Effect of Foramsulfuron and Isoxaflutole Residues on Rotational Vegetable Crops

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Abstract. There is little information published on the effect of residues from postemergence (POST) applications of foramsulfuron and preemergence (PRE) applications of isoxaflutole, and isoxaflutole plus atrazine in the year after application on vegetable crops. Three trials were established from 2000 to 2002 in Ontario to determine the effects of residues of foramsulfuron, isoxaflutole, and isoxaflutole plus atrazine on cabbage, processing pea, potato, sugar beet, and tomato 1 year after application. Aside from a reduction in sugar beet plant stand, there were no visual injury symptoms in any crop at 7, 14, and 28 days after emergence (DAE) in any of the herbicide carryover treatments. Isoxaflutole residues reduced shoot dry weight and yield as much as 27% and 28% in cabbage, and 57% and 60% in sugar beets, respectively. The addition of atrazine to isoxaflutole caused further reductions in shoot dry weight and yield of cabbage and sugar beet. Isoxaflutole plus atrazine residues reduced shoot dry weight and yield as much as 42% and 43% in cabbage, and 58% and 82% in sugar beets, respectively. There were no adverse effects on shoot dry weight and yield of processing pea, potato, and tomato from isoxaflutole or isoxaflutole plus atrazine residues in the year following application. Foramsulfuron residues at either rate did not reduce shoot dry weight or yield of any crops 1 year after application. Based on these results, it is recommended that cabbage and sugar beet not be grown in the year following the PRE application of isoxaflutole or isoxaflutole plus atrazine.

In southern Ontario, vegetable crops are commonly grown in rotation with agronomic crops such as field corn, as they offer growers greater value than traditional agronomic crops. Vegetable crops differ in their response to residues from herbicides applied in previous years (Greenland, 2003; O'Sullivan et al., 1998, 1999; Vencill et al., 1990).

Foramsulfuron (trade name Option) was recently registered for postemergence (POST) control of grasses and small-seeded broadleaf weeds in field corn [Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 2002; Vencill, 2002]. Sulfonyleurea herbicides are applied at very low use rates, have low mammalian toxicity, and have unprecedented herbicidal activity, and hence have become popular in many parts of the world (Sarmah and Sabadie, 2002). Some sulfonyleurea herbicides have minimal carryover problems while others such as metsulfuron have a minimum rotation restriction of 34 months for some vegetable crops (Schroeder, 1998). Degradation occurs first through acid hydrolysis, which is pH dependent, and later through biological processes involving microorganisms (Sarmah and Sabadie, 2002). Vegetable crops have shown sensitivity to soil residues of a number of sul-

fonylurea herbicides, which have resulted in some restrictions in the selection of rotational crops (Al-Khatib et al., 1992, 1993; Greenland, 2003). There is little published information on the potential for foramsulfuron applied to corn to injure vegetable crops in rotation, especially under northern temperate environmental conditions.

Isoxaflutole plus atrazine (trade name Converge) is another recently registered soil-applied isoxazole plus s-triazine herbicide in corn that provides residual control of broadleaf and grass weeds such as velvetleaf (*Abutilon theophrasti*), redroot pigweed (*Amaranthus retroflexus* L.), smartweed (*Polygonum* spp.), common lambsquarters (*Chenopodium album*), annual nightshades (*Solanum* spp.), fall panicum (*Panicum dichotomiflorum*), common ragweed (*Ambrosia artemisiifolia* L.), giant foxtail (*Setaria faberii*), green foxtail (*Setaria viridis*), yellow foxtail (*Setaria glauca*), and barnyard grass (*Echinochloa crusgalli* L. Beauv.) (OMAFRA, 2004; Vencill, 2002). Degradation occurs through chemical and biological processes. The rate of isoxaflutole breakdown is concurrent with increases in soil moisture and temperature (Beltran et al., 2003). The authors are unaware, however, of any published data that illustrate the effect of isoxaflutole residues alone or in tank mix combination with other herbicides on vegetable crops grown in Ontario 1 year after application.

