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Comparison of 2,4-D, dicamba and halauxifen-methyl alone or in combination with glyphosate for preplant weed control

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2,4-D; dicamba; glyphosate; halauxifen-methyl; horseweed; *Conyza canadensis* L.; common chickweed, *Stellaria media* L. Vill.; curly dock, *Rumex crispus* L.; cutleaf evening primrose, *Oenothera laciniata* Hill; henbit, *Lamium amplexicaule* L.; purple cudweed, *Gamochaeta purpurea* L. Cabrera; purple deadnettle, *Lamium purpureum* L.

Keywords:
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Abstract

A field study was conducted in 2017 and 2018 to determine foliar efficacy of halauxifen-methyl, 2,4-D, or dicamba applied alone and in combination with glyphosate at preplant burndown timing. Experiments were conducted near Painter, VA; Rocky Mount, NC; Jackson, NC; and Gates, NC. Control of horseweed, henbit, purple deadnettle, cutleaf evening primrose, curly dock, purple cudweed, and common chickweed were evaluated. Halauxifen-methyl applied at 5 g ae ha^{-1} controlled small and large horseweed 89% and 79%, respectively, and was similar to control by dicamba applied at 280 g ae ha^{-1}. Both rates of 2,4-D—533 g ae ha^{-1}(low rate [LR]) or 1,066 g ae ha^{-1} (high rate [HR])—were less effective than halauxifen-methyl and dicamba for controlling horseweed. Halauxifen-methyl was the only auxin herbicide to control henbit (90%) and purple deadnettle (99%). Cutleaf evening primrose was controlled 74% to 85%, 51%, and 4% by 2,4-D, dicamba, and halauxifen-methyl, respectively. Dicamba and 2,4-D controlled curly dock 59% to 70% and were more effective than halauxifen-methyl (5%). Auxin herbicides applied alone controlled purple cudweed and common chickweed 21% or less. With the exception of cutleaf evening primrose (35%) and curly dock (37%), glyphosate alone provided 95% or greater control of all weeds evaluated. These experiments demonstrate halauxifen-methyl effectively (≥79%) controls horseweed, henbit, and purple deadnettle, whereas common chickweed, curly dock, cutleaf evening primrose, and purple cudweed control by the herbicide is inadequate (≤7%).

Introduction

Horseweed is a broadleaf weed that can act as winter or summer annual (Weaver 2001). Horseweed can produce up to 200,000 seeds plant^{-1} (Bhowmik and Bekech 1993) and is problematic in reduced- or no-tillage systems (Uva et al. 1997). Competition from horseweed has been reported to reduce soybean (*Glycine max* L.) yield up to 83% and cotton (*Gossypium hirsutum* L.) lint yield by as much as 46% (Bruce and Kells 1990; Steckel and Gwathmey 2009). Traditionally, glyphosate applied preplant burndown has been used to control horseweed prior to crop planting (Bruce and Kells 1990). However, glyphosate-resistant (GR) horseweed was first confirmed in Delaware in 2000 and has since spread to many other states (Eubank et al. 2008; Heap 2018; Koger et al. 2004; Main et al. 2004; Steckel and Gwathmey 2009; VanGessel 2001). Along with glyphosate, horseweed biotypes have also evolved resistance to paraquat (Smisek et al. 1998; VanGessel et al. 2006) and acetolactate synthase (ALS)-inhibiting herbicides (Heap 2018; Zheng et al. 2011). Furthermore, biotypes of the weed have developed multiple resistance to glyphosate and paraquat (Eubank et al. 2012) as well as glyphosate and ALS inhibitors (Heap 2018; Kruger et al. 2009; Trainer et al. 2005).

