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Soybean (*Glycine max*) Tolerance to Timing Applications of Pyroxasulfone, Flumioxazin, and Pyroxasulfone + Flumioxazin

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Four field studies were conducted over a 3-yr period (2011 to 2013) to determine the tolerance of four soybean cultivars to pyroxasulfone (89 and 178 g ai ha^{-1}), flumioxazin (71 and 142 g ai ha^{-1}), and pyroxasulfone + flumioxazin (160 and 320 g ai ha^{-1}) applied either preplant incorporated (PPI), PRE, or at the soybean cotyledon stage (COT). When pyroxasulfone + flumioxazin was applied at 160 and 320 g ai ha^{-1}, at the cotyledon stage soybean yield was decreased by 9 and 14%, respectively. The only other treatment that decreased soybean yield was pyroxasulfone (178 g ai ha^{-1}) applied PPI; yield was decreased by 6% despite minimal injury and dry biomass reductions observed during the season. Soybean tolerance to pyroxasulfone or flumioxazin applied alone was generally similar and injury was less than with pyroxasulfone + flumioxazin. Similarly, herbicides applied PPI and PRE were less injurious to soybean than the COT timing. Results suggest that soybean is tolerant to PPI and PRE applications of pyroxasulfone + flumioxazin but COT applications should be avoided.
Nomenclature: Flumioxazin; pyroxasulfone; soybean, *Glycine max* (L.) Merr.
Key words: Postemergence (POST); preemergence (PRE); preplant (PP); preplant incorporated (PPI).

Se realizaron cuatro estudios de campo durante un período de 3 años (2011 a 22013) para determinar la tolerancia de cuatro cultivares de soya a pyroxasulfone (89 y 178 g ai ha^{-1}), flumioxazin (71 y 142 g ai ha^{-1}), y pyroxasfulone + flumioxazin (160 y 320 g ai ha^{-1}) aplicados ya sea incorporados en presiembra (PPI), PRE, o en el estado cotiledonal de la soya (COT). Cuando se aplicó pyroxasulfone + flumioxazin a 160 y 320 g ai ha^{-1} en el estado cotiledonal, el rendimiento de la soya se redujo en 9 y 14%, respectivamente. El único otro tratamiento que disminuyó el rendimiento de la soya fue pyroxasulfone (178 g ai ha^{-1}) aplicado PPI, en el cual el rendimiento se redujo 6% a pesar de que el daño y reducciones de biomasa seca observados fueron mínimos durante la temporada de crecimiento. La tolerancia de la soya a pyroxasulfone o flumioxazin aplicados solos fue generalmente similar y el daño fue menor que con pyroxasulfone + flumioxazin. Similarmente, los herbicidas aplicados PPI y PRE fueron menos dañinos a la soya que al aplicarse COT. Los resultados sugieren que la soya es tolerante a aplicaciones PPI y PRE de pyroxasulfon + flumioxazin, pero las aplicaciones COT deberían ser evitadas.

Pyroxasulfone is a newly registered soybean herbicide in the United States for preplant (PP), preplant incorporated (PPI), and early POST (EPOST) use (Anonymous 2013a). Pyroxasulfone controls susceptible annual grass and some broadleaf weeds, such as eastern black nightshade (*Solanum ptychanthum* Dunal) and certain pigweed species (*Amaranthus* spp.) by inhibiting very-long-chain fatty acid synthesis (Tanetani et al. 2009). Although pyroxasulfone has a similar weed control spectrum as *S*-metolachlor and dimethenamid-P, it has a higher specific activity allowing for use rates approximately eight times lower than *S*-metolachlor and four times lower than dimethenamid-P (Curran and Lingenfelter 2013). Combining pyroxasulfone with other PRE broadleaf herbicides broadens the spectrum of weeds controlled.

