stunting was determined by calculating area under the cumulative injury curve (AUCIC):

$$\mathrm{AUCIC} = \sum_{i=1}^{N_i-1} [(y_i + y_{i+1})/2](t_{i+1} - t_i) \quad [1]$$

where y_i = corn stunting at the ith observation, t_i = days at the ith observation, and N_i = total number of observations. This calculation is known as area under the curve and provides a quantitative summary of herbicide injury intensity over time for comparison across management tactics or sites.

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Table 2. Twisting and leaning of sensitive and tolerant corn hybrids as influenced by herbicide and corn hybrid sensitivity 3 d after treatment.

		Corn twisting and leaning[b]						
		2009[c]		2010[c]		2011[c]		
Herbicide[a]	Rate	Snstv[e]	Tlrnt	Snstv	Tlrnt	Snstv	Tlrnt	2012[d]
	g ai ha^{-1}	% twisting						
Dicamba + diflufenzopyr	420 + 168	16 a	16 a	13 a	7 bc	37 a	23 b	18 a
Nicosulfuron	57	0 d	0 d	0 d	0 d	0 d	0 d	0 b
Rimsulfuron + dicamba	35 + 269	4 c	8 b	10 ab	5 c	20 b	14 c	4 b
Rimsulfuron + nicosulfuron	26 + 52	0 d	0 d	0 d	0 d	0 d	0 d	0 b
Rimsulfuron + thifensulfuron	32 + 7	0 d	0 d	0 d	0 d	0 d	0 d	0 b

[a] All herbicide treatments included adjuvants. See Table 1 for adjuvant type and rates.

[b] Values followed by the same letter within a year are not significantly different at $\alpha = 0.05$.

[c] Data are averaged over isoxadifen absence/presence because this variable and its interactions were not significant.

[d] Data are averaged over hybrid sensitivity and isoxadifen absence/presence because these variables and their interactions were not significant.

[e] Abbreviations: Snstv, sensitive; Tlrnt, tolerant. See materials and methods for description of the sensitive and tolerant hybrids.

Lower values are the result of lower initial corn stunting, faster recovery rate, or both. Area under the curve is commonly used with plant epidemiology research (Shaner and Finney 1977; Tooley and Grau 1984).

Data were checked for normality and appropriate transformations were used if needed. Data were analyzed using PROC GLIMMIX in SAS (version 9.4; SAS Institute Inc., Cary, NC), using strip-plot analysis, with year, herbicide, absence/presence of isoxadifen, and corn hybrid as fixed effects and replication as a random effect. Fixed effects and interactions were tested using Tukey's mean separation at $P = 0.05$ and degrees of freedom calculated according to the Kenward–Roger method. Yield data were converted to percentage of nontreated check because hybrids were not the same for each year of the study.

To test the relationship between corn injury and yield, PROC CORR was used to calculate the correlation coefficient. Cumulative injury value and percent stunting at 7 to 28 DAT were tested for correlation with corn yield.

Results and Discussion

There was a year by treatment interaction for all corn response variables; therefore, data are presented separately by year. If there were no significant three-way interactions, data were pooled over factors that are not significant. Twisting of corn leaves in the whorl or plant leaning was rated at 3 DAT, and only with treatments containing dicamba showed this response (Table 2). In 2009, isoxadifen improved crop safety with all dicamba-containing herbicides applied to the sensitive hybrid, but not with the tolerant hybrid (data not shown). In all other years, isoxadifen did not reduce the amount of corn twisting or leaning. In general, more twisting and leaning was observed with dicamba plus diflufenzopyr than dicamba plus rimsulfuron, presumably because of higher dicamba rates (Table 2). The tolerant hybrid showed less twisting than the sensitive hybrid in 2010 and 2011. In 2012, dicamba plus diflufenzopyr caused 18% corn twisting and leaning 3 DAT, but there was no effect of corn hybrid.

Chlorosis showed little consistency across the 4 yr. Only dicamba plus diflufenzopyr caused little to no chlorosis over the 4 yr (Table 3). Isoxadifen had a negligible effect on chlorosis. In 2009, nicosulfuron applied to the sensitive hybrid and rimsulfuron plus thifensulfuron applied to the tolerant hybrid resulted in 10% or greater chlorosis 3 DAT. In 2010, rimsulfuron plus nicosulfuron or rimsulfuron plus thifensulfuron applied to either hybrid or rimsulfuron plus dicamba applied to sensitive hybrids exhibited 12 to 18% chlorosis. In 2011, rimsulfuron plus dicamba applied to a sensitive hybrid resulted in 20% chlorosis, and rimsulfuron plus dicamba applied to tolerant hybrid and rimsulfuron plus nicosulfuron or rimsulfuron plus

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Table 3. Chlorosis of corn tissue as influenced by herbicide and corn hybrid sensitivity 3 d after treatment.

