

## Research Article

# Weed Management in Spring Seeded Barley, Oats, and Wheat with Prosulfuron

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A limited number of preplant (PP) herbicides are available for spring seeded cereals in Ontario. Six field trials were conducted at the Huron Research Station, Exeter, Ontario, over a two-year period (Exeter, 2010 and 2011) to evaluate glyphosate, prosulfuron, and glyphosate plus prosulfuron applied PP for weed management in spring seeded no-till barley, oats, and wheat. There was no injury in barley, oats, and wheat with glyphosate, prosulfuron, and glyphosate plus prosulfuron applied preplant at the rates evaluated at 1, 2, and 4 weeks after crop emergence. Prosulfuron provided 49–99% control of AMBEL, 28% or less control of CONAR, 31–94% control of POLCO, 49–98% control of SINAR, and 46–79% control of SONAR. Prosulfuron in combination with glyphosate provided 73–98% control of AMBEL, less than 43% control of CONAR, 39–94% control of POLCO, 63–98% control of SINAR, and 60–85% control of SONAR. Prosulfuron reduced density of AMBEL 76% and SINAR 93% but had no significant effect on density of CONAR, POLCO, or SONAR. Prosulfuron in combination with glyphosate reduced biomass of AMBEL as much as 96% and SINAR 98% but had no significant effect on biomass of CONAR, POLCO, or SONAR. Yield of barley, oats, and wheat was not affected with glyphosate, prosulfuron, and glyphosate plus prosulfuron at the rates evaluated.

## 1. Introduction

Cereals are important crops grown on approximately 25% of the arable land in Ontario [1]. The most widely grown cereals in Ontario are winter wheat followed by spring barely (*Hordeum vulgare* L.), spring wheat (*Triticum aestivum* L.), and oats (*Avena sativa* L.) [1]. Cereals are popular rotational crops for growers as they help maintain soil structure and break weed cycles. One of the most significant aspects of spring cereal production is weed management. Substantial crop yield and associated economic losses can occur if weeds are not adequately controlled. With the increased interest in reduced and no-till spring cereal production in Ontario, it would be advantageous for producers if herbicides that provide residual broadleaved weed control could be added to glyphosate applied preplant. This would allow growers to combine two weed management operations and increase production efficiency. Spring cereal grower need new residual herbicides that provide selective and consistent control of annual broadleaved weeds to improve their competitive position in the global market.

Prosulfuron is a sulfonylurea herbicide that controls certain annual broadleaved weeds including *Abutilon theophrasti* Medic. (velvetleaf), *Xanthium strumarium* L. (common cocklebur), *Chenopodium album* L. (common lambsquarters), *Amaranthus retroflexus* L. (redroot pigweed), *Polygonum* spp., *Ambrosia* spp. (ragweed), and *Kochia scoparia* L. (Kochia) [2, 3]. Sulfonylurea herbicides inhibit the production of branched-chain amino acids, including valine, leucine, and isoleucine [3]. Without these amino acids, protein synthesis is not possible, and susceptible plants cease growth and die. Sulfonylurea herbicides are applied at low doses and have high level of herbicide activity [3]. Sulfonylurea herbicides are absorbed quickly by the shoots or roots of susceptible plants and are translocated throughout the plant. Visible injury symptoms from sulfonylurea herbicides in susceptible plants include severely stunted growth, a red to purple colouring of grass weed foliage, and chlorosis and necrosis eventually spreading from the meristems throughout the plant [2, 3]. Sulfonylurea herbicides have a favorable environmental and toxicological profile with relatively low toxicity to mammals, birds, and aquatic species [2, 3].

There is limited information published on the tolerance of spring seeded barley, oats, and wheat to prosulfuron and the efficacy of prosulfuron for the control of broadleaf weeds under Ontario environmental conditions. Prosulfuron at relatively low use doses can provide growers with season-long control of some annual broadleaved weeds including triazine-resistant biotypes in spring seeded barley, oats, and wheat. Prosulfuron can be tank mixed with glyphosate applied preplant in no-tillage cropping systems to combine two weed management operations.

The objective of this research was to evaluate glyphosate, prosulfuron, and glyphosate plus prosulfuron applied preplant (PP) for weed management in spring seeded no-till barley, oats, and wheat.

## 2. Materials and Methods

Six field studies were conducted at the Huron Research Station, Exeter, Ontario, over a two-year period (Exeter, 2010 and 2011). The soils for the study sites were a Brookston clay loam with 29–32% sand, 40–44% silt, 27–28% clay, and pH of 7.7–7.9. All of the experiments were established using no-tillage crop production systems.