Flumioxazin is a protoporphyringogen oxidase-inhibiting herbicide (Yoshida et al. 1991) that provides residual control of broadleaf weed species when applied PRE. Flumioxazin applied after soybean have emerged causes soybean injury, and mechanical incorporation after application might reduce weed control (Anonymous 2013b). Recently, the premix formulation of pyroxasulfone + flumioxazin was registered for PRE soybean use in the United States (Anonymous 2013c). The combination offers growers a non-glyphosate herbicide option with residual, broad-spectrum weed

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control. Glyphosate-resistant weed species, such as horseweed [*Conyza Canadensis* (L.) Cronq.] and common ragweed (*Ambrosia artemisiifolia* L.) have been found in fields across the United States and Canada (Heap 2014). Pyroxasulfone + flumioxazin provides partial control of these glyphosate-resistant weeds early in the season. Additionally, for producers not dealing with glyphosate-resistant weeds, Ellis and Griffin (2002) found that the use of a PRE herbicide in glyphosate-resistant soybean decreased weed density and generally only required one glyphosate application per season compared to two applications when no PRE was applied.

The purpose of this study was to examine the tolerance of four soybean cultivars grown in Ontario to PPI, PRE, and EPOST applications of pyroxasulfone, flumioxazin, and pyroxasulfone + flumioxazin. Some earlier work suggests that there might be differences in cultivar tolerance to flumioxazin (Taylor-Lovell et al. 2001) and pyroxasulfone (Anonymous 2013a).

Materials and Methods

Field Study Sites. Four field studies were conducted at the Huron Research Station (HRS) (43°19′N, 81°30′W), Exeter, Ontario, Canada (2012 to 2013) and at the University of Guelph, Ridgetown Campus (RC) (42°26′N, 81°53′W), Ridgetown, Ontario, Canada (2011 and 2013). Soybean cultivars included in this study were: ProSeeds 'Pro 2715R', Pioneer '5201 RR2Y', Dekalb 'DKB 2860RY', and Country Farms '5221 RR2Y'. Four cultivars were selected because soybean cultivar sensitivity to Group 14 herbicides has been previously identified (Taylor-Lovell et al. 2001). Cultivars chosen for this study represent those commonly grown in Ontario and possess a wide genetic diversity from each other. Planting dates, planting densities, and soil specifications are listed in Table 1. The soil at the HRS location was a Brookston clay loam, the RC-2011 site was a Maplewood/Normandale series, and the RC-2013 site was a Watford/Brady series. Site preparation included fall moldboard plowing followed by two passes with an s-tine cultivator with rolling basket harrows in the spring prior to herbicide application. Fertilizer applied included approximately 10 kg ha^{-1} actual nitrogen (N), whereas phosphorous (P) and potassium (K) requirements for each trial were determined based on soil P and K levels and the recommended nutrient application rate cited by the Ontario Ministry of Agriculture Food publication 811 (OMAFRA 2009). Seeds were planted to moisture using a conventional precision planter at all locations. Plots were 3 m wide and consisted of one row of each of the four soybean cultivars in rows spaced 75 cm apart. At HRS, plots were 10 m long, and at RC they were 8 m long.