The objectives of this research were to determine the potential for foramsulfuron, isoxaflutole alone, and isoxaflutole plus atrazine residues to cause injury to cabbage

(*Brassica oleracea* L.), processing pea (*Pisum sativum*), potato (*Solanum tuberosum* L.), sugar beet (*Beta vulgaris*) and tomato (*Lycopersicon esculentum* Mill.), which are grown in rotation with field corn in Ontario.

Materials and Methods

Field studies were established in 2000, 2001, and 2002 at Ridgetown College, Ridgetown, Ontario. Glufosinate-tolerant field corn was planted in a loam soil (pH 6.8, OM 4.6%, sand 51%, silt 31%, clay 18%) in 2000, a silt loam soil (pH 6.3, OM 6.7%, sand 47%, silt 36%, clay 17%) in 2001, and a very fine sandy loam soil (pH 6.4, OM 4.7%, sand 79%, silt 15%, clay 6%) in 2002. Seedbed preparation at all locations consisted of fall moldboard plowing followed by three passes with a field cultivator in the spring.

In the year of herbicide application (i.e., 2000, 2001, 2002), the experimental design was a randomized complete block design with four replications. Each plot was 6 m wide and 22 m long. The following treatments were applied: isoxaflutole preemergence (PRE) at 105 and 210 g·ha⁻¹ a.i., a tank mix of isoxaflutole plus atrazine (PRE) at 105+1063 and 210+2126 g·ha⁻¹ a.i., and foramsulfuron postemergence (POST) at 70 and 140 g·ha⁻¹ a.i., representing the label rate and twice the label rate of the above herbicides or herbicide tank mixes. PRE treatments were made 1 to 2 d after planting to the soil surface and POST treatments were applied to 6 to 7 leaf field corn. Foramsulfuron treatments included 1.75 and 3.50 L·ha⁻¹ of methylated seed oil (MSO) and 2.50 and 5.00 L·ha⁻¹ of 28% urea ammonium nitrate (UAN) at 70 and 140 g·ha⁻¹ a.i., respectively. Treatments also included an untreated control as a check. Field corn was maintained weed free with two applications of glufosinate-ammonium (500 g·ha⁻¹ a.i.), grown to maturity and harvested according to standard agronomic practices.

Herbicide applications were made with a CO₂-pressurized backpack sprayer calibrated to deliver 200 L·ha⁻¹ of spray solution at a pressure of 200 kPa using Teejet 8002 flat-fan nozzles (Spraying Systems Co., Wheaton, Ill.). The boom was 2.5 m long with six nozzles spaced 0.5 m apart.

In the year following herbicide application (i.e., 2001, 2002, and 2003), the trial areas were shallow disked (10 cm depth) followed by two passes with a field cultivator. The experimental design was a randomized complete block with a split-plot arrangement and four replications with herbicide treatment as main plot and rotational crops as subplots. All sub-plots consisted of 6-m-long rows of the five vegetable crops spaced 1.5 m apart planted across the main plot. Plots were planted with cabbage ('Atlantic'), processing pea ('Bolero'), potato ('Superior'), sugar beet ('E 17') and tomato ('Heinz 9478') during mid to late May and fertilized according to recommended Ontario crop production practices. To avoid any weed competition with vegetable crops, the trials were maintained weed free by hand-weeding as required in the re-cropping year.

Percent visual injury of each vegetable

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crop was determined on a scale of 0% to 100% at 7, 14, and 28 d after emergence (DAE). A rating of 0 was defined as no visible plant injury, and a rating of 100 was defined as plant death. Visual crop injury symptoms evaluated included chlorosis of leaves, necrosis of leaves and growth reduction. At 28 DAE, plants were removed from a 1-m² quadrat in each herbicide treatment and in the untreated control. Fresh weights (g-m⁻²) were determined, the plant samples were dried to a constant weight at 80 °C, and dry weight (g-m⁻²) was recorded. The remaining plants in each plot were harvested by hand, and yields (t-ha⁻¹) were determined. Also, the number of plants from a 10-m row of sugar beet plots was counted to determine plant stand.

