Response of Pumpkin to Over-the-Top Applications of *S*-Metolachlor

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Abstract. Expanding preemergence herbicide registrations to include over-the-top (OTT) applications of *S*-metolachlor in pumpkins could extend the duration of residual weed control, which would provide the crop with a competitive advantage over weeds. In 2021, field trials were conducted at two locations in Indiana (IN) and a single location each in Delaware (DE), Maryland (MD), Michigan (MI), North Carolina (NC), North Dakota (ND), New Jersey (NJ), New York (NY), Ohio (OH), and Pennsylvania (PA) to evaluate the safety of *S*-metolachlor OTT in jack-o-lantern varieties across multiple production regions. All locations included treatments consisting of *S*-metolachlor applied at 1.4 and 2.8 kg·ha^{-1} at one of two timings (early or late). At some locations, additional treatments included halosulfuron-methyl at 26 g·ha^{-1} a.i., combined with 0.25% (v/v) nonionic surfactant tank-mixed with *S*-metolachlor and applied as previously described. With the exception of MI [20 d after planting (DAP)], early applications were made 12 to 15 DAP. Late applications were made between 25 and 31 DAP at all locations. *S*-metolachlor applied at 1.4 or 2.8 kg·ha^{-1} caused less than 10% crop injury within a week of application, which declined over time. The highest injury levels were observed with early applications and on loamy sand soils containing ≤2% organic matter. The addition of halosulfuron-methyl significantly increased crop injury to 15% at 1 week after treatment (WAT), with early applications causing more severe damage (25%) than late applications (11%), although pumpkins recovered completely by 6 WAT. Although total and marketable fruit yields were unaffected by herbicide treatments, adding halosulfuron-methyl to OTT application reduced marketable fruit numbers to 84% of the standard control and decreased the proportion of large fruits from 97% to 65%. *S*-metolachlor applied at 2.8 kg·ha^{-1} tended to reduce the percentage of commercial-grade fruit and, depending on application timing, increased the proportion of small fruit. Results indicate that applications of *S*-metolachlor at 1.4 kg·ha^{-1} a.i. applied 12 to 31 DAP causes minimal crop injury and yield loss and could be a valuable tool for extending residual weed control in pumpkins.

In 2024, US producers harvested 28,000 ha of pumpkins with a value exceeding $274 million; Illinois (6230 ha), IN (2870 ha), PA (2750 ha), MI (2060 ha), California (1900 ha), Virginia (1900 ha), OH (1820 ha), NC (1660 ha), NY (1620 ha), and Wisconsin (1250 ha) were the top 10 producing states (USDA-NASS 2024). Most of the US pumpkin production ($262 million) is destined for fresh market utilization, with the remainder processed into canned products, primarily puree. Pumpkin yield and quality can be greatly reduced by numerous pests, including weeds. Weed interference can decrease fruit weight and diameter, resulting in lost farm revenue (Walters and Young 2022). Weeds may also alter the microclimate around the crop, facilitating disease development (Van Wychen 2022b). In addition, weeds can impede mechanical or manual harvesting by obstructing access to the pumpkins, leading to delays and increased labor costs. Pigweeds (*Amaranthus* spp.), common lambsquarters (*Chenopodium album*), nutsedges (*Cyperus* spp.), ragweeds (*Ambrosia* spp.), and crabgrasses (*Digitaria* spp.) are the most commonly occurring weeds across all cucurbit crops, including pumpkins, with the most troublesome species including pigweeds, nutsedges, common lambsquarters, and morningglories (*Ipomoea* spp.) (Van Wychen 2022a).

Unlike many annual agronomic and vegetable crops, pumpkins are planted at relatively low densities, which delays canopy closure and allows weeds to become established between the pumpkin plants. Planting density recommendations vary according to cultivar growth habit (bush vs. vining) with between- and within-row spacing ranging from 1.2 to 2.4 m and 0.5 to 1.5 m, respectively (Phillips et al. 2024). Although some growers use polyethylene mulch or ended cover crops to provide a physical barrier to emerging weed seedlings, pumpkin weed control is primarily based on the combined use of preplant tillage, between-row cultivation, and herbicide applications. With the exception of halosulfuron-methyl, clethodim, and sethoxydim, which may be applied OTT of the pumpkin crop, postemergence (POST) herbicide applications are limited to preplant or between-row use of carfentrazone, glyphosate, and paraquat (Phillips et al. 2024). Residual, preemergence (PRE) herbicide options are limited to trifluralin, ethalfluralin, clomazone, bensulide, *S*-metolachlor, and fomesafen, with application patterns varying based on market destination (fresh vs. processing) and state-specific 24(c) Special Local Need (SLN) labels. In addition, broadcast PRE applications are confined to "at planting" and may not offer adequate residual weed control throughout the long growing season required for pumpkins (Walters and Young 2022). Expanding the registration of some PRE herbicides to allow for posttransplant OTT applications could help extend residual control and reduce reliance on POST herbicides, especially important given the limited number of available POST herbicide options. Preliminary and glasshouse studies indicate that *S*-metolachlor demonstrated potential as a relatively safe herbicide for this application strategy (Vollmer et al. 2024).