Experimental Design. Studies were designed as a two-way factorial with four replications, where the factors examined were soybean cultivar and herbicide treatment. Herbicide treatments consisted of three herbicides each applied at two rates at three different timings, PPI, PRE, and EPOST at the cotyledon stage (COT) plus a nontreated check. Herbicides used were pyroxasulfone at 89 and 178 g ai ha^{-1} (Zidua® 85 WG, BASF, 100 Milverton Dr., Mississauga, ON, L5R 4H1, Canada), flumioxazin at 71 and 142 g ha^{-1} (Valtera® 51 DF, Valent, 6–130 Research Ln., Guelph, ON, N1G 5G3, Canada), and pyroxasulfone + flumioxazin at 160 and 320 g ha^{-1} (Fierce® 76 WG, Valent). The herbicide rates chosen represent the respective registered or proposed rate in Ontario and a 2× rate. Although COT applications of flumioxazin and pyroxasulfone + flumioxazin are not recommended, they were included in the study to document the degree of injury and yield loss possible if the herbicides were applied at ground crack or EPOST. The potential for growers applying herbicide outside the recommended application window exist due to the volume of acres to be planted, weather conditions, and soil differences within the field. Incorporation of herbicides sometimes allows for increased crop tolerance to the herbicide. Growers occasionally choose to incorporate potentially injurious herbicides to minimize crop damage and yield losses, knowing that a reduction in weed control also might occur. Therefore, the PPI application of flumioxazin and pyroxasulfone + flumioxazin was examined, despite the potential for reduced weed control. All PPI treatments were shallowly incorporated within 1 h of herbicide application with two passes (opposite directions) of a field cultivator with rolling basket harrows. Because soybean cultivars were glyphosate-resistant, plots were maintained weed-free using a combination of glyphosate and hand hoeing. Herbicides were applied at the appropriate timing

Table 1. Soil specifications and planting dates and densities for soybean tolerance to pyroxasulfone, flumioxazin, and pyroxaxulfone + flumioxazin trials at the Huron Research Station, Exeter, Ontario, Canada (HRS) and Ridgetown Campus, University of Guelph, Ridgetown, Ontario, Canada (RC) (2011 to 2013).[a]

Location	Planting date	Planting density	Sand	Silt	Clay	OM	pH	CEC
		seeds ha^{-1}	——————	%	——————			
RC-2011	June 3	370,370	71.2	16.3	12.5	3.5	6.8	11
HRS-2012	May 14	358,000	41	40	19	3.8	7.8	29.2
HRS-2013	May 14	380,000	48	28	24	6.7	6.6	22
RC-2013	May 14	372,809	17	46	37	3	7.7	35.2

[a] Abbreviations: OM, organic matter; CEC, cation exchange capacity.

using a CO_2-pressurized back-pack sprayer (R&D CO_2 pressurized sprayer, 419 Hwy. 104, Opelousas, LA 70570) calibrated for an output of 200 L ha^{-1} when fitted with Hypro Ultra-Lo Drift 120-02 nozzles (Hypro® ULD 120-02 nozzle, 375 5th Ave. NW, New Brighton, MN 55112) at 207 kPa at RC and 241 kPa at HRS.

Data Collection. Data for all rating parameters were collected relative to the last herbicide timing application, at the cotyledon stage (DAT-C). Crop injury was visually estimated on a scale of 0 to 100% where 0% represented no soybean injury and 100% represented complete death. Although injury ratings were conducted at 7, 14, and 28 DAT-C, only data from the 7 and 28 DAT-C rating dates are presented because the general trend is similar across rating dates. Soybean stand and dry biomass data were collected from a 1-m harvest area at 14 DAT-C. Soybean was harvested at maturity using a small plot combine; weight and moisture were recorded and yields adjusted to 13.0% moisture.

Statistical Analysis. Data were analyzed as a two-way factorial using PROC MIXED in SAS 9.2 (SAS, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513). Fixed effects included the two treatment factors, soybean cultivar and herbicide treatment, and their interaction; random effects included year–location combinations (environment), interactions between environment and the fixed effects, and replicate nested within environment. Significance of fixed effects was tested using F-tests and random effects were tested using a Z-test of the variance estimate. The UNIVARIATE procedure was used to test data for normality and homogeneity of variance. To satisfy the assumptions of the variance analysis, the injury at 7 DAT-C required an arcsine square root transformation, and the 28 DAT-C injury rating required a square root transformation; no other evaluation rating required data to be transformed. For all injury ratings, the nontreated check was assigned a value of zero and was therefore excluded from analysis. However, all values were compared independently to zero to evaluate treatment differences with the nontreated check. Treatment comparisons were made using a Fisher's protected LSD at a level of $P < 0.05$ and any data compared on the transformed scale were back-transformed to the original scale for presentation of results. Contrasts were also used to compare the three herbicides to each other (across all cultivars, herbicide rates, and application timings) as well as the three application timings to each other (across all cultivars, herbicides, and herbicide rates) at a significance level of $P < 0.05$. For each variable analyzed, the herbicides and application timings were ranked from least to most injurious using the contrast results.