Herbicide[a]	Rate	Chlorotic tissue[b] 2009[c] Snstv[e]	2009[c] Tlrnt	2010[c] Snstv	2010[c] Tlrnt	2011[c] Snstv	2011[c] Tlrnt	2012[d]
	g ai ha^{-1}	% chlorosis						
Dicamba + diflufenzopyr	420 + 168	0 c	0 c	0 e	0 e	5 c	5 c	0 b
Nicosulfuron	57	12 a	7 ab	12 bc	6 d	8 bc	7 bc	12 a
Rimsulfuron + dicamba	35 + 269	4 bc	5 bc	12 ab	6 cd	20 a	14 ab	14 a
Rimsulfuron + nicosulfuron	26 + 52	9 ab	6 abc	18 a	14 ab	10 bc	10 bc	13 a
Rimsulfuron + thifensulfuron	32 + 7	9 ab	10 ab	17 ab	13 ab	14 ab	12 b	13 a

[a] All herbicide treatments included adjuvants. See Table 1 for adjuvant type and rates.
[b] Values followed by the same letter within a year are not significantly different at $\alpha = 0.05$.
[c] Data are averaged over isoxadifen absence/presence because this variable and the interactions were not significant.
[d] Data are averaged over hybrid sensitivity and isoxadifen absence/presence because these variables and their interactions were not significant.
[e] Abbreviations: Snstv, sensitive; Tlrnt, tolerant. See materials and methods for description of the sensitive and tolerant hybrids.

thifensulfuron applied to either hybrid resulted in 10 to 14% chlorosis. In 2012, there was no effect of hybrid, but nicosulfuron, rimsulfuron plus dicamba, rimsulfuron plus nicosulfuron, and rimsulfuron plus thifensulfuron had similar levels of chlorosis, ranging from 12 to 14%.

Treatment effects on stunting was similar at 7 and 14 DAT, so only stunting 7 DAT is presented. In 2009, 35% stunting was observed after rimsulfuron plus thifensulfuron without isoxadifen application to a sensitive hybrid (Table 4). Similar stunting levels (12 to 23%) were observed with rimsulfuron plus thifensulfuron without isoxadifen applied to a tolerant hybrid; rimsulfuron plus dicamba without isoxadifen, regardless of hybrid; rimsulfuron plus dicamba with isoxadifen applied to a sensitive hybrid; rimsulfuron plus nicosulfuron without isoxadifen applied to a sensitive hybrid; and rimsulfuron plus thifensulfuron with isoxadifen applied to a sensitive hybrid. In 2010, only the

Table 4. Corn stunting as influenced by herbicide, isoxadifen absence/presence, and corn hybrid sensitivity 7 d after treatment.

Herbicide[a]	Rate	Isoxadifen rate	Corn stunting[b] 2009 Snstv[e]	2009 Tlrnt	2010[c]	2011[d]	2012[c]
	g ai ha^{-1}		% stunting				
Dicamba + diflufenzopyr	420 + 168	0	0 f	0 f	6 c	10 de	6 b
Dicamba + diflufenzopyr	420 + 168	53	0 f	0 f		9 e	
Nicosulfuron	57	0	8 def	0 f	8 c	13 cde	12 ab
Nicosulfuron	57	16	2 ef	0 f		6 e	
Rimsulfuron + dicamba	35 + 269	0	22 bc	17 bcd	19 ab	22 b	14 a
Rimsulfuron + dicamba	35 + 269	16	18 bcd	10 cdef		18 bcd	
Rimsulfuron + nicosulfuron	26 + 52	0	18 bcd	10 cdef	15 b	20 bc	16 a
Rimsulfuron + nicosulfuron	26 + 52	16	12 cde	9 def		14 bcde	
Rimsulfuron + thifensulfuron	32 + 7	0	35 a	23 b	23 a	38 a	15 a
Rimsulfuron + thifensulfuron	32 + 7	14	12 bcde	11 cdef		19 bc	

[a] All herbicide treatments included adjuvants. See Table 1 for adjuvant type and rates.
[b] Values followed by the same letter within a year are not significantly different at $\alpha = 0.05$.
[c] Data are averaged over hybrid sensitivity and isoxadifen absence/presence.
[d] Data are averaged over hybrid sensitivity because the main effect was significant, but interactions were not significant.
[e] Abbreviations: Snstv, sensitive; Tlrnt, tolerant. See "Materials and Methods" for a description of the sensitive and tolerant hybrids.