S-metolachlor is a Weed Science Society of America Group 15 chloroacetamide herbicide that inhibits very long chain fatty acid synthesis (Shaner 2014). *S*-metolachlor has been shown to provide excellent control of weeds that are problematic in cucurbit crops, including smooth pigweed (*Amaranthus hybridus* L.), redroot pigweed (*Amaranthus retroflexus* L.), American black nightshade (*Solanum americanum* Mill.), giant foxtail (*Setaria faberi*

Herrm.), and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] (Besançon et al. 2020; Ferebee et al. 2019; Van Wychen 2022a). Cucurbit crops differ in their responses to *S*-metolachlor, with applications to *Cucurbita pepo* resulting in acceptable levels of crop safety (Bean et al. 2023; Besançon et al. 2020; Sosnoskie et al. 2008; Vollmer et al. 2024). Although *S*-metolachlor is registered in pumpkins, its use pattern can differ between the federal Section 3 label and state-specific 24(c) SLN labels. For example, to ensure crop safety, the Section 3 label for *S*-metolachlor requires that the applicator maintain an area of untreated soil 15 cm in all directions from a planted row or hill (Syngenta 2024). However, some state 24(c) labels (e.g., Georgia, MI, or Oregon) allow for a broadcast application over the entire field with no stated buffer requirement (Syngenta 2025). Additional field research across representative pumpkin-producing states in the United States is necessary to support Section 3 label modifications that promote consistent and simplified use of *S*-metolachlor across regions. The goal is to standardize the *S*-metolachlor label for use in pumpkins nationally, eliminating the need for additional residue testing or multiple state-specific 24(c) labels. Therefore, the objective of this study was to evaluate pumpkin crop response to OTT applications of *S*-metolachlor while adhering to the current maximum total application rate (1.4 kg·ha^{-1}) and preharvest interval (30 d).

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Materials and methods

Environments. Field trials were conducted in 2021 at two locations in IN (Lafayette and Vincennes) and a single location each in DE, MD, MI, OH, PA, NJ, NY, NC, and ND. GPS coordinates, soil type and properties, and pumpkin cultivars seeded at each location are reported in Table 1. Sites selected in each state represented typical pumpkin production environments and adhered to local production recommendations (Fig. 1). All pumpkin cultivars used in this study were orange-skinned, jack-o-lantern types. Pumpkins were direct-seeded at all locations from May 20 (MI) to Jul 28 (OH) at densities ranging from 3100 (IN) to 8700 plants/ha (PA) (Table 1). Within 1 DAP, all trial sites received a premix application of ethalfluralin (897 g·ha^{-1} a.i.) and clomazone (280 g·ha^{-1} a.i.) labeled for pumpkin use (Strategy™, Loveland Products, Inc., Greeley, CO, USA) to minimize weed interference.

Treatments. The study used a three-factor factorial design with the factors being *S*-metolachlor rate, application timing, and tank-mixture with halosulfuron-methyl. Treatments were arranged in a randomized complete block design with either three (DE, MD, NY, and PA) or four replicates (IN-Lafayette, IN-Vincennes, MI, OH, NJ, and ND). The number of treatments and replications at each location varied according to the locally available research capacity. All locations evaluated *S*-metolachlor (Dual Magnum®, Syngenta Crop Protection, LLC, Greensboro, NC, USA) applied at 1.4 and 2.8 kg·ha^{-1}. The 1.4 kg·ha^{-1} rate represents the current maximum labeled application rate, whereas the 2.8 kg·ha^{-1} rate represents a 2x exaggerated dose frequently required by regulatory agencies to assess crop safety margins. Herbicides were applied at two timings, either early (12–15 DAP, 20 DAP in MI) or late (25–31 DAP). The average time between the early and late applications was 14 d, ranging from 11 d (MI) to 18 d (NC). The third factor involved tank-mixing halosulfuron-methyl (Sandea® 75%, Gowan Company, LLC, Yuma, AZ, USA) at 26 g·ha^{-1} a.i. plus 0.25% (v/v) nonionic surfactant with *S*-metolachlor. The sites at OH, PA, and ND did not include the treatments with the addition of halosulfuron-methyl.