Statistical analysis. There were no significant treatment × year interactions for all crops evaluated so data were pooled over years for all crops. Assumptions of homogeneity of variance terms and normal distribution of error were confirmed using residual plots and the Shapiro-Wilk normality test. To meet these assumptions, data were transformed using the arcsine transformation, and analysis of variance was conducted on the transformed data using PROC MIXED (SAS Version 8.2). Treatment means were separated using orthogonal contrasts ($\alpha = 0.05$) to compare vegetable crops visual injury, biomass and yield between each herbicide treatment and the untreated control.

Results and Discussion

Cabbage. Foramsulfuron residues caused no visual injury at 7, 14, and 28 DAE (data not shown), and did not reduce shoot dry weight or yield of cabbage at either rates in the year following application (Table 1). Isoxaflutole alone or isoxaflutole plus atrazine residues did not cause any significant visual injury in cabbage at either rate in the year following application (data not shown). However, isoxaflutole residues reduced shoot dry weight 22% and 27%, and yield 22% and 28% at the label rate and twice the label rate, respectively (Table 1). The addition of atrazine to isoxaflutole decreased cabbage shoot dry weight 33% and 42%, and yield 33% and 43% at the label rate and twice the label rate, respectively (Table 1). These levels of yield loss are consistent with those caused by persistent herbicides in other studies. Residues of imazamox and imazethapyr reduced cabbage yield as much as 38% and 51%, respectively, 1 year after application (O'Sullivan et al., 1998). In other studies, residues from other sulfonylurea or ALS-inhibiting herbicides such as nicosulfuron, flumetsulam, and imazethapyr also injured cabbage 1 year after the application (Greenland, 2003; O'Sullivan et al., 1999).

Processing pea. There was no visual injury at 7, 14, and 28 DAE (data not shown), and no reduction in shoot dry weight, tenderness or yield of processing pea in the year after application of foramsulfuron, isoxaflutole, or isoxaflutole plus atrazine (Table 2). Other studies have shown little or no response in processing pea to residues of certain herbicides.

For example, O'Sullivan et al. (1999) observed that flumetsulam, an ALS-inhibiting herbicide, applied in combination with clopyralid was not

injurious to peas 1 year after application. *Potato.* Foramsulfuron, isoxaflutole, and isoxaflutole plus atrazine residues did not cause

Table 1. Effect of herbicide treatment and rate on cabbage shoot dry weight and yield, 1 year after herbicide application.^z

Herbicide treatment ^y	Herbicide rate (g-ha ⁻¹ a.i.)	Shoot dry wt (g-m ⁻²)	Yield (t-ha ⁻¹)
Untreated check	0	124.5	36.7
Foramsulfuron	70	113.6	33.3
Foramsulfuron	140	104.9	30.7
Isoxaflutole	105	97.4*	28.5*
Isoxaflutole	210	91.2*	26.5*
Isoxaflutole plus atrazine	105 + 1063	83.3*	24.5*
Isoxaflutole plus atrazine	210 + 2126	72.5*	21.1*
Standard error		11.9	3.1

^zMeans denoted by an asterisk are significantly different than the untreated check ($p < 0.05$).

^yForamsulfuron treatments were applied postemergence and included 1.75 and 3.50 L-ha⁻¹ of methylated seed oil (MSO) and 2.50 and 5.00 L-ha⁻¹ of 28% urea ammonium nitrate (UAN) at 70 and 140 g-ha⁻¹ a.i., respectively; isoxaflutole and isoxaflutole plus atrazine treatments were applied preemergence.

Table 2. Effect of herbicide treatment and rate on processing pea shoot dry weight, tenderness and yield, 1 year after herbicide application.^z

Herbicide treatment ^y	Herbicide rate (g-ha ⁻¹ a.i.)	Shoot dry wt (g-m ⁻²)	Tenderness (PSI)	Yield (t-ha ⁻¹)
Untreated check	0	33.4	81.7	3.9
Foramsulfuron	70	27.6	79.2	4.1
Foramsulfuron	140	30.6	80.1	3.8
Isoxaflutole	105	26.7	80.2	3.7
Isoxaflutole	210	32.2	81.5	3.9
Isoxaflutole plus atrazine	105 + 1063	26.7	82.6	3.9
Isoxaflutole plus atrazine	210 + 2126	30.3	82.9	3.8
Standard error		8.4	3.6	0.5

^zMeans denoted by an asterisk are significantly different than the untreated check ($p < 0.05$).