Table 5. Cumulative corn stunting based on area under the curve as influenced by herbicide, isoxadifen absence/presence, and corn hybrid sensitivity. Cumulative corn stunting are based on weekly ratings of corn stunting and calculating the area under the curve.

			Cumulative stunting[b]					
			2009			2011		
Herbicide[a]	Rate	Isoxadifen rate	Snstv[e]	Tlrnt	2010[c]	Snstv	Tlrnt	2012[d]
	g ai/ha							
Dicamba + diflufenzopyr	420 + 168	0	53 defg	43 efg	96 c	105 efg	119 efg	244 cd
Dicamba + diflufenzopyr	420 + 168	53	0 g	0 g		122 efg	117 efg	215 de
Nicosulfuron	57	0	77 defg	15 g	141 bc	82 fg	61 g	337 bcd
Nicosulfuron	57	16	30 fg	22 fg		26 g	33 g	92 e
Rimsulfuron + dicamba	35 + 269	0	343 ab	207 bcde	226 ab	289 bc	289 bc	463 ab
Rimsulfuron + dicamba	35 + 269	16	219 bcd	39 fg		216 cd	206 cd	354 bcd
Rimsulfuron + nicosulfuron	26 + 52	0	184 b–f	71 defg	153 bc	211 cde	177 def	399 ab
Rimsulfuron + nicosulfuron	26 + 52	16	97 c–g	86 c–g		82 fg	116 defg	374 bc
Rimsulfuron + thifensulfuron	32 + 7	0	483 a	245 bc	259 a	707 a	376 b	549 a
Rimsulfuron + thifensulfuron	32 + 7	14	158 c–g	118 c–g		180 def	183 c–f	360 bcd

[a] All herbicide treatments included adjuvants. See Table 1 for adjuvant type and rates.

[b] Values followed by the same letter within a year are not significantly different at $\alpha = 0.05$.

[c] Data are averaged over hybrid sensitivity and isoxadifen absence/presence. The main effect of hybrid sensitivity was significant, but isoxadifen absence/presence and the interactions were not significant.

[d] Data are averaged over hybrid sensitivity.

[e] Abbreviations: Snstv, sensitive; Tlrnt, tolerant. See "Materials and Methods" for a description of the sensitive and tolerant hybrids.

main effect of herbicide was significant. Corn exhibited 23% stunting after rimsulfuron plus thifensulfuron, which was significantly higher than rimsulfuron plus nicosulfuron or nicosulfuron alone. In 2011, the two-way interactions of herbicide by isoxadifen and isoxadifen by hybrid were significant. Plots treated with rimsulfuron plus thifensulfuron without isoxadifen were stunted 38%, but including isoxadifen reduced stunting to 19%. Stunting was not significantly reduced when isoxadifen was used with the other herbicides. Stunting with other treatments containing rimsulfuron ranged from 14 to 22%. Averaged over herbicides, treatments applied to a sensitive hybrid without isoxadifen resulted in 22% stunting, whereas a tolerant hybrid averaged 19% stunting without isoxadifen (data not shown). Regardless of corn hybrid, 13 to 14% stunting was observed even in the presence of isoxadifen. In 2012, the main effect of herbicide was significant, with a similar amount of stunting for all treatments containing rimsulfuron as well as nicosulfuron alone (Table 4). The main effect of hybrid sensitivity was also significant in 2012, with tolerant hybrids significantly reducing injury compared with sensitive hybrids 12 and 14%, respectively (data not shown).

Crop stunting is valuable information for farmers and advisors, but this information does not reflect how quickly corn recovers from initial injury. Calculating area under the curve for a cumulative stunting value provides information on both severity of stunting and corn recovery rate. Cumulative stunting values incorporated data collected at 1 to 4 wk after treatment. In 2009, rimsulfuron plus thifensulfuron or rimsulfuron plus dicamba, both without isoxadifen, applied to a sensitive hybrid had the greatest values for cumulative stunting, indicating a longer period of recovery from stunting (Table 5). A sensitive hybrid treated with rimsulfuron plus thifensulfuron plus isoxadifen or application to a tolerant hybrid, regardless of isoxadifen, all had similar areas under the curve. The rimsulfuron plus dicamba combination had a lower cumulative stunting only if it was applied with isoxadifen to a tolerant hybrid when compared with the other combinations. All treatments, including dicamba plus diflufenzopyr, nicosulfuron alone, or rimsulfuron plus nicosulfuron with isoxadifen, had the lowest values for cumulative stunting.