All applications were broadcast-applied with either backpack or tractor-mounted sprayers calibrated to deliver 140 to 187 L·ha^{-1} at 97 to 207 kPa and fitted with 80 or 110° flat fan spray tips (TeeJet Technologies, Glendale Heights, IL, USA). A standard control treatment receiving only the PRE application of clomazone and ethalfluralin was included for comparison.

Data collection. At all locations, visual crop injury was assessed using a scale ranging from 0 (no injury) to 100% (crop death), relative to the standard control, at 1, 2, and 4 WAT. Identical assessments were collected at 6 WAT in NC, NJ, and OH. Across sites, stunting was the predominant injury response, with minor chlorosis and necrosis also incorporated into the overall crop injury rating. A single harvest was conducted at all locations (Table 1) except in OH, where late-season disease caused complete crop failure. In DE, IN (Lafayette and Vincennes), MD, MI, NJ, NY, and NC, all mature fruit were harvested from each plot and classified as either orange (commercially acceptable) or green based on their predominant surface color. Fruits were then counted and weighed. Total

Table 1. Geographic coordinates, soil properties, and crop parameters for *S*-metolachlor over-the-top application sites in pumpkin in 2021.

Site name[i]	GPS coordinates	Texture	pH	OM (%)	Cultivar	Planting density (per ha)	Planting date[ii]	Harvest date[iii]
Delaware	38.64°N, 75.46°W	Loamy sand	6.2	1.2	Gladiator	3700	Jun 16	Sep 7
IN-Lafayette	40.29°N, 86.88°W	Silty clay loam	6.1	3.3	Bayhorse Gold	3100	Jun 8	Sep 1
IN-Vincennes	38.74°N, 87.49°W	Sandy loam	7.0	1.6	Bayhorse Gold	4600	Jun 17	Sep 17
Maryland	38.92°N, 76.14°W	Silt loam	6.2	2.2	Magic Lantern	4800	Jun 21	Sep 10
Michigan	42.71°N, 84.53°W	Loamy sand	7.0	2.1	Howden	3700	May 20	Oct 1
Ohio	41.04°N, 82.68°W	Muck	6.0	24.8	Gladiator	6200	Jul 28	N/A
Pennsylvania	40.71°N, 77.96°W	Silt loam	6.7	2.7	Gladiator	8700	Jun 7	Sep 8
New Jersey	39.31°N, 75.12°W	Loamy sand	5.0	2	Gladiator	6200	Jul 15	Oct 19
New York	42.88°N, 77.03°W	Loam	6.7	2.5	Field Trip	4500	Jun 24	Sep 30
North Carolina	36.12°N, 76.62°W	Sandy loam	6.0	0.9	Kratos	6200	Jun 14	Sep 13
North Dakota	48.89°N, 96.81°W	Silty clay	7.2	5.0	Howden	4600	Jun 1[iii]	Oct 9

[i] IN = Indiana; N/A = not applicable; OM = organic matter.
[ii] Seeds were planted at the North Dakota location on 20 May 2021; however, due to excessively dry conditions, the first significant rainfall event after planting was considered the de facto planting date.
[iii] Due to a late-season disease-related crop failure, pumpkins at the Ohio location were not harvested.

fruit number and average fruit weight were calculated using data from both orange and green fruit. Commercial yields were determined using only orange fruit. In ND, only the total number and weight of fruit per plot were recorded. In PA and DE, pumpkins were categorized by fruit diameter as small (>18 to ≤24 cm), medium (>24 to ≤32 cm), and large (>32 cm).

