Weed Technology

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Research Article

Cite this article: Ferebee JH IV, Cahoon CW Jr., Besançon TE, Flessner Michael L., Langston DB, Hines TE, Blake HB, Askew M. Carter (2019) Fluridone and acetochlor cause unacceptable injury to pumpkin. Weed Technol. **33**: 748–756. doi: 10.1017/wet.2019.42

Received: 27 February 2019
Revised: 29 April 2019
Accepted: 1 May 2019
First published online: 1 July 2019

Associate Editor:
Robert Nurse, Agriculture and Agri-Food Canada

Nomenclature:
Acetochlor; clomazone; ethalfluralin; fomesafen; fluridone; halosulfuron; *S*-metolachlor; common ragweed; *Ambrosia artemisiifolia* L.; ivyleaf morningglory, *Ipomoea hederacea* Jacq.; redroot pigweed, *Amaranthus retroflexus* L.; pumpkin, *Cucurbita pepo* L.

Keywords:
Crop tolerance; herbicide resistance management; preemergence herbicides; residuals

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*This article has been corrected since its original publication. Please see doi: 10.1017/wet.2019.77

Fluridone and acetochlor cause unacceptable injury to pumpkin*

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Abstract

Residual herbicides are routinely applied to control troublesome weeds in pumpkin production. Fluridone and acetochlor, Groups 12 and 15 herbicides, respectively, provide broad-spectrum PRE weed control. Field research was conducted in Virginia and New Jersey to evaluate pumpkin tolerance and weed control to PRE herbicides. Treatments consisted of fomesafen at two rates, ethalfluralin, clomazone, halosulfuron, fluridone, *S*-metolachlor, acetochlor emulsifiable concentrate (EC), acetochlor microencapsulated (ME), and no herbicide. At one site, fluridone, acetochlor EC, acetochlor ME, and halosulfuron injured pumpkin 81%, 39%, 34%, and 35%, respectively, at 14 d after planting (DAP); crop injury at the second site was 40%, 8%, 19%, and 33%, respectively. Differences in injury between the two sites may have been due to the amount and timing of rainfall after herbicides were applied. Fluridone provided 91% control of ivyleaf morningglory and 100% control of common ragweed at 28 DAP. Acetochlor EC controlled redroot pigweed 100%. Pumpkin treated with *S*-metolachlor produced the most yield (10,764 fruits ha^{-1}) despite broadcasting over the planted row; labeling requires a directed application to row-middles. A separate study specifically evaluated fluridone applied PRE at 42, 84, 126, 168, 252, 336, and 672 g ai ha^{-1}. Fluridone resulted in pumpkin injury ≥95% when applied at rates of ≥168 g ai ha^{-1}; significant yield loss was noted when the herbicide was applied at rates >42 g ai ha^{-1}. We concluded that fluridone and acetochlor formulations are unacceptable candidates for pumpkin production.

Introduction

US pumpkin production in 2016 totaled 26,710 ha, with an average yield of 26,992 kg ha^{-1}, and generated approximately $207.66 million (USDA 2016). Traditionally, in the mid-Atlantic region, pumpkin crops are direct-seeded into fields prepared with conventional tillage or no-till (direct) seeded into a winter small-grains cover crop. Transplanting pumpkin plants into a plasticulture system is less popular (Bratsch 2009). For both systems, irrigation is used to sustain pumpkin growth during hot and dry periods (Bratsch 2009; Kuhar et al. 2018).

A 2006 survey found pigweed (*Amaranthus* spp.), nutsedge (*Cyperus* spp.), and morningglory (*Ipomoea* spp.) species to be common and troublesome weeds in the southern United States (Webster 2006). These weeds also are problematic for producers of cucurbit crops (Friesen 1978). Morningglory species, common ragweed, and smooth pigweed (*Amaranthus hybridus* L.) reduced pumpkin and cucumber (*Cucumis sativus* L.) yield by as much as 79% and 100%, respectively, when left uncontrolled (Trader et al. 2007). Particularly troublesome are biotypes of Palmer amaranth (*Amaranthus palmeri* S. Wats.) resistant to glyphosate and acetolactate synthase (ALS)–inhibiting herbicides (Cahoon et al. 2015a; Kuhar et al. 2018), which are widespread throughout the southern United States (Heap 2018).

Pumpkin producers have traditionally relied upon ethalfluralin and halosulfuron applied PRE to control pigweed species (Kuhar et al. 2018). Ethalfluralin applied preplant incorporated (PPI) and PRE resulted in similar control of annual grass species (Prostko et al. 2001). However, ethalfluralin product labels do not allow PPI applications because of potential crop injury to cucurbits (Anonymous 2016; Kuhar et al. 2018). Furthermore, no-till pumpkin production is increasing in popularity, resulting in greater dependence on PRE herbicides. A pre-mixture of ethalfluralin plus clomazone is also a popular residual choice for pumpkin producers, but like other ethalfluralin-containing products, it may not be incorporated (Anonymous 2011). Furthermore, clomazone does not effectively control pigweed species. Clomazone alone controlled redroot pigweed 7% 21 d after treatment (DAT) (Brown and Masiunas 2002). Halosulfuron, an ALS-inhibiting herbicide, has long been used PRE and POST in pumpkin (Trader et al. 2007). Applied PRE, halosulfuron effectively controls pigweed species (Brandenberger et al. 2005; Shaner 2014). Halosulfuron plus clomazone plus ethalfluralin applied PRE controlled yellow nutsedge (*Cyperus esculentus* L.) 38% to 70% (Trader et al. 2008). Previous research demonstrated that halosulfuron applied PRE and PPI controlled pigweed species 95% and 97%, respectively (Soltani et al. 2014). Despite its effectiveness against pigweed species, halosulfuron does not effectively control ALS-resistant biotypes of Palmer amaranth (Kuhar et al. 2018). *S*-metolachlor is also labeled for use in pumpkin and has residual herbicide activity against pigweed species, other small-seeded broadleaf weeds, and most annual grasses (Anonymous 2015; Kuhar et al. 2018; Shaner 2014). Despite effectiveness of *S*-metolachlor, pumpkin producers are reluctant to use it because of potential crop injury. *S*-metolachlor product labels restrict applications to inter-row or inter-hill areas with 30 cm of nontreated area directly over the row or 15 cm to either side of a planted hill to avoid *S*-metolachlor contact with ungerminated pumpkin seed (Anonymous 2015; Kuhar et al. 2018). More recently, no-till pumpkin producers have turned to fomesafen applied PRE to control Palmer amaranth (Kuhar et al. 2018). Fomesafen is a protoporphyrinogen oxidase (PPO)–inhibiting herbicide with residual and POST herbicide activity (Kuhar et al. 2018; Shaner 2014). Fomesafen injury is transitory in several cucurbit crops, including both pumpkin and winter squash types (*Cucurbita moschata* Duchesne) (Peachey et al. 2012). Weeds controlled ≥80% by residual activity of fomesafen include pigweed species, yellow nutsedge, cocklebur (*Xanthium strumarium* L.), common lambsquarters (*Chenopodium album* L.), common purslane (*Portulaca oleraceae* L.), and hairy nightshade (*Solanum villosum* L.) (Peachey et al. 2012; Shaner 2014; York and Cahoon 2018). However, biotypes of Palmer amaranth have developed resistance to PPO inhibitors throughout much of the mid-South as well as in North Carolina (Heap 2018; Place 2018).