Results and Discussion

Visible Estimates of Injury. At the 7 DAT-C injury rating, a significant herbicide treatment by cultivar interaction was observed, requiring the data to be separated by cultivar (Table 2). Generally, when the three herbicides were applied PPI there was no increase in injury for any soybean cultivar compared to the nontreated check at the 1× and 2× rate. Although pyroxasulfone + flumioxazin (160 g ha^{-1}) applied PPI caused 6% injury in PRO 3751R, this was still equivalent to the nontreated control. Generally, pyroxasulfone or flumioxazin applied PRE at the 1× or 2× rate to PRO 3751R, 5201 RR2Y, or DKB 2860RY cultivars resulted in injury equivalent to the nontreated control. There was one exception: flumioxazin (142 g ha^{-1}) applied PRE caused 11% injury to the CF 5221 RR2Y cultivar.

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Table 2. Percent injury 7 d after cotyledon application (DAT-C) for four soybean cultivars treated with pyroxasulfone, flumioxazin, and pyroxasulfone + flumioxazin at three different timings at the Huron Research Station, Exeter, Ontario, Canada (HRS)and Ridgetown Campus, University of Guelph, Ridgetown, Ontario, Canada (RC) (2011 to 2013).[a]

Herbicide treatment	Rate	Timing	Soybean injury			
			PRO 3751R	5201 RR2Y	DKB 2860RY	CF 5221 RR2Y
	g ai ha^{-1}		%			
Nontreated check			0 a	0 a	0 a	0 a
pyroxasulfone	89	PPI	0 aZ	0 aZ	1 aZ	1 aZ
pyroxasulfone	178	PPI	1 abZ	1 aZ	1 aZ	2 aZ
pyroxasulfone	89	PRE	1 abZ	0 aZ	1 aZ	1 aZ
pyroxasulfone	178	PRE	1 abZ	1 aZ	1 aYZ	3 abY
pyroxasulfone	89	COT	7 bcdZ	8 bcdZ	8 bcdZ	9 bcdZ
pyroxasulfone	178	COT	11 deZ	12 dZ	13 dZ	14 dZ
flumioxazin	71	PPI	3 abcY	1 aZ	1 aZ	3 abY
flumioxazin	142	PPI	2 abcZ	1 aZ	1 aZ	3 ab Z
flumioxazin	71	PRE	1 abZ	1 aZ	2 aYZ	3 abY
flumioxazin	142	PRE	4 abcdZ	3 abcZ	4 abcZ	11 cdY
flumioxazin	71	COT	17 efZ	15 deZ	17 deZ	18 deZ
flumioxazin	142	COT	25 fgZ	24 efZ	27 de Z	28 deZ
Pyroxasulfone + flumioxazin	160	PPI	6 abcX	2 abZ	2 aZ	4 abcY
Pyroxasulfone + flumioxazin	320	PPI	3 abcZ	2 abZ	2 aZ	3 abZ
Pyroxasulfone + flumioxazin	160	PRE	3 abcYZ	2 abZ	3 abYZ	4 abcY
Pyroxasulfone + flumioxazin	320	PRE	8 cdeZ	9 cdZ	10 cdZ	15 deY
Pyroxasulfone + flumioxazin	160	COT	28 fgZ	29 fZ	30 efZ	33 fZ
Pyroxasulfone + flumioxazin	320	COT	37 gZ	36 f Z	39 fZ	39 fZ

[a] Abbreviations: PPI, preplant incorporated; COT, cotyledon stage.