Statistical analysis. Because of unequal variance, crop injury data were transformed using the arcsine square root method before conducting analysis of variance (ANOVA), and then back-transformed for presentation (Grafen and Hails 2002). All yield data were expressed as percentage of the standard control to account for varietal differences and to maintain the factorial structure of the experiment during the statistical analysis. Data were analyzed using ANOVA via the GLIMMIX procedure in SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA). The analysis evaluated the effects of *S*-metolachlor rate, halosulfuron-methyl rate, and application timing on crop injury as well as relative fruit count, yield, and individual fruit weight. These factors and their interactions were considered fixed effects, whereas locations and replications (nested within location) were considered random effects. Because of methodological differences, pumpkin size data from PA and DE were analyzed separately. When no interactions occurred among the main factors, data were combined across fixed effects, and treatment means were compared using Tukey's honestly significant difference test ($\alpha = 0.05$). Orthogonal contrasts ($P \leq 0.05$) were defined to evaluate differences among 1) *S*-metolachlor applied alone vs. mixed with halosulfuron-methyl, 2) *S*-metolachlor (alone or mixed with halosulfuron-methyl) at 1.4 vs. 2.8 $kg \cdot ha^{-1}$ a.i., and 3) early vs. late applications of *S*-metolachlor (alone or mixed with halosulfuron-methyl) at both rates.

Fig. 1. 'Field Trip' pumpkin trial established in New York in 2021 to assess crop response to over-the-top applications of *S*-metolachlor.

Results and discussion

Crop injury. Pumpkin injury was minimal and not significantly affected by *S*-metolachlor application rates (1.4 or 2.8 $kg \cdot ha^{-1}$ a.i.) when averaged across application timing and halosulfuron-methyl rates. Injury levels were 8%, 9%, and 5% at 1, 2, and 4 WAT, respectively (Table 2). However, orthogonal contrast analysis indicated that *S*-metolachlor applied alone at 2.8 $kg \cdot ha^{-1}$ a.i. caused slightly more injury at 2 WAT (7%) compared with the 1.4 $kg \cdot ha^{-1}$ a.i. rate (4%). Regardless of application rate, the greatest amount of crop injury was observed in DE and NJ, on loamy sand soils with ≤2% organic matter, averaging 21% at 1 WAT (data not shown).

When averaged across all *S*-metolachlor and halosulfuron-methyl rates, pumpkin injury was consistently greater

Table 2. Pumpkin injury in response to over-the-top application of *S*-metolachlor and halosulfuron-methyl at application timings across multiple states (DE, IN, MD, MI, NC, NJ, NY, OH, and PA) in 2021.

Factor	1 WAT[i]	2 WAT		4 WAT	6 WAT
S-metolachlor rate (kg·ha^{-1} a.i.)[ii]		%			
1.4	8	8		4	0
2.8	9	9		5	1
P	0.8753	0.3149		0.2110	0.5656
Application timing[iii]					
Early	12[iv] a	–		6 a	2 a
Late	6 b	–		4 b	0 b
P	0.0425	–		0.0412	0.0184
		Application timing			
Halosulfuron-methyl rate (g·ha^{-1} a.i.)		Early	Late		
0	3 b	4 c	2 c	3 b	0
26	15 a	25 a	11 b	7 a	1
P	<0.0001	0.0061		0.0001	0.3368
Orthogonal contrast		*P*			
S-metolachlor alone vs. mixed with halosulfuron-methyl	<0.0001	<0.0001		0.0005	0.3368
S-metolachlor alone at 1.4 kg·ha^{-1} a.i. vs. 2.8 kg·ha^{-1} a.i.	0.2633	0.0416		0.9348	0.6796
S-metolachlor alone at 1.4 kg·ha^{-1} a.i. applied early vs. late	0.4849	0.3217		0.6419	0.1271
S-metolachlor alone at 2.8 kg·ha^{-1} a.i. applied early vs. late	0.1421	0.0217		0.2239	0.2333
S-metolachlor at 1.4 kg·ha^{-1} a.i. vs. 2.8 kg·ha^{-1} a.i. plus halosulfuron	0.3504	0.7006		0.1452	0.2960
S-metolachlor at 1.4 kg·ha^{-1} a.i. plus halosulfuron applied early vs. late	0.2922	0.0015		0.6521	0.4563
S-metolachlor at 2.8 kg·ha^{-1} a.i. plus halosulfuron applied early vs. late	0.9660	0.0057		0.4741	0.4785

[i] WAT = weeks after treatment.
[ii] 1 kg·ha^{-1} = 0.8921 lb/acre.
[iii] Early applications were made 12 to 15 d after planting (DAP) except in Michigan (20 DAP); late applications were made 25 to 31 DAP.
[iv] Means followed by the same letter in a WAT column are not significantly different based on Turkey's honestly significant difference (α = 0.05). Data from control plots were not included in the analysis.