Fluridone, a Group 12 herbicide, is a phytoene desaturase inhibitor that provides residual broadleaf weed and annual grass control (Goggin and Powles 2014; Shaner 2014; Waldrep and Taylor 1966). Fluridone has traditionally been used as an aquatic herbicide to control hydrilla [*Hydrilla verticillata* (L.f.) Royle] (Netherland and Jones 2015). Fluridone and acetochlor effectively control troublesome weeds such as Palmer amaranth; fluridone applied PRE controlled Palmer amaranth 100% at 38 DAT (Braswell et al. 2016). Because it persists in the soil, there is concern that fluridone may carry over to subsequent crops (Cahoon et al. 2015b; Hill et al. 2016). However, fluridone carryover to cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench.], peanut (*Arachis hypogaea* L.), and soybean [*Glycine max* (L.) Merr.] resulted in transient injury and did not affect yield (Cahoon et al. 2015b).

Acetochlor, a Group 15 herbicide, is in the chloroacetamide family and acts as a seedling shoot inhibitor (Anonymous 2012; Jhala et al. 2015; Shaner 2014). Acetochlor has a half-life of roughly 27 d in soil (Oliveira et al. 2013). The emulsifiable concentrated (EC) formulation of acetochlor is labeled for use in corn and nonfood perennial bioenergy crops (Anonymous 2012). The microencapsulated (ME) formulation of acetochlor slowly releases the active ingredient, providing greater safety to various crops (Fishel 2010). Acetochlor ME is labeled for use in field corn, cotton, grain sorghum, and soybean (Anonymous 2014). Acetochlor applied PRE effectively controls pigweed species, other small-seeded broadleaf weeds, and most annual grasses (Cahoon et al. 2015a; Shaner 2014); in peanuts (*Arachis hypogaea* L.), Palmer amaranth control was 95% (Grichar et al. 2015). Cahoon and others (2015a) noted that acetochlor ME applied PRE controlled glyphosate-resistant (GR) Palmer amaranth 84% 3 wk after PRE, whereas cotton injury was minimal.

Pumpkin tolerance to fluridone and acetochlor is unknown. Residual effectiveness of fluridone and acetochlor against many troublesome weeds coupled with improved crop safety of acetochlor ME make these herbicides candidates for pumpkin production. The primary objective of this research was to evaluate weed control and pumpkin tolerance to fluridone, acetochlor EC, and acetochlor ME applied PRE compared to commercial standard residual herbicides.

Materials and Methods

Herbicide Comparison Experiment

Experiments were conducted at the Eastern Shore Agricultural Research and Extension Center (ESAREC) near Painter, VA (37.58956°N, 75.82321°W) and a farm near Virginia Beach, VA (36.66752°N, 76.02975°W) during 2017. The experiment was conducted in two separate fields in Painter during 2018 and one location in New Jersey (40.20361°N, 74.55867°W). Soil descriptions for each location are listed in Table 1.

During 2017, pumpkin cultivar 'Kratos' (Syngenta Crop Protection, Greensboro, NC) was planted on June 13 at Painter and on July 6 at Virginia Beach. During 2018, pumpkin cultivar 'Cougar' (Hollmes Seed Co, Canton, OH) was planted on June 8 in both fields near Painter, and pumpkin cultivar 'Kratos' was planted on June 26 in New Jersey. Pumpkins were direct-seeded into fields prepared with one pass by a moldboard plow followed by a disc harrow then a field cultivator. The experimental design was a randomized complete block with treatments replicated four times. Pumpkin were planted at one seed per 0.9 m in New Jersey and at one seed per 1.2 m at all other sites. Plots were one row by 9 m, with rows spaced 229 cm at Painter and 183 cm at New Jersey, and one row by 8 m, with rows spaced 183 cm at Virginia Beach.

PRE treatments were applied immediately after planting and included fomesafen applied at two rates, ethalfluralin, clomazone, halosulfuron, fluridone, *S*-metolachlor, acetochlor EC, and acetochlor ME. A nontreated check was included in each study for comparison. Herbicide rates and sources are listed in Table 2. All herbicides were applied using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (TTI 110015 Turbo TeeJet Induction flat spray nozzles; TeeJet Technologies, Wheaton, IL) delivering 140 L ha^{-1} at 220 kPa in Virginia, and flat-fan nozzles (XR8004VS TeeJet Extended Range Flat spray nozzles; TeeJet Technologies, Wheaton, IL) delivering 140 L ha^{-1} at 138 kPa in New Jersey.