There were three trials established in each year (one for each cereal type: barley, oats, and wheat) adjacent to each other as a randomized complete block design with four replications. Treatments included a weedy control, a weed-free control, glyphosate ( $900 \text{ g ae ha}^{-1}$ ), prosulfuron (2.5, 5, and  $10 \text{ g ai ha}^{-1}$ ), and glyphosate plus prosulfuron ( $900 + 2.5$ ,  $900 + 5$ , and  $900 \text{ g ae ha}^{-1} + 10 \text{ g ai ha}^{-1}$ ) applied preplant (PP). All prosulfuron treatments/tank mixtures included a nonionic surfactant (Agral 90 at 0.2% v/v). Plots for each trial were 2 m wide and 10 m long. Spring seeded barley (Bornholm), oats (Sherwood), and wheat (Hobson) were seeded with a double disc drill at  $140 \text{ kg ha}^{-1}$  in rows spaced 17.5 cm apart at a depth of 4 cm in late April.

The PP herbicide treatments were applied within 4 days before seeding. Treatments were applied with a  $\text{CO}_2$  pressurized backpack sprayer calibrated to deliver  $200 \text{ L ha}^{-1}$  at 240 kPa. The boom was 1.5 m long with four Hypro-ULD 120-02 nozzles (Hypro Corp., New Brighton, MN, USA) spaced 50 cm apart.

Crop injury and weed control in spring cereals (barley, oat, and wheat) were estimated visually on a scale of 0 (no injury/control) to 100% (complete plant death). Injury was rated at 1, 2, and 4 weeks after crop emergence (WAE) and weed control for common ragweed (AMBEL), field bindweed (CONAR), wild buckwheat (POLCO), wild mustard (SINAR), and perennial sowthistle (SONAR) was rated at 2, 4, and 8 WAE. Spring cereals were harvested at maturity with a small plot combine, weight and seed moisture content were recorded, and yields were adjusted to 14.8% (barley), 13.5% (oat), and 14% (wheat) seed moisture content.

Data were analyzed as an RCBD using PROC MIXED in SAS 9.2 [4]. Herbicide treatment was considered a fixed effect, while environment (year-location combinations), the interaction between environment and herbicide treatment, and replicate nested within environment were considered

random effects. Significance of the fixed effect was tested using *F*-test and random effects were tested using a *Z*-test of the variance estimate. Environments were combined for all variables. The UNIVARIATE procedure was used to test data for normality and homogeneity of variance. For all weed control ratings, the untreated control (assigned a value of zero) was excluded from the analysis. However, all values were compared independently to zero to evaluate treatment differences with the untreated control. To satisfy the assumptions of the variance analyses, 2 WAE weed control ratings for AMBEL and POLCO were arcsine square root transformed; 4 WAE weed control ratings for CONAR were square root transformed; 4 WAE weed control ratings for AMBEL were arcsine square root transformed; 8 WAE weed control ratings for SINAR were arcsine square root transformed; plant density for AMBEL, CONAR, SINAR, and SONAR was log transformed; plant density for POLCO was square root transformed; plant dry weight for AMBEL, POLCO, SINAR, and SONAR was log transformed. Treatment comparisons were made using Fisher's protected LSD at a level of  $P < 0.05$ . Data compared on the transformed scale were converted back to the original scale for presentation of results. Environment by cereal type by rate interaction was not significant for all variables evaluated; therefore, the three datasets were analyzed together (Tables 1–5).

## 3. Results and Discussion

**3.1. Injury.** There was no injury in spring seeded barley, oats, and wheat with glyphosate, prosulfuron, and glyphosate plus prosulfuron applied preplant at the rates evaluated at 1, 2, and 4 WAE (data not shown). The absence of injury observed in this study is similar to the level of injury found with many currently used POST herbicides in cereals such as 2,4-D, MCPA, dichlorprop plus 2,4-D, and bromoxynil plus MCPA [2, 5–10].

**3.2. Weed Control.** Prosulfuron applied PP provided 60–99, 49–95, and 67–86% control of AMBEL at 2, 4, and 8 WAE, respectively (Table 1). Prosulfuron ( $10 \text{ g ai ha}^{-1}$ ) reduced AMBEL density 76% and AMBEL biomass 96% in spring seeded cereals (Table 1). Prosulfuron in combination with glyphosate applied PP provided 83–97, 77–98, and 73–88% control of AMBEL at 2, 4, and 8 WAE, respectively (Table 1). Glyphosate plus prosulfuron ( $10 \text{ g ai ha}^{-1}$ ) applied PP reduced AMBEL density 76% and AMBEL biomass 91% in spring seeded cereals compared to the weedy control (Table 1). AMBEL percent control generally increased as the prosulfuron or glyphosate plus prosulfuron rate was increased although results were not always statistically significant.