following early *S*-metolachlor applications compared with late applications (Table 2). Early applications resulted in 2% to 12% injury 1 to 4 WAT, whereas late applications caused ≤6% injury during the same period. Early *S*-metolachlor applications on loamy sand soils caused severe crop injury in DE (39%) and NJ (32%) at 1 WAT, whereas late applications at these same locations resulted in minimal injury (≤10%) (data not shown). Orthogonal contrast analysis further distinguished treatment effects, showing that early applications of *S*-metolachlor applied alone at the higher rate (2.8 kg·ha^{-1} a.i.) caused significantly greater crop injury at 2 WAT (9%) compared with late applications at the same rate (4%). In contrast, no timing effect was observed with the lower *S*-metolachlor rate (1.4 kg·ha^{-1} a.i.), which consistently produced minimal injury (4%) regardless of application timing.

Halosulfuron-methyl tank-mixed with *S*-metolachlor caused significantly greater crop injury at 1 WAT (15%) compared with treatments without halosulfuron-methyl (3%), regardless of application timing (Table 2). A significant interaction ($P < 0.05$) between halosulfuron-methyl rate and application timing was observed at 2 WAT. Therefore, injury data were pooled across *S*-metolachlor rates, then analyzed and presented separately by application timing. The addition of halosulfuron-methyl to *S*-metolachlor consistently increased crop injury across all rates and application timings. Injury, mostly in the form of stunting, was significantly more severe with early *S*-metolachlor applications containing halosulfuron-methyl (25%, Fig. 2) than with late applications (11%, Fig. 3). Orthogonal contrast analysis

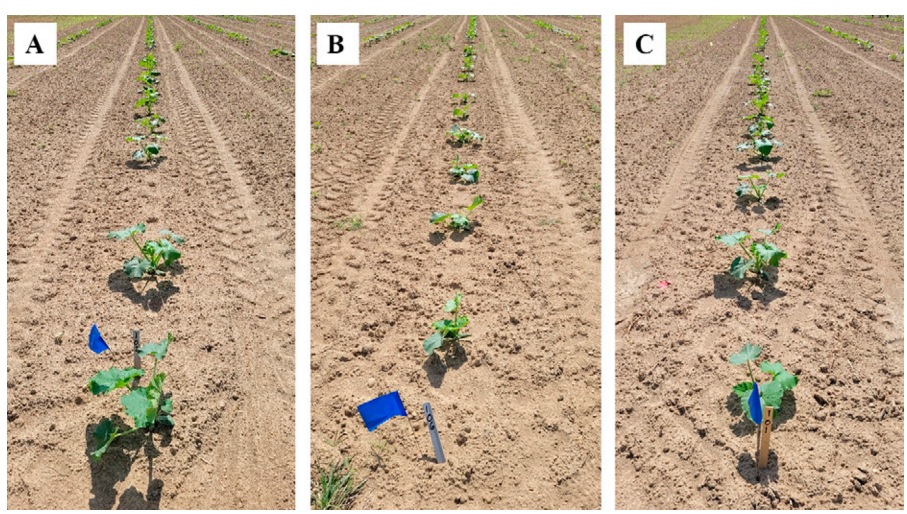

Fig. 2. 'Gladiator' pumpkin seedling response to *S*-metolachlor applied 14 d after planting at 1.4 kg·ha^{-1} alone (A) or mixed with halosulfuron-methyl at 26 g·ha^{-1} a.i. (B) as compared with the nontreated weed-free control (C) in Upper Deerfield, NJ, USA, on 2 Aug 2021. Pictures were taken 1 week after herbicide applications.