Pumpkin stand was determined 14 DAP by counting all emerged pumpkin plants in each plot. Visible estimates of weed control, 0 to 100%, and pumpkin injury (a composite rating of growth reduction, chlorosis, and necrosis) were collected 14, 28, 42, 56, and 90 DAP. During 2017, ivyleaf morningglory and spurred anoda [*Anoda cristata* (L.) Schltdl.] were evaluated in Painter; pitted morningglory (*Ipomoea lacunosa* L.) was evaluated

https://doi.org/10.1017/wet.2019.42 Published online by Cambridge University Press

Table 1. Soil descriptions for experiment sites in New Jersey and Virginia, 2017 and 2018.[a–c]

Location	Years	Soil series	Soil texture	OM[d]	pH
Herbicide comparison experiment				%	
Painter	2017	Bojac[a]	Sandy loam	1	6.4
Virginia Beach	2017	Munden[b]	Sandy loam	2	6.5
Painter, field 1	2018	Bojac	Sandy loam	1	6
Painter, field 2	2018	Bojac	Sandy loam	1	6
New Jersey	2018	Othello[c]	Silt loam	1.8	6
Fluridone rate study					
Painter, field 1	2018	Bojac	Sandy loam	1	6
Painter, field 2	2018	Bojac	Sandy loam	1	6
New Jersey	2018	Othello[c]	Silt loam	1.8	6

[a]Coarse-loamy, mixed, semiactive, thermic Typic Hapludults.
[b]Coarse-loamy, mixed, semiactive, thermic Aquic Hapludults.
[c]Fine-silty, mixed, active, mesic Typic Endoaquults.
[d]Abbreviation: OM, organic matter.

Table 2. Herbicides used in experiments in New Jersey and Virginia, 2017 and 2018.[a]

Herbicides	Trade names	Formulation concentration	Application time	Application rate	Manufacturer
Fomesafen	Reflex®	240 g ai L^{-1}	PRE	210 (LR) or 280 (HR) g ai ha^{-1}	Syngenta Crop Protection
Ethalfluralin	Curbit® EC	360 g ai L^{-1}	PRE	631 g ai ha^{-1}	Loveland Products Inc.
Clomazone	Command® 3ME	360 g ai L^{-1}	PRE	289 g ai ha^{-1}	FMC Corp.
Halosulfuron	Sandea®	75% (w/w)	PRE	39 g ai ha^{-1}	Gowan Co.
Fluridone[b]	SP1182	144 g ai L^{-1}	PRE	Various rates	SePRO Corp.
S-metolachlor	Dual Magnum®	914 g ai L^{-1}	PRE	1,068 g ai ha^{-1}	Syngenta Crop Protection
Acetochlor EC	Harness®	839 g ai L^{-1}	PRE	1,264 g ai ha^{-1}	Monsanto Co.
Acetochlor ME	Warrant®	359 g ai L^{-1}	PRE	1,262 g ai ha^{-1}	Monsanto Co.
Clethodim	Select Max®	116 g ai L^{-1}	POST	136 g ai ha^{-1}	Valent U.S.A LLC
Nonionic surfactant	Scanner®	100%	POST	0.25% (v/v)	Loveland Products, Inc.

[a]Specimen labels for each product, mailing addresses, and website addresses of each manufacturer can be found at http://www.cdms.net/LabelsSDS/home/.
[b]Fluridone was applied at 168 g ai ha^{-1} for herbicide comparison experiments and at 42, 84, 126, 168, 252, 336, and 672 g ai ha^{-1} for fluridone rate study.
[c]Abbreviations: EC, emulsifiable concentrate; HR, high rate; LR, low rate; ME, microencapsulated.

in Virginia Beach. During 2018, ivyleaf morningglory and yellow nutsedge were evaluated at Painter field 1, ivyleaf morningglory and spurred anoda were evaluated at Painter field 2, and common ragweed, redroot pigweed, and common lambsquarters were evaluated in New Jersey. Pumpkins were hand harvested, counted, and weighed to determine total fruit number, average fruit size, and total yield. As a result of prolific late-season rainfall and disease during 2017, the Virginia Beach site experienced nearly complete crop loss, and yield was not measured. Inadequate rainfall throughout the growing season during 2018 significantly reduced pumpkin growth in New Jersey, and yield was not measured.

Data for weed control, pumpkin injury, and pumpkin yield were subjected to ANOVA using JMP PRO 13 software (SAS Institute Inc., Cary, NC). Treatment and location were considered fixed effects, and replications were random effects. When treatment-by-location interaction was significant ($P = 0.05$), data are presented by location. If the interaction was not significant, data were pooled across locations before analysis. Treatment means were separated using Fisher's protected LSD ($P = 0.05$) when appropriate.

Fluridone Rate Study

A separate study evaluated pumpkin tolerance to a range of fluridone rates. The experiments were conducted during 2018 in two separate fields at Painter and one site in New Jersey. Soil descriptions for each location are listed in Table 1.

During 2018, pumpkin cultivar 'Cougar' was planted on June 8 in both fields near Painter and pumpkin cultivar 'Kratos' was planted on June 26 in New Jersey. Pumpkins were direct–seeded into fields prepared with one pass by a moldboard plow followed by a disc harrow then a field cultivator. All plots were kept weed free throughout the season. The experimental design was a randomized complete block with treatments replicated four times. Plots were one row by 9 m, with rows spaced 229 and 183 cm at Painter and New Jersey, respectively.

Fluridone treatments were applied PRE immediately after planting at 42, 84, 126, 168, 252, 336, and 672 g ai ha^{-1}. A nontreated, weed-free plot was included in each study for comparison. The nontreated check was kept free of weeds via hand weeding plus clethodim with nonionic surfactant to control annual grasses. Herbicide rates and sources are listed in Table 2. All herbicides were applied using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (TTI 110015 Turbo TeeJet Induction flat-spray nozzles; TeeJet Technologies, Wheaton, IL) delivering 140 L ha^{-1} at 220 kPa in Virginia, and flat-fan nozzles (XR8004VS TeeJet Extended Range Flat-spray nozzles; TeeJet Technologies, Wheaton, IL) delivering 140 L ha^{-1} at 138 kPa in New Jersey.