Prosulfuron applied PP alone or in combination with glyphosate at rates evaluated provided minimal (4–43%) control of CONAR and caused no significant reduction in CONAR density and biomass compared to the weedy control (Table 2).

Prosulfuron applied PP provided 51–94, 31–71, and 37–76% control of POLCO at 2, 4, and 8 WAE, respectively (Table 3). Prosulfuron in combination with glyphosate

TABLE 1: Visual estimates of percent AMBEL weed control at 2, 4, and 8 WAE as well as weed density and dry weight with different rates of prosulfuron alone and in combination with glyphosate on spring cereals at Exeter, Ontario, in 2010-2011. Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at  $P < 0.05^z$ .

Treatment	Rate g ai ha <sup>-1</sup>	Weed control						Density		Dry weight	
		2 WAE		4 WAE		8 WAE		Plant number		Grams	
				%							
Weedy control		0	f	0	e	0	e	3.4	c	2.3	c
Weed-free		100	a	100	a	100	a	0.0	a	0.0	a
Glyphosate	900	17	e	32	d	58	d	3.3	c	1.2	b
Prosulfuron <sup>y</sup>	2.5	60	d	49	d	67	cd	2.4	bc	0.9	ab
Prosulfuron <sup>y</sup>	5.0	91	bc	86	bc	80	bc	1.4	ab	0.3	a
Prosulfuron <sup>y</sup>	10.0	99	ab	95	abc	86	ab	0.8	a	0.1	a
Glyphosate + prosulfuron <sup>y</sup>	900 + 2.5	83	c	77	c	73	bcd	2.1	bc	0.8	ab
Glyphosate + prosulfuron <sup>y</sup>	900 + 5.0	92	bc	80	c	82	bc	0.8	a	0.3	a
Glyphosate + prosulfuron <sup>y</sup>	900 + 10.0	97	ab	98	ab	88	ab	0.8	a	0.2	a

<sup>z</sup> AMBEL: common ragweed; WAE: weeks after crop emergence.

<sup>y</sup> Agral 90 added at 0.2% v/v.

TABLE 2: Visual estimates of percent CONAR weed control at 2, 4, and 8 WAE as well as weed density and dry weight with different rates of prosulfuron alone and in combination with glyphosate on spring cereals at Exeter, Ontario, in 2010-2011. Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at  $P < 0.05^z$ .

Treatment	Rate g ai ha <sup>-1</sup>	Weed control						Density <sup>x</sup>		Dry weight <sup>x</sup>	
		2 WAE		4 WAE		8 WAE		Plant number		Grams	
				%							
Weedy control		0	d	0	e	0	d	9.5		20.9	
Weed-free		100	a	100	a	100	a	0.0		0.0	
Glyphosate	900	20	c	20	bc	23	bc	9.1		37.6	
Prosulfuron <sup>y</sup>	2.5	18	c	4	d	18	bc	10.6		36.0	
Prosulfuron <sup>y</sup>	5.0	17	c	13	cd	33	bc	9.6		25.1	
Prosulfuron <sup>y</sup>	10.0	28	bc	16	bcd	17	c	5.9		30.7	
Glyphosate + prosulfuron <sup>y</sup>	900 + 2.5	42	b	23	bc	40	b	10.7		44.9	
Glyphosate + prosulfuron <sup>y</sup>	900 + 5.0	41	b	22	bc	31	bc	11.5		39.1	
Glyphosate + prosulfuron <sup>y</sup>	900 + 10.0	43	b	33	b	39	bc	10.5		48.0	

<sup>z</sup> CONAR: field bindweed; WAE: weeks after crop emergence.

<sup>y</sup> Agral 90 added at 0.2% v/v.

<sup>x</sup> Treatments were not statistically significant.

applied PP provided 70–94, 52–78, and 39–77% control of POLCO at 2, 4, and 8 WAE, respectively (Table 3). Prosulfuron applied PP alone or in combination with glyphosate at rates evaluated provided no significant reduction in POLCO density and biomass compared to the weedy control (Table 3).