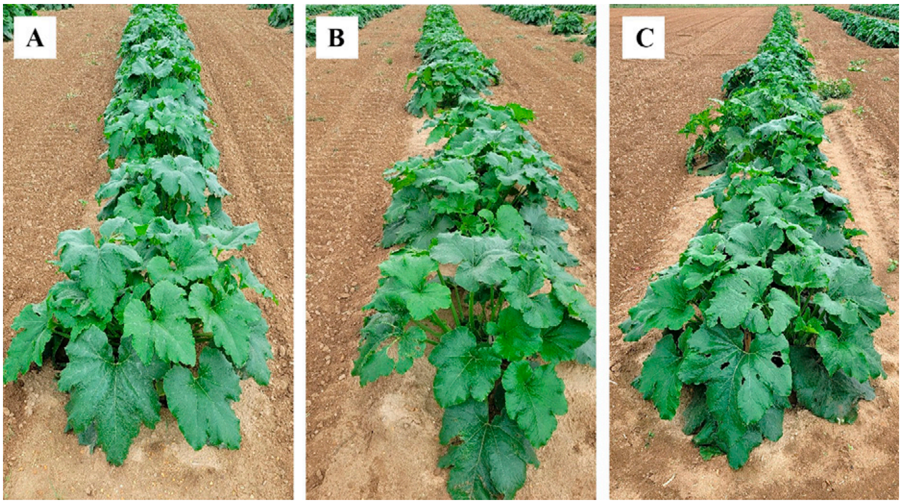

Fig. 3. 'Gladiator' pumpkin seedling response to *S*-metolachlor applied 28 d after planting at 1.4 kg·ha^{-1} alone (A) or mixed with halosulfuron-methyl at 26 g·ha^{-1} a.i. (B) as compared with the nontreated weed-free control (C) in Upper Deerfield, NJ, USA, on 17 Aug 2021. Pictures were taken 1 week after herbicide applications.

revealed that mixing halosulfuron-methyl with early *S*-metolachlor applications at either 1.4 or 2.8 kg·ha^{-1} a.i. induced significantly greater crop injury 2 WAT (30% and 28%, respectively) compared with later applications (≤17%). The greatest level of injury associated with halosulfuron-methyl mixing was observed in DE, NJ, and NC with damages ≥35% at 1 WAT and 2 WAT. Greater injury was still apparent 4 WAT in response to the inclusion of halosulfuron-methyl (7%) compared with *S*-metolachlor alone (3%), averaged across *S*-metolachlor rates and application timings. By 6 WAT, injury ≤1% indicated that pumpkin completely recovered from the damage observed earlier in the season.

Fruit count, yield, and mean fruit weight. No significant interactions were detected among the main effects of *S*-metolachlor rate, halosulfuron-methyl rate, and herbicide application timing; therefore, each main effect is presented independently, pooled across all other factors (Table 3). The proportion of nonmarketable green fruits was unaffected by *S*-metolachlor application rate, timing, or tank-mixing with halosulfuron-methyl (data not shown). Across sites, standard control plots produced an average of 7341 commercial fruits/ha and 9895 total fruits/ha. Herbicide application timing had no significant effect on either commercial or total fruit number. However, *S*-metolachlor applied at the higher rate (2.8 kg·ha^{-1} a.i.) reduced the commercial fruit count (85% of standard control) compared with the lower rate of 1.4 kg·ha^{-1} a.i. (92%) when averaged across application timing and halosulfuron-methyl

Table 3. Relative commercial and total pumpkin fruit count, yield, and mean fruit weight in response to over-the-top application of *S*-metolachlor and halosulfuron-methyl at application timings across multiple states (Delaware, Indiana, Maryland, Michigan, North Carolina, North Dakota, New Jersey, and New York) in 2021.

	Fruit count		Fruit yield		Mean fruit wt	
Factor	Com.[i]	Total	Com.	Total	Com.	Total
S-metolachlor rate (kg·ha^{-1} a.i.)[ii]			% of SCT[iii]			
1.4	92 a	97	94	94	95 b	96
2.8	85 b	94	97	97	99 a	97
P	0.0484	0.5398	0.4522	0.4317	0.0485	0.3807
Application timing[iv]						
Early	86	95	95	95	99	97
Late	90	96	96	96	96	96
P	0.4240	0.7324	0.7488	0.8533	0.1532	0.6980
Halosulfuron-methyl rate (g·ha^{-1} a.i.)						
0	92[v] a	100 a	95	96	96	96
26	84 b	92 b	95	95	98	97
P	0.0427	0.0189	0.9811	0.9935	0.4534	0.6255
Orthogonal contrast			*P*			
S-metolachlor alone vs. mixed with halosulfuron-methyl	0.0427	0.0189	0.9811	0.9935	0.4534	0.6255
S-metolachlor alone at 1.4 kg·ha^{-1} a.i. vs. 2.8 kg·ha^{-1} a.i.	0.1285	0.5318	0.9973	0.9863	0.4086	0.4948
S-metolachlor alone at 1.4 kg·ha^{-1} a.i. applied early vs. late	0.9935	0.9620	0.1256	0.1161	0.1251	0.0934
S-metolachlor alone at 2.8 kg·ha^{-1} a.i. applied early vs. late	0.3700	0.2161	0.4861	0.4411	0.9017	0.6003
S-metolachlor at 1.4 kg·ha^{-1} a.i. vs. 2.8 kg·ha^{-1} a.i. plus halosulfuron	0.5948	0.8068	0.2910	0.2637	0.0920	0.0579
S-metolachlor at 1.4 kg·ha^{-1} a.i. plus halosulfuron applied early vs. late	0.8958	0.8228	0.1441	0.1764	0.3709	0.3866
S-metolachlor at 2.8 kg·ha^{-1} a.i. plus halosulfuron applied early vs. late	0.5734	0.7858	0.9797	0.8509	0.1617	0.5916

[i] Com. = commercial; SCT = standard control treatment.