In 2010, isoxadifen had no effect. The highest values for cumulative stunting were with treatments containing rimsulfuron plus thifensulfuron or rimsulfuron plus dicamba (Table 5). Dicamba plus

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Table 6. Corn yield calculated as percentage of the nontreated check.

Herbicide[a]	Rate	2009[b]	2010[b]	2011[c] Snstv[d]	2011[c] Tlrnt	2012[b]
	$g\ ai\ ha^{-1}$	% yield[e]				
Dicamba + diflufenzopyr	420 + 168	97 a	91 b	105 abc	107 ab	92 ab
Nicosulfuron	57	100 a	104 a	106 abc	112 ab	86 ab
Rimsulfuron + dicamba	35 + 269	96 a	100 ab	101 bc	111 ab	96 a
Rimsulfuron + nicosulfuron	26 + 52	97 a	98 ab	103 bc	119 a	89 ab
Rimsulfuron + thifensulfuron	32 + 7	91 a	93 ab	90 c	113 ab	77 b

[a] All herbicide treatments included adjuvants. See Table 1 for adjuvant type and rates.

[b] Data are averaged over isoxadifen absence/presence and hybrid sensitivity.

[c] Data are averaged over isoxadifen absence/presence.

[d] Abbreviations: Snstv, sensitive; Tlrnt, tolerant. See "Materials and Methods" for a description of the sensitive and tolerant hybrids.

[e] Values followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

diflufenzopyr, nicosulfuron alone, and rimsulfuron plus nicosulfuron had similar values for cumulative stunting. The main effect of corn sensitivity was significant, with an overall value of 182 for the sensitive hybrid and 168 for the tolerant hybrid (data not shown).

In 2011, rimsulfuron plus thifensulfuron without isoxadifen applied to the sensitive hybrid had the highest cumulative stunting value, but cumulative stunting was reduced if this herbicide combination was applied to the tolerant hybrid and saw an additional reduction if isoxadifen was included (Table 5). Rimsulfuron plus dicamba without isoxadifen had similar levels of cumulative stunting to rimsulfuron plus thifensulfuron without isoxadifen applied to a tolerant hybrid. All treatments with rimsulfuron plus dicamba had similar values for cumulative stunting, regardless of isoxadifen or sensitivity of the corn hybrid. Dicamba plus diflufenzopyr and nicosulfuron alone, regardless of isoxadifen or hybrid sensitivity, and rimsulfuron plus nicosulfuron with isoxadifen all had the lowest values for cumulative corn stunting.

In 2012, two interactions were significant. There was a herbicide by isoxadifen interaction, with the highest cumulative stunting values for rimsulfuron plus thifensulfuron, rimsulfuron plus dicamba, or rimsulfuron plus nicosulfuron, all without isoxadifen (Table 5). Rimsulfuron plus thifensulfuron or nicosulfuron alone had a reduction in cumulative stunting if isoxadifen was included. Herbicide by corn hybrid sensitivity was also significant (data not shown). The highest cumulative stunting values, ranging from 454 to 539, were observed after the application of rimsulfuron plus thifensulfuron, rimsulfuron plus dicamba, or rimsulfuron plus nicosulfuron to a sensitive hybrid. Cumulative stunting was similar, ranging from 319 to 379, with rimsulfuron plus thifensulfuron, rimsulfuron plus nicosulfuron, or rimsulfuron plus dicamba if applied to the tolerant hybrid. Dicamba plus diflufenzopyr and nicosulfuron alone, regardless of hybrid sensitivity, had similar cumulative stunting, ranging from 152 to 277.

Yield was calculated as percentage of the nontreated check to allow for multifactor analysis and to account for differences in inherent yield potential of the hybrids. Analysis of variance was similar for both yield as well as percentage of the nontreated check. The main effects of hybrid sensitivity was significant in 2009, with the tolerant hybrid producing 105% of the untreated check and the sensitive hybrid producing 88% (data not shown). The lower yields with the sensitive hybrid cannot be fully explained by herbicide response. Herbicide treatments resulted in differences in stunting and cumulative stunting, but no hybrid by herbicide interaction was observed for yield. Herbicides were significant in 2010, with nicosulfuron having a higher yield than dicamba plus diflufenzopyr (Table 6). In 2011, herbicide by hybrid sensitivity was significant as well as the isoxadifen absence/presence main effect. Percent yields were the highest with the tolerant hybrid, regardless of herbicide treatment, as well as the sensitive hybrid treated with dicamba plus diflufenzopyr and nicosulfuron alone. The sensitive hybrid treated with rimsulfuron plus thifensulfuron yielded less than treatments with the tolerant hybrid, regardless of herbicide treatment. Treatments that included isoxadifen yielded 111% of the nontreated check, whereas treatments without isoxadifen yielded 103% (data not shown). The main effects of herbicides were significant in 2012, with rimsulfuron plus dicamba yield higher than rimsulfuron plus thifensulfuron (Table 6).