[b] Means followed by the same letter within a column (a–g) or row (X–Z) are not significantly different according to Fisher's protected LSD at $P < 0.05$. Data required an arcsine square root transformation for analysis but were back-transformed for the purpose of reporting.

Pyroxasulfone + flumioxazin (160 g ha^{-1}) applied PRE did not cause significant soybean injury; however; when the rate was increased to 320 g ha^{-1}, injury was observed in all four soybean cultivars (Table 2). Pyroxasulfone (89 or 178 g ha^{-1}), flumioxazin (71 or 142 g ha^{-1}), or pyroxasulfone + flumioxazin (160 or 320 g ha^{-1}) applied at the cotyledon stage caused injury to all four soybean cultivars. Despite increased injury compared to the nontreated check when pyroxasulfone was applied COT at 89 g ha^{-1}, mean injury ratings were 9% or less, depending on cultivar. Conversely, when flumioxazin (71 g ha^{-1}) or pyroxasulfone + flumioxazin (160 g ha^{-1}) were applied COT, injury ranged from 15 to 18% and 28 to 33%, respectively, depending on cultivar (Table 2). Injury symptoms observed typically consisted of cotyledon/leaf necrosis and plant stunting.

At the 28 DAT-C injury evaluation, there was no significant cultivar by herbicide treatment interaction, so all four cultivars were combined to examine herbicide treatment effects (Table 3). Similar to the 7 DAT-C injury rating, all of the herbicides at 1× and 2× rates and applied PPI caused 5% or less injury, although some significant differences between herbicide treatments and the nontreated check were observed. Pyroxasulfone (178 g ha^{-1}) and pyroxasulfone + flumioxazin applied PPI caused increased injury compared to the nontreated check. A similar trend was observed for the PRE application timing; the exception being that the 320 g ha^{-1} rate of pyroxasulfone + flumioxazin not only caused increased crop injury compared to the nontreated check, but the injury was also greater than 10%. All three herbicides (1× and 2× rates) applied COT caused injury to soybean. Pyroxasulfone (89 or 178 g ha^{-1}) and flumioxazin (71 g ha^{-1}) caused 8% or less injury to soybean. Pyroxasulfone + flumioxazin at both rates evaluated caused unacceptable crop injury when applied at the COT (Table 3).

Table 3. Main effects and interaction for injury, dry biomass, and yield of soybean treated with pyroxasulfone, flumioxazin, and pyroxasulfone + flumioxazin at three different timings at the Huron Research Station, Exeter, Ontario, Canada (HRS) and Ridgetown Campus, University of Guelph, Ridgetown, Ontario, Canada (RC) (2011 to 2013).[a,b]

Main effects	Rate (g ai ha^{-1})	Timing	Soybean injury 7 DAT-C	Soybean injury 28 DAT-C	Dry biomass	Yield
			%	%	g m^{-1}	T ha^{-1}
Soybean cultivar			NS	NS	NS	**
Pro 2715R			7	7	6.9	2.41 c
5201 RR2Y			6	6	7.1	3.51 a
DKB 2860RY			6	7	7.1	2.93 b
CF 5221 RR2Y			8	9	5.9	3.26 ab
Herbicide treatment			**	**	**	**
Nontreated check			0	0 a	7.2 ab	3.10 abc
pyroxasulfone	89	PPI	1	2 ab	7.4 a	3.03 bcd
pyroxasulfone	178	PPI	1	4 b	6.8 ab	2.91 de
pyroxasulfone	89	PRE	1	2 ab	7.5 a	3.11 abc
pyroxasulfone	178	PRE	1	3 b	7.3 ab	3.11 abc
pyroxasulfone	89	COT	8	4 b	6.7 abc	3.09 abcd
pyroxasulfone	178	COT	12	6 bc	6.6 abc	3.05 abcd
flumioxazin	71	PPI	2	2 ab	7.5 a	3.17 ab
flumioxazin	142	PPI	2	2 ab	7.4 a	3.12 ab
flumioxazin	71	PRE	2	2 ab	7.5 a	3.23 a
flumioxazin	142	PRE	5	5 bc	7.5 a	3.12 ab
flumioxazin	71	COT	17	8 bc	6.1 bc	3.04 bcd
flumioxazin	142	COT	26	24 de	5.7 cd	2.93 cde
Pyroxasulfone + flumioxazin	160	PPI	3	4 b	7.0 a	3.09 abcd
Pyroxasulfone + flumioxazin	320	PPI	3	5 bc	6.9 ab	2.99 bcde
Pyroxasulfone + flumioxazin	160	PRE	3	4 b	7.1 ab	3.00 bcde
Pyroxasulfone + flumioxazin	320	PRE	11	16 cd	6.3 bc	2.94 cde
Pyroxasulfone + flumioxazin	160	COT	30	29 de	5.0 d	2.82 ef
Pyroxasulfone + flumioxazin	320	COT	38	42 e	4.6 d	2.65 f
Interaction						
V × H			**	NS	NS	NS