[ii] 1 kg·ha^{-1} = 0.8921 lb/acre.

[iii] In standard control plots, commercial and total fruit counts were 7341 and 9895 fruits/ha, respectively. Commercial and total fruit yields reached 700,566 and 717,994 kg·ha^{-1}, whereas mean fruit weights were 6.51 and 5.83 kg/fruit, respectively.

[iv] Early applications were made 12 to 15 d after planting (DAP) except in Michigan (20 DAP); late applications were made 25 to 31 DAP.

[v] Means followed by the same letter in a column are not significantly different based on Turkey's honestly significant difference (α = 0.05). Data from control plots were not included in the analysis.

Table 4. **Relative pumpkin fruit count by size category following over-the-top applications of *S*-metolachlor and halosulfuron-methyl at the Delaware and Pennsylvania sites in 2021.**

Factor		Small[i]		Medium	Large
		% of SCT[ii]			
	Application timing	Early	Late		
S-metolachlor rate ($kg\cdot ha^{-1}$ a.i.)[iii]					
1.4		126[iv] b	173 ab	88	88
2.8		255 a	254 a	82	74
	P	0.0209		0.5519	0.1821
Application timing[v]					
Early		—		86	56 b
Late		—		84	106 a
	P	—		0.8814	0.0070
Halosulfuron-methyl rate ($g\cdot ha^{-1}$ a.i.)					
0		195		76	97 a
26		208		94	65 b
	P	0.7620		0.1540	0.0406
Orthogonal contrast			*P*		
S-metolachlor alone vs. mixed with halosulfuron-methyl		0.7620		0.1540	0.0406
S-metolachlor alone at 1.4 $kg\cdot ha^{-1}$ a.i. vs. 2.8 $kg\cdot ha^{-1}$ a.i.		0.0584		0.3059	0.2174
S-metolachlor alone at 1.4 $kg\cdot ha^{-1}$ a.i. applied early vs. late		0.8649		0.9127	0.0016
S-metolachlor alone at 2.8 $kg\cdot ha^{-1}$ a.i. applied early vs. late		0.3651		0.1243	0.0740
S-metolachlor at 1.4 $kg\cdot ha^{-1}$ a.i. vs. 2.8 $kg\cdot ha^{-1}$ a.i. plus halosulfuron		0.4802		1.0000	0.8828
S-metolachlor at 1.4 $kg\cdot ha^{-1}$ a.i. plus halosulfuron applied early vs. late		0.0117		0.5198	0.8350
S-metolachlor at 2.8 $kg\cdot ha^{-1}$ a.i. plus halosulfuron applied early vs. late		0.3202		0.5198	0.3058

[i] Pumpkin categories: small (>18 to <24 cm), medium (>24 to <32 cm), large (≥32 cm).
[ii] SCT = standard control treatment.
[iii] 1 $kg\cdot ha^{-1}$ = 0.8921 lb/acre.
[iv] Means followed by the same letter within a fruit size column are not significantly different based on Turkey's honestly significant difference (α = 0.05). Data from control plots were not included in the analysis.
[v] Early applications were made 12 to 15 d after planting (DAP) except in Michigan (20 DAP); late applications were made 25 to 31 DAP.

treatments. Compared with treatments without halosulfuron-methyl, the addition of halosulfuron-methyl to *S*-metolachlor, regardless of rate or timing, significantly reduced commercial fruit count (92% vs. 84% of the standard control, respectively) and total fruit count (100% vs. 92% of the standard control, respectively).

Averaged across sites, commercial and total yields for the standard control plots were 700,566 $kg\cdot ha^{-1}$ and 717,994 $kg\cdot ha^{-1}$, respectively. Mean fruit weight was 6.51 kg and 5.83 kg for commercial and total fruits, respectively. Unlike pumpkin fruit number, commercial and total pumpkin fruit yield as well as mean fruit weight, were not significantly affected by *S*-metolachlor rate, halosulfuron-methyl rate, or herbicide application timing. Walters and Young (2010) demonstrated that weed interference reduced fruit count and yield by up to 10% and 67%, respectively, relative to weed-free controls.