Prosulfuron applied PP provided 49–88, 47–83, and 68–98% control of SINAR at 2, 4, and 8 WAE, respectively (Table 4). Prosulfuron (10 g ai ha<sup>-1</sup>) reduced SINAR density 93% and SINAR biomass 98% compared to the weedy control in spring seeded cereals (Table 4). Prosulfuron in combination with glyphosate applied PP provided 63–87, 66–86, and 67–98% control of SINAR at 2, 4, and 8 WAE, respectively (Table 4). Glyphosate plus prosulfuron (10 g ai ha<sup>-1</sup>) applied PP reduced SINAR density 93% and SINAR biomass 98% compared to the weedy control in spring seeded cereals (Table 4). SINAR percent control generally increased as

the prosulfuron or glyphosate plus prosulfuron rate was increased although results were not always statistically significant.

Prosulfuron applied PP alone or in combination with glyphosate at rates evaluated provided 67–85% control of SONAR at 2 WAE but had no significant effect on SONAR control at 4 and 8 WAE or SONAR density and biomass compared to the weedy control (Table 5).

In other studies, residual herbicides such as mesotrione provided 80% or greater reduction in density and biomass of CHEAL and SINAR but provided less than 80% reduction in density and biomass of AMBEL and POLCO in spring seeded wheat, barley, and oats [11].

3.3. Yield. Yields ranged from 3.3 to 3.7 t ha<sup>-1</sup> for spring seeded barley, oats, and wheat (data not shown). There was

TABLE 3: Visual estimates of percent POLCO weed control at 2, 4, and 8 WAE as well as weed density and dry weight with different rates of prosulfuron alone and in combination with glyphosate on spring cereals at Exeter, Ontario, in 2010-2011. Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at  $P < 0.05^z$ .

Treatment	Rate g ai ha <sup>-1</sup>	Weed control						Density <sup>x</sup>		Dry weight <sup>x</sup>	
		2 WAE	4 WAE		56 DAE		Plant number		Grams		
			%								
Weedy control		0	e	0	f	0	f	3.3		0.7	
Weed-free		100	a	100	a	100	a	0.0		0.0	
Glyphosate	900	44	d	44	de	28	ef	4.9		1.1	
Prosulfuron <sup>y</sup>	2.5	51	d	31	e	37	e	7.1		1.0	
Prosulfuron <sup>y</sup>	5.0	84	bc	65	bc	56	cd	6.2		0.8	
Prosulfuron <sup>y</sup>	10.0	94	ab	71	b	76	b	6.6		0.8	
Glyphosate + prosulfuron <sup>y</sup>	900 + 2.5	70	cd	52	cd	39	de	5.0		0.7	
Glyphosate + prosulfuron <sup>y</sup>	900 + 5.0	84	bc	68	bc	62	bc	4.0		0.7	
Glyphosate + prosulfuron <sup>y</sup>	900 + 10.0	94	ab	78	b	77	b	4.3		0.4	

<sup>z</sup>POLCO: wild buckwheat; WAE: weeks after crop emergence.

<sup>y</sup>Agral 90 added at 0.2% v/v.

<sup>x</sup>Treatments were not statistically significant.

TABLE 4: Visual estimates of percent SINAR weed control at 2, 4, and 8 WAE as well as weed density and dry weight with different rates of prosulfuron alone and in combination with glyphosate on spring cereals at Exeter, Ontario, in 2010-2011. Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at  $P < 0.05^z$ .

Treatment	Rate g ai ha <sup>-1</sup>	Weed control						Density		Dry weight	
		2 WAE	4 WAE		8 WAE		Plant number		Grams		
			%								
Weedy control		0	f	0	f	0	e	4.6	d	11.2	d
Weed-free		100	a	100	a	100	a	0.0	a	0.0	a
Glyphosate	900	31	e	28	e	41	d	1.5	bc	2.1	c
Prosulfuron <sup>y</sup>	2.5	49	d	47	d	68	cd	2.0	c	1.6	abc
Prosulfuron <sup>y</sup>	5.0	77	bc	66	c	83	abc	0.7	ab	0.4	abc
Prosulfuron <sup>y</sup>	10.0	88	ab	83	abc	98	ab	0.3	a	0.2	ab
Glyphosate + prosulfuron <sup>y</sup>	900 + 2.5	63	cd	66	c	67	cd	1.5	bc	1.8	bc
Glyphosate + prosulfuron <sup>y</sup>	900 + 5.0	74	bc	74	bc	80	bc	0.8	abc	0.6	abc
Glyphosate + prosulfuron <sup>y</sup>	900 + 10.0	87	ab	86	ab	98	ab	0.3	a	0.2	ab

<sup>z</sup>SINAR: wild mustard; WAE: weeks after crop emergence.