Current recommendations for managing horseweed include an auxin herbicide in combination with glyphosate, applied as a burndown prior to crop planting. This mixture offers broad-spectrum weed control as well as control of glyphosate- and ALS-resistant horseweed; these herbicides are particularly effective if applied while horseweed is small (Bruce and Kells 1990; Byker 2013; Eubank et al. 2008; Loux et al. 2006). Bruce and Kells (1990) reported 97% to 100% control of horseweed with 2,4-D when applied at 0.56 kg ae ha^{-1} and 100% at 1.12 kg ae ha^{-1}. Dicamba, another auxin herbicide, effectively controlled glyphosate- and ALS-resistant horseweed (Byker et al. 2013; Eubank et al. 2008; Loux et al. 2006). Byker et al. (2013) observed similar levels of GR-horseweed control after applications of dicamba plus

Table 1. Locations, soil descriptions, and herbicide application dates.[a]

Location	Year	Soil series	pH	Humic matter[b]	Application date
Painter, VA, field 1	2017	Bojac[c]	6.4	0.5	March 20
Painter, VA, field 2	2017	Bojac	6.4	0.5	April 20
Painter, VA, field 3	2017	Bojac	6.4	0.5	March 3
Rocky Mount, NC	2017	Aycock[d]	5.9	0.36	March 23
Jackson, NC	2017	Craven[e]	5.7	0.13	March 23
Painter, VA, field 1	2018	Bojac	6.4	0.5	March 31
Painter, VA, field 2	2018	Bojac	6.4	0.5	April 6
Jackson, NC, field 1	2018	Craven	6.5	0.32	March 28
Jackson, NC, field 2	2018	Craven	6.5	0.32	April 3
Gates, NC, field 1	2018	Noboco[f]	7.1	0.46	March 28
Gates, NC, field 2	2018	Goldsboro[g]	6.0	0.56	March 28
Rocky Mount, NC	2018	Aycock	6.4	0.32	April 18

[a] Soil texture at all sites was sandy loam.
[b] Humic matter determined according to Mehlich (1984).
[c] Coarse-loamy, mixed, semiactive, thermic Typic Hapludults.
[d] Fine-silty, siliceous, subactive, thermic Typic Paleudults.
[e] Fine, mixed, subactive, thermic Aquic Hapludults.
[f] Fine-loamy, siliceous, subactive, thermic Oxyaquic Paleudults.
[g] Fine-loamy, siliceous, subactive, thermic Aquic Paleudults.

glyphosate compared with 2,4-D applied in combination with glyphosate. Horseweed control by auxin herbicides is influenced by size of the weed (Budd et al. 2017; Kruger et al. 2010; McCauley and Young 2016; Zimmer et al. 2018a; 2018b). Kruger et al. (2010) reported dicamba alone controlled horseweed 30 cm or less in height 97% to 99% and was similar to control by 2,4-D alone; dicamba alone was more effective than 2,4-D in controlling horseweed taller than 30 cm. Despite effectiveness, varying sensitivity of horseweed biotypes to 2,4-D have been observed, which raises concern about horseweed evolving resistance to auxin herbicides (Eubank et al. 2008; Kruger et al. 2007).

Halauxifen-methyl is a new Group 4 synthetic auxin herbicide and a member of the pyridine-2-carboxylate (or arylpicolinate) herbicide chemical family (Epp et al. 2016; WSSA 2018). Other members of the pyridine-2-carboxylate family include picloram, clopyralid, and aminopyralid (Epp et al. 2016). Halauxifen-methyl effectively controls horseweed at varying sizes (McCauley and Young 2016; Zimmer et al 2018a, Zimmer et. al 2018b). Zimmer et al. (2018a, 2018b) reported halauxifen-methyl applied alone at 5 g ae ha^{-1} controlled GR horseweed 90%, and halauxifen-methyl in combinations with 2,4-D, dicamba, and/or glyphosate controlled GR horseweed 87% to 97%. In another study, dicamba and halauxifen-methyl applied alone provided 80% control of 30-cm horseweed, whereas 2,4-D applied at 560 g ae ha^{-1} controlled the weed less than 50% (McCauley and Young 2016).