Fruit count based on size (DE and PA). The standard control yielded 896, 3968, and 2387 fruit/ha for small, medium, and large fruit sizes, respectively. In the absence of significant interactions among *S*-metolachlor rate, halosulfuron-methyl rate, and herbicide application timing, main effects are presented independently for medium and large fruits, pooled across all other factors (Table 4). However, for small fruits, there was a significant interaction between *S*-metolachlor rate and application timing. Early or late applications of *S*-metolachlor at 2.8 $kg\cdot ha^{-1}$ a.i. produced more small fruits than an early application at $kg\cdot ha^{-1}$ a.i.

Although halosulfuron-methyl addition did not affect overall small fruit count, orthogonal contrast analysis revealed that the late application of *S*-metolachlor (1.4 $kg\cdot ha^{-1}$ a.i.) mixed with halosulfuron-methyl increased the number of small fruits, whereas *S*-metolachlor alone had no effect (Table 4). For medium fruits, halosulfuron-methyl had no significant impact. However, the addition of halosulfuron-methyl significantly reduced large fruit count (65% of the standard control) compared with *S*-metolachlor alone (97% of the standard control) when averaged across *S*-metolachlor rates and timings. The proportion of large fruits was lower following early (56% of the standard control) rather than late herbicide application (106% of the standard control). *S*-metolachlor rate did not affect medium or large fruit count.

Overall, S-metolachlor applied alone at either 1.4 or 2.8 $kg\cdot ha^{-1}$ a.i., whether early or late OTT of pumpkins, resulted in minimal and transient crop injury. Injury at most locations increased with the addition of halosulfuron. With few exceptions, the level of injury we observed in the present study from halosulfuron-methyl was similar to that of Kammler et al. (2008), who applied 35 $g\cdot ha^{-1}$ a.i. halosulfuron-methyl 21 DAP to 'Howdy Doody' pumpkin and reported 14% to 30% injury 2 WAT, and 14% to 27% injury 4 WAT. Similarly, Trader et al. (2007) reported 14% to 27% injury at 10 d after treatment following application of halosulfuron-methyl (27 $g\cdot ha^{-1}$ a.i.) at the three- to four-leaf stage in 'Appalachian' pumpkin.

With respect to *S*-metolachlor, Besançon et al. (2020) reported that 0.7 and 1.4 $kg\cdot ha^{-1}$ applied at planting or to two- to three-leaf seedlings did not impact marketable 'Gold Prize' summer squash (*Cucurbita pepo* L.) fruit number/plant or individual fruit weight, although 'Python' cucumber (*Cucumis sativus* L.) yields were reduced 21% to 39% compared with a standard PRE application of clomazone and ethalfluralin. Sosnoskie et al. (2008) reported that 0.5 $kg \cdot ha^{-1}$ *S*-metolachlor applied 3 weeks after planting or transplanting (WAP) did not reduce yields of 'Enterprise' and 'Payroll' summer squash, whereas 1.0 $kg \cdot ha^{-1}$ *S*-metolachlor decreased fruit number and weight by 14% and 20%, respectively. In a greenhouse study, Vollmer et al. (2024) applied 1.6 and 3.2 $kg \cdot ha^{-1}$ *S*-metolachlor to two-leaf stage pumpkin plants and reported ≤6% injury 1 WAT. S-metolachlor applied POST OTT at 1.6 $kg \cdot ha^{-1}$ did not significantly reduce pumpkin seedling dry weight at 2 WAT compared with the nontreated control. However, varietal sensitivity was observed, with 'Munchkin' showing up to 18% dry biomass reduction at 2 WAT, whereas 'Baby Bear', 'Champion', 'Gladiator', 'Prankster', and 'Solid Gold' showed no effect.

Conclusion

Results from 10 US states indicate that *S*-metolachlor at 1.4 $kg \cdot ha^{-1}$ a.i. applied OTT 12 to 31 DAP causes minimal crop injury and yield loss, although the addition of halosulfuron-methyl increased injury risk. Because *S*-metolachlor lacks postemergence activity and may not control all weeds present, producers must weigh increased injury risk against improved weed control when considering halosulfuron-methyl tank-mixing vs. alternative methods like cultivation. Results from the present field study as well from previous evaluations in controlled environments (Vollmer et al. 2024) demonstrate acceptable crop safety for pumpkin, supporting future registration of *S*-metolachlor for POST use at the evaluated growth stages and application rates.

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