Pumpkin stand was determined 14 and 28 DAP by counting all emerged pumpkin plants in each plot. Visible estimates of pumpkin injury were collected at 14 and 28 DAT, and pumpkins were hand-harvested as previously described.

Data for pumpkin stand, injury, and yield were subjected to ANOVA using JMP PRO 13 software (SAS Institute Inc., Cary, NC). Treatment and location were considered fixed effects and replication as a random effect. When treatment-by-location interaction was significant ($P = 0.05$), data are presented by location. If the interaction was not significant, data were pooled across

https://doi.org/10.1017/wet.2019.42 Published online by Cambridge University Press

Table 3. Pumpkin injury 14 and 28 d after planting (DAP) in New Jersey and Virginia for herbicide comparison experiment, 2017 and 2018.[a,b]

	Painter[c]				Virginia Beach				New Jersey			
Herbicides	14 DAP		28 DAP		14 DAP		28 DAP		14 DAP		28 DAP	
	%											
Fomesafen LR[d]	8	c	4	c	0	c	0	c	20	a	15	a
Fomesafen HR[d]	14	c	6	c	0	c	0	c	25	a	21	a
Ethalfluralin	7	c	3	c	1	c	0	c	26	a	17	a
Clomazone	7	c	5	c	1	c	0	c	32	a	22	a
Halosulfuron	35	b	19	b	2	c	5	c	33	a	27	a
Fluridone	81	a	73	a	26	b	8	bc	40	a	17	a
S-metolachlor	6	c	3	c	2	c	0	c	16	a	18	a
Acetochlor EC[d]	39	b	15	bc	53	a	26	a	8	a	12	a
Acetochlor ME[d]	34	b	9	bc	33	b	14	b	19	a	11	a

[a]Means within a column followed by the same letter are not different according to Fisher's protected LSD test at P = 0.05.
[b]Application rates were as listed in Table 2.
[c]Pumpkin injury pooled across experiment sites in Painter.
[d]Abbreviations: EC, emulsifiable concentrate; HR, high rate; LR, low rate; ME, microencapsulated.

locations before analysis. In addition, a predictive regression equation for pumpkin tolerance to fluridone was estimated using JMP PRO 13 (SAS Institute Inc., Cary, NC).

Results and Discussion

Herbicide Comparison Experiment

Treatment effects on pumpkin stand and yield were not consistent across locations; therefore, data for these parameters are presented by location. Likewise, the two-way interactions of treatment by location were significant for pumpkin injury; however, the three Painter sites responded similarly. As a result, data for pumpkin injury is presented pooled for the Painter sites, with data for Virginia Beach and New Jersey locations presented separately. Treatment-by-location interactions for weed control were not significant; thus, data for weed control were pooled across locations with corresponding weed species.

Pumpkin Response

Treatment effects on pumpkin injury varied across locations. Overall, injury to pumpkin was greatest at the Painter location (Table 3). At Painter, fluridone, acetochlor EC, acetochlor ME, and halosulfuron were most injurious at 14 DAP, causing 81%, 39%, 34%, and 35% injury to pumpkins, respectively. Injury caused by *S*-metolachlor and fomesafen was less, ranging from 6% to 14%. Injury caused by all treatments decreased at 28 DAP, but the initial injury trends noted at 14 DAP remained. At Painter, fluridone injured pumpkin 73% at 28 DAP, whereas halosulfuron injured pumpkin 19%, similar to both formulations of acetochlor (9% to 15%). Pumpkin injury in response to fomesafen low rate (LR), fomesafen high rate (HR), ethalfluralin, clomazone, and *S*-metolachlor ranged from 3% to 6%. Halosulfuron is capable of injuring cucurbit crops, especially on coarse-textured soils with little organic matter (Trader et al. 2007), as was the case at Painter. However, halosulfuron injury is normally transitory and does not result in yield loss. Likewise, Trader and others (2008) reported that halosulfuron applied PRE injured squash 42%, but injury was transient and did not result in squash yield loss.

At Virginia Beach, acetochlor EC (53%) injured pumpkin more than acetochlor ME (33%) 14 DAP. Much like acetochlor ME, fluridone caused 26% pumpkin injury. At this location, pumpkin injury caused by all other treatments was minimal (0 to 2%). Pumpkin injury at 28 DAP, like injury at 14 DAP, was greatest in plots treated with acetochlor EC (26%). Again, acetochlor ME (14%) and fluridone (8%) were less injurious than acetochlor EC, and injury by all other treatments was negligible (≤5%). Pumpkin injury at New Jersey was statistically similar across all treatments at 14 and 28 DAP, and injury ranged from 8% to 40% at 14 DAP and 11% to 27% at 28 DAP.

Despite broadcasting over the planted row, *S*-metolachlor resulted in a maximum pumpkin injury of 16% at 14 DAP and 18% at 28 DAP. Labels for *S*-metolachlor–containing products require a 30-cm zone of nontreated soil directly over the row or 15 cm to each side of a planted hill or emerged pumpkins to avoid potential stand loss and pumpkin injury (Anonymous 2015; Kuhar et al. 2018). Results of this experiment confirm that *S*-metolachlor is a useful tool for pumpkin weed management with minimal risk for crop injury.

Pumpkin stand in nontreated plots ranged from 6 to 10 plants per 9-m row depending on location (Table 4). At all three sites at Painter, both rates of fomesafen reduced pumpkin stand 20% to 75%. Halosulfuron reduced pumpkin stand compared to nontreated pumpkin at Painter in 2017, whereas fluridone caused complete stand loss at both Painter sites in 2018. The excessive stand loss at Painter in 2018 may have resulted from heavy rainfall shortly after planting. In 2018, Painter received 0.7 cm of rainfall at 2 DAP and 2.6 cm at 3 DAP, compared to 1.5 cm at 4 DAP in 2017; New Jersey received 0.2 cm at 2 DAP. At Virginia Beach (six to seven plants per 9-m row) and New Jersey (four to six plants per 9-m row), no treatments reduced pumpkin stand relative to the nontreated. Moreover, no treatment differences were observed at these locations.