<sup>y</sup>Agral 90 added at 0.2% v/v.

TABLE 5: Visual estimates of percent SONAR weed control at 2, 4, and 8 WAE as well as weed density and dry weight with different rates of prosulfuron alone and in combination with glyphosate on spring cereals at Exeter, Ontario, in 2010-2011. Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at  $P < 0.05^z$ .

Treatment	Rate g ai ha <sup>-1</sup>	Weed control				Density <sup>x</sup>		Dry weight <sup>x</sup>	
		2 WAE	4 WAE		8 WAE	Plant number		Grams	
			%						
Weedy control		0	c	0	0	2.6		4.0	
Weed-free		100	a	100	100	0.0		0.0	
Glyphosate	900	74	b	73	63	2.0		2.5	
Prosulfuron <sup>y</sup>	2.5	69	b	55	60	1.5		2.2	
Prosulfuron <sup>y</sup>	5.0	67	b	59	55	1.3		1.7	
Prosulfuron <sup>y</sup>	10.0	70	b	79	46	1.9		2.5	
Glyphosate + prosulfuron <sup>y</sup>	900 + 2.5	79	b	74	74	0.9		1.3	
Glyphosate + prosulfuron <sup>y</sup>	900 + 5.0	85	a	71	63	1.0		0.9	
Glyphosate + prosulfuron <sup>y</sup>	900 + 10.0	75	b	73	60	1.5		1.8	

<sup>z</sup>SONAR: perennial sowthistle; WAE: weeks after crop emergence.

<sup>y</sup>Agral 90 added at 0.2% v/v.

<sup>x</sup>Treatments were not statistically significant.

no adverse effect on yield of barley, oats, and wheat compared to the untreated control when treated with glyphosate, prosulfuron, and glyphosate plus prosulfuron applied PP at the rates evaluated (data not shown). In other studies, residual herbicides such as mesotrione had no adverse effect on yield of spring barley or spring oats but caused a decrease in the yield of spring wheat of up to 14% [11]. Saflufenacil applied POST also reduced yield of spring barley 24% and spring wheat 13% but had no effect on the yield of spring oats [12].

#### 4. Conclusions

Based on this study, there was no injury in spring seeded barley, oats, and wheat with glyphosate, prosulfuron, and glyphosate plus prosulfuron applied PP at the rates evaluated. Prosulfuron applied PP at higher doses has potential to control AMBEL, SINAR, and POLCO but does not adequately control CONAR and SONAR. Prosulfuron in combination with glyphosate applied PP similarly provided adequate control of AMBEL, SINAR, and POLCO at the high dose but did not adequately control CONAR and SONAR at all doses evaluated. Yield of spring barley, spring wheat, and spring oats was not adversely affected with glyphosate, prosulfuron, and glyphosate plus prosulfuron applied PP at rates evaluated. Based on this study, prosulfuron alone or in combination with glyphosate can be safely used in no-till spring seeded barley, oats, and wheat for the control of some broadleaf weeds.

#### Abbreviations

AMBEL: Common ragweed  
 CONAR: Field bindweed  
 PP: Preplant  
 PRE: Preemergence  
 POST: Postemergence  
 POLCO: Wild buckwheat  
 SINAR: Wild mustard  
 SONAR: Perennial sowthistle  
 WAE: Weeks after crop emergence.

#### Conflict of Interests

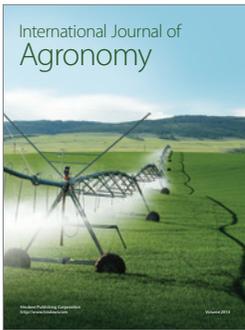
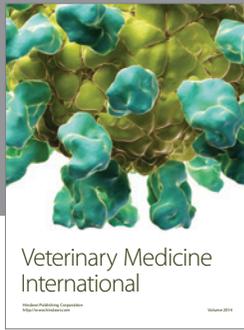
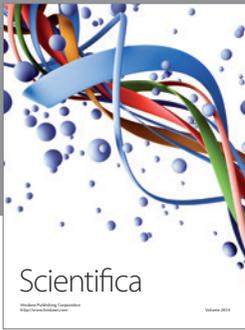
The authors declare that there is no conflict of interests regarding the publication of this paper.

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