[a] Abbreviations: DAT-C, days after cotyledon application; PPI, preplant incorporated; COT, cotyledon stage; V, soybean cultivar; H, herbicide treatment.

[b] Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at $P < 0.05$. Means for a main effect were separated only if there was no significant interaction involving that main effect. The 7 and 28 DAT-C data required an arcsine square root and square root transformation, respectively, for analysis, but were back-transformed for the purpose of reporting.

** Significant at $P < 0.01$; NS, not significant at $P = 0.05$ level.

Increased soybean injury has been reported in soils with high moisture after flumioxazin application (Taylor-Lovell et al. 2002). In this study injury, biomass, and yield data could be combined, suggesting that rainfall/soil moisture did not affect injury to such an extent at any location that data required a separate analysis. At the HRS 2012, RC 2011, and RC 2013 locations, rainfall during the month when flumioxazin was applied was equivalent or lower than the 30-yr average. Only the RC 2011 location had a significant rainfall (17.2 mm) 4 d prior to the COT application, and conditions had been dry up to that rainfall event. The HRS 2013 location did have monthly precipitation levels exceeding the 30-yr average during the time of flumioxazin applications; however, injury values were similar to the other three study locations. At the HRS 2013 location there were significant rainfall events 4 d following the PRE application (19.3 mm) and prior to the COT application (18.6 mm over 3 d).

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Table 4. Estimated values for all parameters, ranked according to the relative sensitivity of soybean to three herbicides and three application timings at the Huron Research Station, Exeter, Ontario, Canada (HRS) and Ridgetown Campus, University of Guelph, Ridgetown, Ontario, Canada (RC) (2011 to 2013). Values are ordered from least to most injurious and differences determined using contrasts ($P < 0.05$).[a,b]

Variable	Relative soybean sensitivity				
Herbicides	pyroxasulfone		flumioxazin		pyroxasulfone + flumioxazin
Injury 7 DAT-C (%)	3	<	7	<	12
Injury 28 DAT-C (%)	3	=	6	<	13
Plant stand (no. m^{-1})	26	=	26	=	26
Dry weight (g m^{-1})	7.0	=	6.9	<	6.1
Yield (T ha^{-1})	3.05	=	3.10	<	2.92
Application timings	PPI		PRE		COT
Injury 7 DAT-C (%)	2	=	3	<	21
Injury 28 DAT-C (%)	3	=	5	<	16
Plant stand (no. m^{-1})	26	=	26	=	26
Dry weight (g m^{-1})	7.1	=	7.2	<	5.8
Yield (T ha^{-1})	3.05	=	3.08	<	2.93

[a] Abbreviations: DAT-C, days after cotyledon application; PPI, preplant incorporated; COT, cotyledon stage.

[b] The 7 and 28 DAT-C data required an arcsine square root and square root transformation, respectively for analysis but were back-transformed for the purpose of reporting.