Weed Control

Ivyleaf morningglory, spurred anoda, and yellow nutsedge were present in four, three, and two sites, respectively. Despite severe pumpkin injury, fluridone controlled ivyleaf morningglory 91% at 28 DAP and 73% at 42 DAP (Table 5). In a previous study, fluridone at 336 g ai ha^{-1} controlled pitted morningglory 86% at 12 wk after planting (Hill et al. 2017). No other treatment controlled ivyleaf morningglory >52% at 28 DAP or 33% at 42 DAP. Morningglory species are particularly troublesome in cucurbit crops, and no viable chemical options currently exist (Friesen 1978). Likewise, fluridone controlled spurred anoda 93% at 28 and 42 DAP, whereas clomazone provided 92% control at 28 DAP and 96% at 42 DAP. Comparatively, spurred anoda control

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Table 4. Pumpkin stand 14 d after planting (DAP) in New Jersey and Virginia for herbicide comparison experiment, in Virginia and New Jersey, 2017 and 2018.[a,b]

Herbicides	2017				2018					
	Painter		Virginia Beach		Painter, field 1		Painter, field 2		New Jersey	
	plants 9 m row^{-1}									
Fomesafen LR[c]	8	b	7	a	4	c	5	C	5	a
Fomesafen HR[c]	8	b	6	a	2	d	3	D	6	a
Ethalfluralin	10	a	6	a	8	ab	7	B	5	a
Clomazone	10	a	7	a	8	ab	7	B	6	a
Halosulfuron	8	b	6	a	9	a	9	A	6	a
Fluridone	9	ab	6	a	0	e	0	E	4	a
S-metolachlor	11	a	6	a	8	ab	7	B	5	a
Acetochlor EC[c]	9	ab	6	a	7	b	8	ab	5	a
Acetochlor ME[c]	10	a	6	a	9	a	8	ab	6	a
Nontreated	10	a	6	a	8	ab	8	ab	6	a

[a]Means within a column followed by the same letter are not different according to Fisher's protected LSD test at P = 0.05.
[b]Application rates were as listed in Table 2.
[c]Abbreviations: EC, emulsifiable concentrate; HR, high rate; LR, low rate; ME, microencapsulated.

Table 5. Ivyleaf morningglory, spurred anoda, and yellow nutsedge control by herbicides applied PRE for herbicide comparison experiment, 2017 and 2018.[a–c]

Herbicides	Ivyleaf morningglory				Spurred anoda				Yellow nutsedge			
	28 DAP		42 DAP		28 DAP		42 DAP		14 DAP		28 DAP	
	%											
Fomesafen LR[d]	37	bc	6	d	37	b	15	b	21	cd	20	c
Fomesafen HR[d]	47	bc	29	bc	21	b	6	b	62	ab	56	ab
Ethalfluralin	38	bc	22	bcd	31	b	18	b	21	cd	19	c
Clomazone	16	d	11	cd	92	a	96	a	29	cd	13	c
Halosulfuron	52	b	25	bcd	36	b	14	b	79	a	63	a
Fluridone	91	a	73	a	93	a	93	a	4	d	0	c
S-metolachlor	30	cd	33	b	29	b	6	b	68	ab	66	a
Acetochlor EC[d]	41	bc	23	bcd	31	b	20	b	70	ab	69	a
Acetochlor ME[d]	28	cd	18	bcd	34	b	20	b	44	bc	29	bc

[a]Means within a column followed by the same letter are not different according to Fisher's protected LSD test at P = 0.05.
[b]Application rates were as listed in Table 2.
[c]Data pooled across experiment sites where weeds were present. Ivyleaf morningglory control pooled across all experiment sites in NJ and Painter. Spurred anoda control pooled across Painter, 2017 and Painter field 2, 2018. Yellow nutsedge control pooled across experiment sites in New Jersey and Painter field 1, 2018.
[d]Abbreviations: EC, emulsifiable concentrate; HR, high rate; LR, low rate; ME, microencapsulated.

by fomesafen, ethalfluralin, halosulfuron, *S*-metolachlor, and acetochlor was ≤37%. Little information is available on the efficacy of fluridone for spurred anoda control. York (2018) reported that fluridone + fomesafen controlled spurred anoda ≥80%. Halosulfuron controlled yellow nutsedge 79% at 28 DAP and 63% at 42 DAP. Yellow nutsedge control was similar with halosulfuron, fomesafen HR, *S*-metolachlor, and acetochlor EC, ranging from 62% to 70% at 28 DAP and 56% to 69% at 42 DAP. Yellow nutsedge is a common weed to vegetable production, and its control has been previously investigated (Trader et al. 2008). Halosulfuron, fomesafen, and *S*-metolachlor have all been reported to provide >70% residual control of yellow nutsedge (Meyers 2017; Reed et al. 2016; Trader et al. 2008)

Common ragweed, redroot pigweed, and common lambsquarters infested only the New Jersey location. At this location, fluridone completely controlled common ragweed at 28 DAP and provided 83% control at 42 DAP (Table 6). At 28 DAP, fomesafen, halosulfuron, and acetochlor EC controlled common ragweed similarly to fluridone (64% to 100%), whereas all other treatments resulted in 0 to 15% control. Similar trends for common ragweed control 42 DAP were observed with the exception of halosulfuron, which resulted in less control (38%) compared to fluridone. Cahoon and others (2017) reported similar common ragweed control by fluridone (93%) and fomesafen (82%) 8 wk after PRE applications to cotton. In contrast to common ragweed control, redroot pigweed was controlled well by *S*-metolachlor, acetochlor, halosulfuron, and fomesafen; at 28 DAP, 80% to 100% control was observed, whereas at 42 DAP control was 75% to 100%. Fluridone was only marginally effective against redroot pigweed, controlling the weed 63% at 28 DAP and 58% at 42 DAP. Braswell and others (2016) reported Palmer amaranth (like redroot pigweed, a member of the *Amaranthus* genus) control by fluridone to be good (100% control 38 DAT). However, these researchers used 280 g ai ha^{-1} fluridone, compared to 168 g ai ha^{-1} used in this experiment. Other researchers recommend 336 g ai ha^{-1} fluridone to effectively control Palmer amaranth when applied alone (York 2018). Furthermore, for more consistent Palmer amaranth control, labels for fluridone-containing products require a tank-mix partner when fluridone is applied at ≤221 g ai ha^{-1} (Anonymous 2018). Rates used in this experiment may explain why fluridone was not more effective at controlling redroot pigweed. Clomazone controlled redroot pigweed poorly and confirms previous reports of inadequate *Amaranthus* spp. control by clomazone (Brown and Masiunas 2002). Fluridone controlled common lambsquarters 99% to 100%. At 28 DAP, clomazone (90%) and halosulfuron (98%) provided control of common lambsquarters similar to