Although halauxifen-methyl effectively controls horseweed, research is limited on its efficacy on many other weeds. Cutleaf evening primrose and curly dock are common weeds in reduced- and no-till systems that are not adequately controlled by glyphosate (Bish and Bradley 2015; Clewis et al. 2007; Culpepper et al. 2005; Scott et al. 1998; Steckel 2008; Vidrine et al. 2007; York and Collins 2016). Because cutleaf evening primrose control by glyphosate and paraquat is inadequate, 2,4-D is normally recommended with the aforementioned herbicides to improve control of cutleaf evening primrose and other weeds (Culpepper et al. 2005). Culpepper et al. (2005) reported glyphosate plus 2,4-D and 2,4-D plus paraquat controlled cutleaf evening primrose 86% and 94%, respectively. Other researchers found that 2,4-D controlled cutleaf evening primrose at rates as low as 134 g ae ha^{-1} (York and Culpepper 2005). Similar results were observed by Clewis et al. (2007), who reported glyphosate plus 2,4-D controlled cutleaf evening primrose 97% to 99%, whereas glyphosate alone provided 83% and 84% control. Bish and Bradley (2015) observed 60% to 80% curly dock control by 2,4-D and dicamba, whereas a combination of the two herbicides controlled the weed 80% to 100%. Furthermore, research is limited on preplant burndown control of henbit, purple deadnettle, purple cudweed, and common chickweed by halauxifen-methyl.

The objective of this study was to further investigate halauxifen-methyl for horseweed control and efficacy against many prevailing weeds frequently encountered preplant burndown.

Materials and Methods

Experiments were conducted at the Eastern Shore Agriculture Research and Extension Center near Painter, VA (37.58°N, 75.78°W), at the Upper Coastal Plain Research Station near Rocky Mount, NC (35.9382°N, 77.7905°W), and in a producer's field near Jackson, NC (36.3896°N, 77.4214°W) during 2017 and 2018 seasons, as well as in two producers' fields near Gates, NC (36.4202°N, 76.6875°W) during the 2018 season. Adjacent areas of the same fields were used for multiple locations at Painter, Rocky Mount, and Jackson (Table 1). The experimental design was a randomized complete block with treatments replicated three or four times, depending on location. Plot sizes ranged from 2.8 to 3.7 m in width and 6 m to 12 m in length depending on locations. Experiments were conducted in the absence of a crop.

Halauxifen-methyl, dicamba, and 2,4-D were applied alone or in combination with glyphosate, along with glyphosate applied alone, in mid-March to mid-April (Tables 1 and 2). Methylated seed oil at 1% vol/vol was included with halauxifen-methyl and glyphosate plus halauxifen-methyl, and nonionic surfactant at 0.25% vol/vol was included with 2,4-D and dicamba; no adjuvants were included with combinations of glyphosate and 2,4-D or dicamba (Table 2). Herbicides were applied using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (TTI 110015 Turbo TeeJet® Induction flat spray tip; TeeJet Technologies, Wheaton, IL) delivering 140 L ha^{-1} at 207 kPa. Weed species varied across locations; average weed size, density in nontreated checks, and number of locations with each species present are listed in Table 3.

Visual estimates of weed control were collected 2 and 4 wk after application using a 0% (no weed control) to 100% scale (complete

Table 2. Herbicides and adjuvants used in experiments.[a]

Herbicides and adjuvants	Trade name	Formulation concentration	Application rate	Manufacturer
		g ae L^{-1}	g ae ha^{-1}	
2,4-D	Weedar 64	456	533 (low rate) or 1,066 (high rate)	Nufarm Inc.
Dicamba	Clarity	480	280	BASF
Halauxifen-methyl	Elevore	69	5	Corteva Agriscience
Glyphosate	Roundup PowerMAX	540	1,260	Monsanto Co.
Methylated seed oil	MSO Concentrate	100%	1% (vol/vol)	Loveland Products, Inc.
Nonionic surfactant	Induce	90%	0.25% (vol/vol)	Helena Chemical Co.

[a] Specimen labels for each product and mailing and web site addresses of each manufacturer can be found at www.cdms.net.

Table 3. Average weed size, density, and number of locations with each species present.

Weed species	Height[a]	Diameter	Density	No. of locations
	cm	cm	plants m^{-2}	
Common chickweed	13	NA	11	6
Curly dock	NA[b]	53	8	3
Cutleaf evening-primrose	NA	16	18	7
Henbit	13	NA	14	4
Horseweed (small)	5	NA	6	6
Horseweed (large)	15	NA	5	3
Purple cudweed	NA	10	2	7
Purple deadnettle	15	NA	16	2

[a] Abbreviation: NA, not applicable.