Soybean Plant Stand and Dry Biomass. Plant stand and dry biomass evaluations were conducted 14 DAT-C and neither evaluation parameter had a significant cultivar by herbicide treatment interaction; therefore, cultivars were combined for the purpose of analysis. Despite previously reported findings (Mahoney et al. 2014; Taylor-Lovell et al. 2001) no herbicide treatment at any rate or application timing decreased soybean plant stand in this study. Average soybean stands ranged from 25 to 27 plants m^{-1} of row (data not shown), even for the 320 g ha^{-1} COT pyroxasulfone + flumioxazin treatment where the average injury rating at 28 DAT-C was 42%. Reductions in soybean dry biomass were only noted when soybean was treated at the COT stage with flumioxazin (142 g ha^{-1}) or pyroxasulfone + flumioxazin (160 and 320 g ha^{-1}); biomass was reduced by 21, 30, and 36%, respectively, compared to the nontreated check (Table 3).

Soybean Yield. Similar to the 28 DAT-C plant stand and plant biomass evaluation parameters, there was no cultivar by herbicide treatment interaction, so cultivars could be combined to examine herbicide treatment effects on soybean yield. There were significant yield differences among cultivars when all herbicide treatments were combined (Table 3). Across all herbicide treatments, the lowest yielding cultivar was Pro 2715R with a mean yield of 2.41 T ha^{-1} and the highest yielding cultivars were 5201 RR2Y and CF 5221 RR2Y, with yields of 3.51 and 3.26 T ha^{-1}, respectively.

When the four cultivars were combined to identify any herbicide treatment effects on yield there was an unexpected yield decrease when pyroxasulfone (178 g ha^{-1}) was applied PPI; yield was reduced by 6% compared to the nontreated check (Table 3). Although this treatment caused injury at 28 DAT-C, injury was only 4% and there was no decrease in soybean stand or biomass. However, as expected based on injury and biomass data, 160 and 320 g ha^{-1} of pyroxasulfone + flumioxazin applied COT decreased soybean yield by 9 and 14%, respectively.

Based on this study, some general trends with respect to soybean tolerance to pyroxasulfone, flumioxazin, and pyroxasulfone + flumioxazin can be made. Contrast analysis indicated that at 7 DAT-C, soybean was most sensitive to pyroxasulfone + flumioxazin, then flumioxazin, and finally pyroxasulfone (application timing, herbicide rate, and cultivars combined) (Table 4). By the 14 DAT-C dry biomass rating and 28 DAT-C injury rating, injury to soybean caused by flumioxazin or pyroxasulfone applied alone was similar and less than when

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the two herbicides were combined; this observation persisted until yield. Similarly, when application timing was examined (herbicide, rate, cultivars combined), PPI- or PRE-applied herbicides caused an equivalent degree of injury across ratings and were less injurious than when the herbicides were applied at the COT stage (Table 4). This finding is consistent with industry standards because the flumioxazin component has been registered for use on soybeans prior to ground crack only (Anonymous 2013b,c) and the pyroxasulfone soybean label cautions against use between ground crack and the unifoliate stage despite its registration for early POST use (Anonymous 2013a).

Pyroxasulfone + flumioxazin is a valuable new weed control option for Ontario soybean producers, although care must be taken to ensure that the product is applied prior to crop emergence. This study suggests that yield reductions of at least 9% could occur if the product were applied at the COT stage. PPI and PRE applications of pyroxasulfone + flumioxazin applied at the suggested field and 2× rate appear to be safe because soybean yield was equivalent to the nontreated check in this study. Although yield was not affected when 320 g ha^{-1} pyroxasulfone + flumioxazin was applied PRE, there was a trend towards decreased yield; combined with the observed decrease in plant biomass suggests soybean can be adversely affected in fields where a PRE-applied spray overlap occurs.

Acknowledgments

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