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Table 6. Weed control 14 and 28 d after planting (DAP) by herbicides applied PRE in New Jersey for herbicide comparison experiment in 2018.[a,b]

Herbicides	Common ragweed				Redroot pigweed				Common lambsquarters			
	28 DAP		42 DAP		28 DAP		42 DAP		28 DAP		42 DAP	
	%											
Fomesafen	64	a	45	ab	80	ab	75	a	23	cd	13	d
Fomesafen	65	a	56	ab	95	ab	95	a	31	cd	60	abc
Ethalfluralin	5	b	4	d	55	b	50	ab	38	cd	23	cd
Clomazone	15	b	10	cd	8	c	0	b	90	ab	69	ab
Halosulfuron	75	a	38	bcd	98	a	95	a	98	a	69	ab
Fluridone	100	a	83	a	63	ab	58	a	99	a	100	a
S-metolachlor	0	b	0	d	100	a	75	a	10	d	5	d
Acetochlor EC[c]	80	a	55	ab	100	a	100	a	51	bc	43	bcd
Acetochlor ME[c]	8	b	0	d	85	ab	75	a	38	cd	24	bcd

[a]Means within a column followed by the same letter are not different according to Fisher's protected LSD test at P = 0.05.
[b]Application rates were as listed in Table 2.
[c]Abbreviations: EC, emulsifiable concentrate; ME, microencapsulated.

Table 7. Pumpkin yield in Virginia for herbicide comparison experiment, 2017 and 2018.[a,b]

Herbicides	Painter, 2017				Painter, field 1, 2018				Painter, field 2, 2018			
	No. fruits ha^{-1}		kg ha^{-1}		No. fruits ha^{-1}		kg ha^{-1}		No. fruits ha^{-1}		kg ha^{-1}	
Fomesafen	6,900	a	62,600	a	5,600	cd	35,800	cd	8,400	a	49,200	a
Fomesafen	7,800	a	72,600	a	5,000	d	30,900	d	8,400	a	48,000	ab
Ethalfluralin	9,000	a	81,400	a	8,000	bc	47,500	bcd	10,000	a	62,600	a
Clomazone	8,600	a	78,000	a	6,300	bcd	41,900	bcd	7,800	ab	46,300	ab
Halosulfuron	8,100	a	76,900	a	7,700	bc	41,400	bcd	5,400	b	32,700	b
Fluridone	8,400	a	80,400	a	0	e	0	e	0	c	0	c
S-metolachlor	7,400	a	59,400	a	10,800	a	68,300	a	9,000	a	56,300	a
Acetochlor EC[c]	7,100	a	58,300	a	7,900	bc	50,200	bc	10,000	a	58,100	a
Acetochlor ME[c]	6,600	a	47,800	a	8,600	ab	53,600	ab	9,000	a	56,600	a
No herbicide	7,700	a	53,200	a	6,900	bcd	41,100	bcd	9,000	a	51,900	a

[a]Means within a column followed by the same letter are not different according to Fisher's protected LSD test at P = 0.05.
[b]Application rates were as listed in Table 2.
[c]Abbreviations: EC, emulsifiable concentrate; ME, microencapsulated.

fluridone. At 42 DAP, fluridone controlled common lambsquarters 100%, compared to 69% by clomazone and halosulfuron.

Yield

Pumpkin yield was not collected at Virginia Beach as a result of severe disease, nor at New Jersey because of lack of rainfall. At Painter in 2017, pumpkin fruit number and total yield ranged from 6,600 to 9,000 fruits ha^{-1} and 47,800 to 81,400 kg ha^{-1}, respectively (Table 7). At this location, fruit number and yield in all plots were similar, regardless of herbicide treatment. At both Painter sites in 2018, fluridone eliminated fruit production. At Painter field 1, plots treated with *S*-metolachlor produced the greatest number of fruits (10,800 fruits ha^{-1}) and greatest yield (68,300 kg ha^{-1}). Pumpkin yield response to acetochlor was variable. Only plots treated with acetochlor ME yielded similarly to *S*-metolachlor–treated plots. All other plots, including those treated with acetochlor EC, produced fewer fruits (5,000 to 8,000 fruits ha^{-1}) and lower yield (30,900 to 50,200 kg ha^{-1}) than plots treated with *S*-metolachlor. Despite early-season injury and stand loss, Peachey and others (2012) reported that fomesafen applied at 350 and 700 g ai ha^{-1} did not significantly reduce pumpkin yield. This was not the case in this study; fomesafen-treated plots at Painter field 1 in 2018 reduced yield by nearly 50% compared to *S*-metolachlor, the treatment with the greatest yield. At field 2, all herbicide treatments resulted in 8,400 to 10,000 fruits ha^{-1} and 46,300 to 62,700 kg ha^{-1}, except halosulfuron and fluridone, which produced fewer fruits and lower yield. Comparatively, halosulfuron-treated plots generated only 5,400 fruits ha^{-1} and 32,600 kg ha^{-1}. This is in contrast to Trader and others (2007), who noted that halosulfuron at 27 g ai ha^{-1} improved yield compared to nontreated pumpkin. Fomesafen-treated plots had yields similar to *S*-metolachlor and acetochlor.

Fluridone Rate Study

The two-way interaction of fluridone rate and location was not significant for pumpkin stand or injury; therefore, data for these parameters were pooled across locations. The fluridone rate-by-location interaction was significant for pumpkin yield. However, the two Painter sites responded similarly. Data for pumpkin yield is presented for New Jersey and pooled across the two Painter sites.