[b] Some weeds are measured by height, some by diameter.

necrosis). Weed density data were collected 4 wk after application by counting the number of weeds $plot^{-1}$; three 0.25-m^2 subsamples were used when weeds were present at higher densities. Plant response to auxin herbicides is relatively slow (Ross and Childs 1996); therefore, results were focused on visible weed control and weed density 4 wk after treatment (WAT).

Statistical Analyses

Data were subjected to ANOVA using the PROC GLIMMIX procedure in SAS, version 9.4, SAS Institute Inc., Cary, NC). Herbicide treatment was considered a fixed factor, whereas locations and replications were treated as random factors. The two-way interactions of location by herbicide treatment were significant for all weed species. However, with the exception of horseweed, the *F* values associated with the main effect of herbicide treatment were approximately 20 to 1,650 times greater than *F* values associated with the interaction; hence, data for these weed species were pooled across locations. Horseweed size influences control by auxin herbicides (Budd et al. 2017; McCauley and Young 2016; Zimmer et al. 2018a; 2018b). Because the two-way interaction of location by herbicide treatment was significant and *F* values would not allow data for horseweed to be pooled across all nine locations, a secondary analysis was conducted for small or large horseweed separately. Weed heights were collected for each species prior to herbicide applications; horseweed that averaged 5 cm tall were considered small and those averaging 15 cm tall were considered large. For these analyses, the two-way interactions of location by herbicide treatment were not significant. Therefore, data for small and large horseweed are reported separately pooled over six and three locations, respectively. Means were separated using Fisher protected LSD at $\alpha = 0.05$. Data for nontreated checks were excluded from analysis except in a separate analysis for which the Dunnett procedure (Dunnett 1955) was used to compare weed density in the nontreated checks to all other treatments.

Results and Discussion

Large horseweed (average height, 15 cm) was more difficult to control than small horseweed (Table 4), which agrees with previous research (Budd et al. 2017; McCauley and Young 2016; Zimmer et al. 2018a; 2018b). Halauxifen-methyl controlled small and large horseweed 89% and 79%, respectively, and was similar to dicamba control, which controlled small horseweed 91% and large horseweed 77%. The LR (50%–72%) and HR (64%–80%) of 2,4-D were less effective than halauxifen-methyl and dicamba for control of small and large horseweed. In general, horseweed density followed similar trends as visual control data (Tables 4 and 5). Small and large horseweed density in nontreated checks averaged 6 and 5 plants m^{-2}, respectively (Table 3). All auxin herbicides applied alone reduced small and large horseweed density compared with the nontreated check (data not shown). Similar to visual estimates of horseweed control, halauxifen-methyl and dicamba reduced small horseweed density greater than did both rates of 2,4-D (Table 5). When horseweed plants were larger (average height, 15 cm), halauxifen-methyl and dicamba remained more effective than 2,4-D LR but provided equivalent reductions in density to 2,4-D HR.

Henbit and purple deadnettle are members of the Lamiaceae and responded similarly to herbicide treatments (Tables 4 and 5). Halauxifen-methyl controlled henbit 90% and purple deadnettle 99%, similar to previous research (Steckel 2018). Of the auxin herbicides applied alone, 2,4-D and dicamba were less effective at controlling henbit and purple deadnettle than was halauxifen-methyl. Glyphosate alone and glyphosate combinations controlled henbit 100% and purple deadnettle 99%.

Halauxifen-methyl efficacy for control of cutleaf evening primrose has not been documented previously, to our knowledge, although control is claimed on the label (Anonymous 2018a). Halauxifen-methyl (4%) and dicamba (51%) were less effective than 2,4-D (74% to 85%) for control of cutleaf evening primrose. Cutleaf evening primrose density in nontreated check plots averaged 18 plants m^{-2} (Table 3); all herbicide treatments, except halauxifen-methyl alone, reduced cutleaf evening primrose density compared with the nontreated (data not shown). Similar to visible control data of the auxin herbicides applied alone, 2,4-D reduced cutleaf evening primrose density the most compared with the nontreated check and was more effective than halauxifen-methyl and dicamba (Table 5).