^yForamsulfuron treatments were applied postemergence and included 1.75 and 3.50 L-ha⁻¹ of methylated seed oil (MSO) and 2.50 and 5.00 L-ha⁻¹ of 28% urea ammonium nitrate (UAN) at 70 and 140 g-ha⁻¹ a.i., respectively; isoxaflutole and isoxaflutole plus atrazine treatments were applied preemergence.

Table 3. Effect of herbicide treatment and rate on potato shoot dry weight and yield, 1 year after herbicide application.^z

Herbicide treatment ^y	Herbicide rate (g-ha ⁻¹ a.i.)	Shoot dry wt (g-m ⁻²)	Yield (t-ha ⁻¹)
Untreated check	0	107.7	25.4
Foramsulfuron	70	112.0	26.0
Foramsulfuron	140	109.7	22.8
Isoxaflutole	105	105.7	21.7
Isoxaflutole	210	114.6	24.7
Isoxaflutole plus atrazine	105 + 1063	114.0	26.0
Isoxaflutole plus atrazine	210 + 2126	100.9	22.8
Standard error		8.1	2.5

^zMeans denoted by an asterisk are significantly different than the untreated check ($p < 0.05$).

^yForamsulfuron treatments were applied postemergence and included 1.75 and 3.50 L-ha⁻¹ of methylated seed oil (MSO) and 2.50 and 5.00 L-ha⁻¹ of 28% urea ammonium nitrate (UAN) at 70 and 140 g-ha⁻¹ a.i., respectively; isoxaflutole and isoxaflutole plus atrazine treatments were applied preemergence.

Table 4. Effect of herbicide treatment and rate on sugar beet stand count, shoot dry weight and yield, 1 year after herbicide application.^z

Herbicide treatment ^y	Herbicide rate (g-ha ⁻¹ a.i.)	Stand count (10-m row)	Shoot dry wt (g-m ⁻²)	Yield (t-ha ⁻¹)
Untreated check	0	33	32.4	81.9
Foramsulfuron	70	29	29.3	75.5
Foramsulfuron	140	30	28.0	74.8
Isoxaflutole	105	22*	15.8*	48.9*
Isoxaflutole	210	19*	13.9*	32.5*
Isoxaflutole plus atrazine	105 + 1063	20*	14.4*	39.3*
Isoxaflutole plus atrazine	210 + 2126	14*	8.6*	14.4*
Standard error		2	4.8	4.8

^zMeans denoted by an asterisk are significantly different than the untreated check ($p < 0.05$).

^yForamsulfuron treatments were applied postemergence and included 1.75 and 3.50 L-ha⁻¹ of methylated seed oil (MSO) and 2.50 and 5.00 L-ha⁻¹ of 28% urea ammonium nitrate (UAN) at 70 and 140 g-ha⁻¹ a.i., respectively; isoxaflutole and isoxaflutole plus atrazine treatments were applied preemergence.

Table 5. Effect of herbicide treatment and rate on tomato shoot dry weight, marketable yield, non-marketable yield and total yield, 1 year after herbicide application^a.

Herbicide treatment ^b	Herbicide rate (g·ha ⁻¹ a.i.)	Shoot dry wt (g·m ⁻²)	Market yield (t·ha ⁻¹)	Nonmarket yield (t·ha ⁻¹)	Total yield (t·ha ⁻¹)
Untreated check	0	34.4	38.4	9.5	47.9
Foramsulfuron	70	29.1	38.3	9.7	48.1
Foramsulfuron	140	28.0	34.5	9.7	44.2
Isoxaflutole	105	32.0	34.5	11.8	46.2
Isoxaflutole	210	27.9	36.0	15.5	51.5
Isoxaflutole plus atrazine	105 + 1063	27.8	39.1	13.9	52.9
Isoxaflutole plus atrazine	210 + 2126	31.9	36.2	13.4	49.6
Standard error		4.7	4.1	1.2	4.4

^aMeans denoted by an asterisk are significantly different than the untreated check ($p < 0.05$).