Yield was correlated with corn injury but the relationship was not very strong. Yield was correlated with each of the four stunting ratings, and the rating at 21 DAT had the best correlation coefficient of −0.41. The rating at 28 DAT was −0.11. Cumulative stunting had a correlation coefficient of −0.34. Correlations were very similar if only sensitive hybrids were included compared with including both hybrids. Few trials exist to support the perception that herbicide injury translates to yield loss in grain corn, primarily because of confounding effects of weed competition. However, Doohan et al. (1998) commented that injury at 21 DAT was a reliable indicator of yield response but provided no analysis to support this observation. Eberlein et al. (1989) reported correlations above 0.86 for yield loss and injury for inbreds when using very high rates of thifensulfuron.

Twisting and chlorosis were transient, and neither were observed at 14 DAT. Dicamba causes corn twisting and leaning, and it was more severe with diflufenzopyr than with rimsulfuron. Isoxadifen reduced twisting with dicamba plus diflufenzopyr, but a reduction was not observed with rimsulfuron plus dicamba. Using a tolerant corn hybrid reduced the amount of twisting in 3 out of 4 yr. Dicamba plus diflufenzopyr had a limited effect on corn stunting. In 2012, initial stunting was $\leq$10%, but corn did not recover as quickly as in other years, possibly because of lower temperatures after application, but corn yield was not reduced. Sikkema et al. (1999) also reported temporary injury with dicamba plus diflufenzopyr, but it did not appear to affect yield.

Among the ALS inhibitors, nicosulfuron alone resulted in less stunting than rimsulfuron plus thifensulfuron. Rimsulfuron plus dicamba and rimsulfuron plus nicosulfuron were intermediate for stunting. These observations follow the patterns of previous research. Doohan et al. (1998) reported that corn is less tolerant of rimsulfuron than nicosulfuron, and Green and Ulrich (1993) reported that corn hybrids generally had greater tolerance to nicosulfuron than thifensulfuron. Mekki and Leroux (1994) reported no interaction on corn biomass with nicosulfuron and rimsulfuron when used singly and in mixtures. Many research trials have reported no injury from the herbicides included in this trial when applied at labeled rates (Damalas and Eleftherohorinos 2001; Isaacs et al. 2002; Krausz et al. 2000; Soltani et al. 2010; Whaley et al. 2006), although there are some reports of temporary injury. Nolte and Young (2002) reported injury from rimsulfuron plus nicosulfuron used along with atrazine, but the injury did not appear to affect yields; Mitra and Bhowmik (1999) and Wilson et al. (2010) observed stunting with rimsulfuron. In general, yield response because of reduced weed competition outweighed any potential effect of rimsulfuron on grain yield.

The use of either isoxadifen or a tolerant corn hybrid often improved crop safety with rimsulfuron plus thifensulfuron and rimsulfuron plus dicamba. Although improved crop safety was observed when nicosulfuron alone or rimsulfuron was applied with isoxadifen, it was only observed 1 out of 4 yr. Averaged across years, corn safety was improved with the use of isoxadifen to a greater extent than with the tolerant corn hybrids used in this trial. Including isoxadifen reduced stunting by 4%, compared with using a tolerant hybrid, which reduced stunting by 2% at 7 DAT. It is acknowledged that only one sensitive and one tolerant hybrid was used each year. Additional work needs to be done to evaluate a wider range of hybrids and determine whether some hybrids might provide a higher level of tolerance than observed in this trial. Green (1998) tested corn inbreds and found a wide range of tolerances to ALS inhibitors, with up to a 50,000-fold difference after a rimsulfuron application. Isoxadifen reduced sweet corn injury when used with tembotrione (Williams and Pataky 2010), and Bunting et al. (2004a) reported a reduction in corn injury from foramsulfuron, with a greater effect on sensitive hybrids compared with tolerant hybrids.

Products containing rimsulfuron are at greater risk of causing corn injury than nicosulfuron or dicamba plus diflufenzopyr. There are methods to mitigate this injury, such as the use of a herbicide safener or a tolerant hybrid, but they do not eliminate visible symptoms or consistently reduce the risk of yield loss. Care should be taken when recommending these herbicides to ensure the benefits outweigh the potential negative effects. Although using products with isoxadifen or a hybrid selection might reduce injury, herbicide selection will have a greater reduction in corn response and yield.

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