Crop Response

Pumpkin stand and injury were inversely related with fluridone rate. Nontreated pumpkin averaged seven plants per 9-m row at 14 DAP (Figure 1). The two lowest rates of fluridone had no effect on pumpkin stand. However, fluridone rates at ≥126 g ai ha^{-1} reduced pumpkin stand by as many as six plants per 9-m row. Pumpkin injury followed a trend similar to that of pumpkin stand; fluridone rates >126 g ai ha^{-1} resulted in 100% injury (Figure 2).

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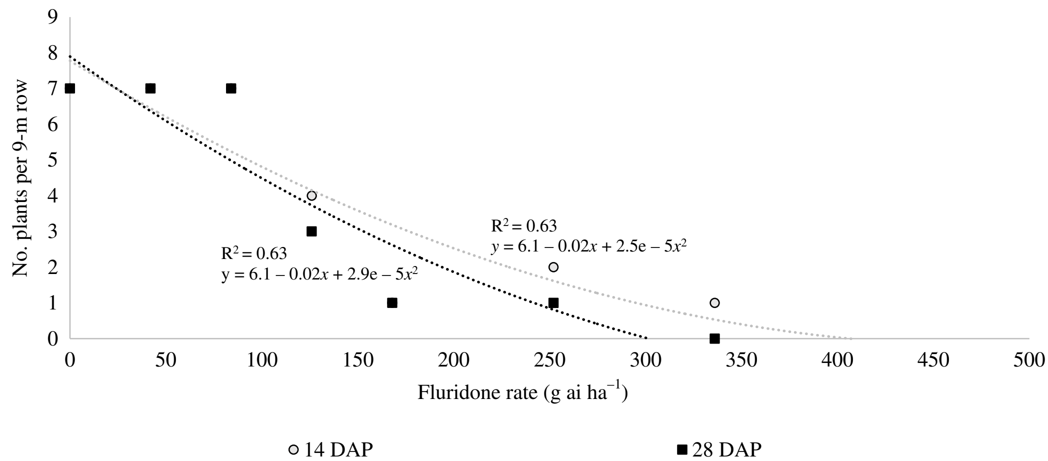

Figure 1. Pumpkin stand 14 and 28 d after planting (DAP) for fluridone rate experiment in New Jersey and Virginia. Application rates are listed in Table 2. Pumpkin stand was pooled across all experiment sites.

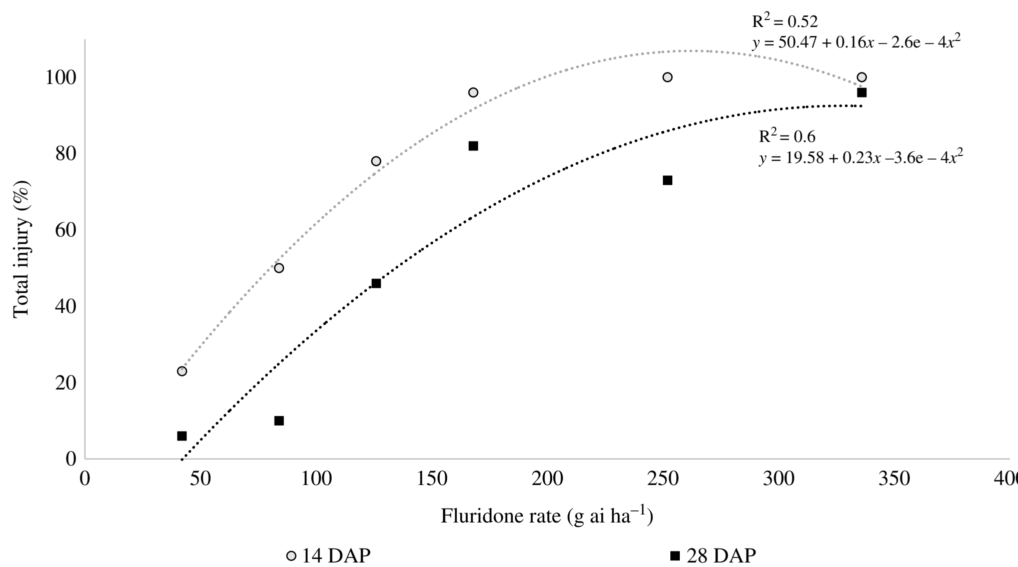

Figure 2. Pumpkin injury 14 and 28 d after planting (DAP) for fluridone rate experiment in New Jersey and Virginia. Application rates are listed in Table 2. Pumpkin injury was pooled across all experiment sites.

Although less injury was observed 28 DAP, the same general trend for pumpkin response to fluridone rate existed.

Yield

Correspondingly with early-season stand loss and pumpkin injury, pumpkin fruit number and yield generally decreased as fluridone rate increased. Nontreated plots at New Jersey yielded 4,900 fruits ha^{-1} (Figure 3). Only plots treated with 84 g ai ha^{-1} produced a similar amount of fruit. All other rates of fluridone reduced fruit 1,000 to 4,100 fruits ha^{-1} compared to the nontreated. Despite a lesser effect on fruit set, total pumpkin yield in New Jersey was reduced approximately 48% to 100% for fluridone rates >126 g ai ha^{-1} (Figure 4). At Painter, nontreated plots resulted in 12,900 fruits ha^{-1} and 84,600 kg ha^{-1}. Only plots treated with 42 g ai ha^{-1} fluridone generated a similar number of fruits (12,200 fruits ha^{-1}) and yield (76,300 kg ha^{-1}) as did nontreated plots (data not shown). Higher fluridone rates significantly reduced fruit set and total yield. Moreover, fluridone rates of ≥168 g ai ha^{-1} caused complete or near-complete fruit loss.