^bForamsulfuron treatments were applied postemergence and included 1.75 and 3.50 L·ha⁻¹ of methylated seed oil (MSO) and 2.50 and 5.00 L·ha⁻¹ of 28% urea ammonium nitrate (UAN) at 70 and 140 g·ha⁻¹ a.i., respectively; isoxaflutole and isoxaflutole plus atrazine treatments were applied preemergence.

visual injury at 7, 14, and 28 DAE (data not shown), and did not reduce shoot dry weight or yield of potato in the year after herbicide application (Table 3). Potato response to herbicides is variable in the literature. O'Sullivan et al. (1998) reported up to 25% visual injury and as much as 23% yield reductions in potato with some ALS-inhibiting herbicides (imazethapyr and imazamox) residues 1 year after application. However, other studies have reported little adverse effects on potato yield 1 year after the application of nicosulfuron, flumetsulam, clopyralid, picloram, and dicamba (Greenland, 2003; O'Sullivan et al., 1999; Thorsness and Messersmith 1991).

Sugar beet. There was no significant visual injury in sugar beet 7, 14, and 28 DAE with the herbicides evaluated (data not shown). Foramsulfuron residues at either rate did not reduce stand count, shoot dry weight or yield of sugar beet the year after application (Table 4). However, isoxaflutole residues reduced sugar beet stands 33% and 42%, shoot dry weight 51% and 57%, and yield 40% and 60% at the label rate and twice the label rate, respectively (Table 4). The addition of atrazine to isoxaflutole increased crop injury responses. Isoxaflutole plus atrazine residues, reduced stand count 39% and 58%, shoot dry weight 56% and 73%, and yield 52% and 82% at the label rate and twice the label rate, respectively (Table 4). The injury seen with isoxaflutole plus atrazine is consistent with injuries seen in sugar beets by other investigators in Minnesota with ALS inhibiting-herbicides such as imazamox 1 year after treatment (Bresnahan et al. 2002).

Tomato. Foramsulfuron, isoxaflutole, and isoxaflutole plus atrazine residues at either rate did not have any adverse effects on visual injury of tomato at 7, 14, and 28 DAE (data

not shown), shoot dry weight, and marketable, non-marketable and total yield in the year after herbicide application (Table 5). O'Sullivan et al. (1998) found only minor crop injury with imazamox residues while the crop injury in tomatoes was significant with imazethapyr residues 1 year after application. Other studies have reported no visual injury and no yield reduction in tomato from sulfonylurea herbicides residues such as nicosulfuron or other ALS-inhibiting herbicides residues such as flumetsulam, imazamox or imazethapyr in the year following application (Greenland, 2003).

Conclusions

The three study locations had acidic, loam soils, which were characteristic of much of the vegetable-growing area in southwestern Ontario. There was no effect of foramsulfuron residues on visual injury, shoot dry weight, and yields of cabbage, processing peas, potato, sugar beet and tomato planted 1 year after herbicide application.

The effect of isoxaflutole and isoxaflutole plus atrazine residues on shoot dry weight and yield varied among cabbage, processing pea, potato, sugar beet and tomato planted 1 year after herbicide application. Biomass reductions and yield losses occurred at both rates of isoxaflutole, and isoxaflutole plus atrazine in cabbage and sugar beets. However, residues from isoxaflutole and isoxaflutole plus atrazine caused no growth reduction in processing peas, potato and tomato at either rate.

Based on these results, cabbage, processing peas, potato, sugar beet and tomato can be safely grown in rotation with field corn treated with foramsulfuron applied POST. It is recommended that cabbage and sugar beet

not be grown in the year following the PRE application of isoxaflutole or isoxaflutole plus atrazine. However, processing pea, potato, and tomato can be grown in the year following PRE application of isoxaflutole or isoxaflutole plus atrazine.

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