Surprisingly, average fruit weight (total yield/number of fruit) did not appear to be influenced by fluridone rate. Average fruit weight at New Jersey averaged 5.8 kg fruit^{-1} in nontreated plots, whereas fruits in fluridone-treated plots, except for the highest rate, ranged from 3.5 to 6.9 kg fruit^{-1} (data not shown). A similar trend was observed in Painter. In treated plots with surviving pumpkins, average fruit weight was 6.2 to 6.4 kg fruit^{-1} compared to 6.6 kg fruit^{-1} for pumpkins in nontreated plots (data not shown). From this, it can be concluded that fluridone reduces pumpkin yield primarily by interfering with fruit set. This effect is probably a response to severe early-season growth reduction and chlorosis from which pumpkins were unable to recover.

Despite excellent weed control, most notably ivyleaf morningglory, these data indicate unacceptably high pumpkin injury by fluridone. Fluridone rates >42 g ai ha^{-1} resulted in significant yield loss. Moreover, fluridone rates that were needed to achieve

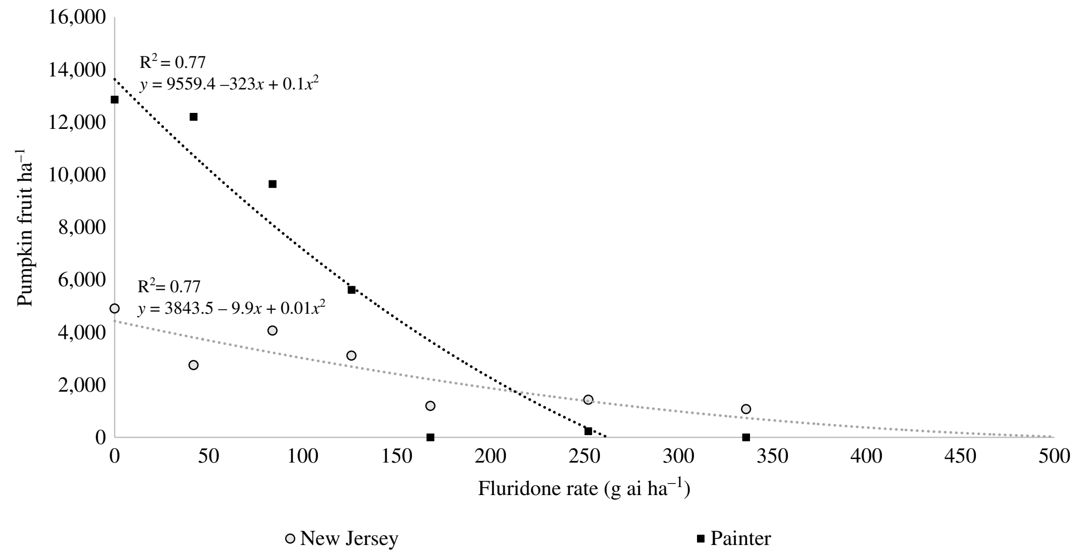

Figure 3. Pumpkin fruits (fruits ha^{-1}) for fluridone rate experiment in New Jersey and Virginia. Application rates are listed in Table 2. Pumpkin fruit data for Painter were pooled across two experiment sites within location.

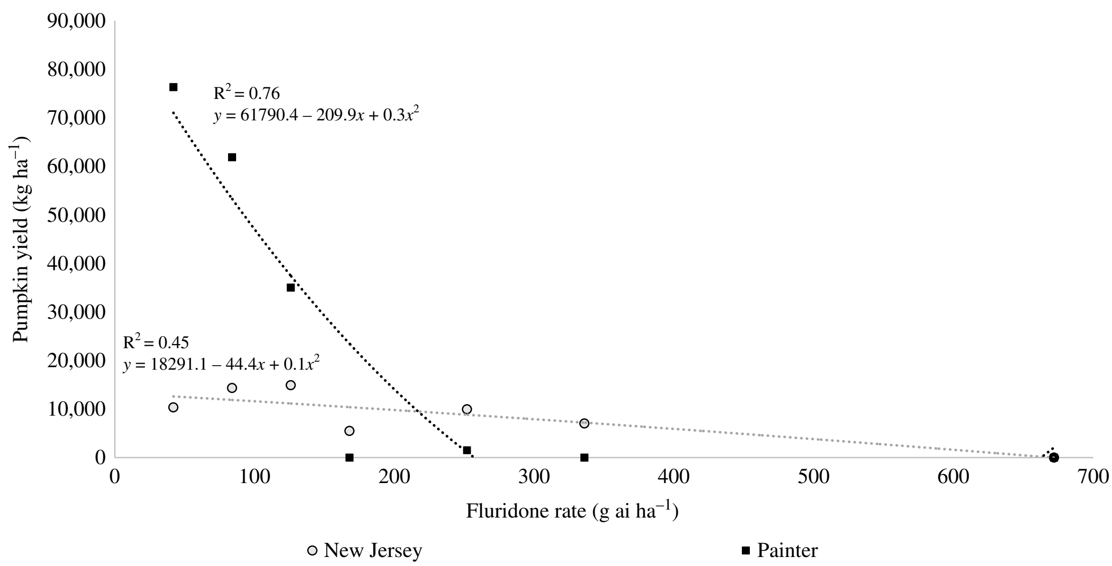

Figure 4. Pumpkin yield (kg ha^{-1}) for fluridone rate experiment in New Jersey and Virginia. Application rates are listed in Table 2. Pumpkin yield data for Painter were pooled across two experiment sites within location.

consistent weed control (>221 g ai ha^{-1}) also reduced pumpkin yield 75% to 100%. Acetochlor EC and acetochlor ME did not injure pumpkins as much as did fluridone. However, acetochlor caused early-season injury to pumpkin, regardless of formulation. *S*-metolachlor, also a member of the chloroacetamide family of herbicides and currently labeled for pumpkin, was much safer than acetochlor. In addition, *S*-metolachlor and acetochlor control a similar spectrum of weeds. For these reasons, like fluridone, acetochlor EC and ME formulations are not recommended for pumpkin production in this region.

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Acknowledgments. Funding for this work was provided in part by the Virginia Agricultural Experiment Station and the Hatch Program of the National Institute of Food and Agriculture, U.S. Department of Agriculture. This research was partially funded by the Virginia Department of Agriculture and Consumer Services Specialty Crop Block. No conflicts of interest have been declared.

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