Like cutleaf evening primrose, curly dock control by glyphosate can be difficult; adequate control may require an additional mode

Table 4. Weed control 4 wk after treatment.[a]

Herbicide[b,c]	Small horseweed[d]	Large horseweed[e]	Henbit	Purple deadnettle	Cutleaf evening-primrose	Curly dock	Purple cudweed	Common chickweed
				%				
Halauxifen-methyl	89 C	79 C	90 B	99 A	4 H	5 F	7 D	6 D
Dicamba	91 C	77 D	8 C	5 B	51 E	59 D	21 B	10 C
2,4-D LR	72 E	50	8 C	3 C	74 C	62 D	13 C	10 C
2,4-D HR	80 D	64 E	8 C	7 B	85 B	70 C	21 B	12 B
Glyphosate	95 B	95 B	100 A	99 A	35 G	37 E	100 A	100 A
Glyphosate + halauxifen-methyl	99 A	99 A	100 A	99 A	46 F	38 E	100 A	100 A
Glyphosate + dicamba	99 A	99 A	100 A	99 A	65 D	72 B	100 A	100 A
Glyphosate + 2,4-D LR	96 AB	98 A	100 A	99 A	83 B	74 B	100 A	100 A
Glyphosate + 2,4-D HR	98 AB	98 A	100 A	99 A	93 A	78 A	100 A	100 A

[a] Means within a column followed by the same letter are not different according to Fisher protected LSD test at $\alpha = 0.05$.

[b] Abbreviations: HR, high rate; LR, low rate.

[c] Halauxifen-methyl, dicamba, 2,4-D LR, 2,4-D HR, and glyphosate were applied at 5, 280, 533, 1,066, and 1,260 g ae ha^{-1}, respectively. Methylated seed oil at 1% vol/vol was included with halauxifen-methyl and glyphosate plus halauxifen-methyl whereas nonionic surfactant at 0.25% vol/vol was included with 2,4-D and dicamba; no adjuvants were included with combinations of glyphosate and 2,4-D or dicamba.

[d] Average height of small horseweed: 5 cm.

[e] Average height of large horseweed: 15 cm.

Table 5. Weed density reduction 4 wk after treatment.[a,b]

Herbicide[c,d]	Small horseweed[e]	Large horseweed[f]	Henbit	Purple deadnettle	Cutleaf evening primrose	Curly dock	Purple cudweed	Common chickweed
				%				
Halauxifen-methyl	97 BC	66 BC	100 A	100 A	0 E	26 E	5 B	0 B
Dicamba	97 BC	79 AB	27 B	3 B	54 D	68 BC	10 B	0 B
2,4-D LR	93 D	46 C	39 B	0 B	69 BC	77 AB	31 B	0 B
2,4-D HR	96 C	60 BC	46 B	0 B	81 AB	96 A	13 B	0 B
Glyphosate	97 BC	90 A	99 A	100 A	20 E	56 CD	95 A	95 A
Glyphosate + halauxifen-methyl	99 AB	100 A	100 A	100 A	31 E	46 DE	100 A	98 A
Glyphosate + dicamba	100 A	95 A	97 A	100 A	58 CD	84 AB	100 A	100 A
Glyphosate + 2,4-D LR	98 ABC	98 A	97 A	100 A	77 AB	88 AB	100 A	100 A
Glyphosate + 2,4-D HR	100 A	98 A	97 A	100 A	91 A	90 A	100 A	100 A

[a] Means within a column followed by the same letter are not different according to Fisher protected LSD test at $\alpha = 0.05$.

[b] Weed density reductions in comparison to nontreated checks. Weed density for small horseweed, large horseweed, henbit, purple deadnettle, cutleaf evening primrose, curly dock, purple cudweed, and common chickweed averaged 6, 5, 14, 16, 18, 8, 2, and 11 plants m^{-2}, respectively.

[c] Abbreviations: HR, high rate; LR, low rate.

[d] Halauxifen-methyl, dicamba, 2,4-D LR, 2,4-D HR, and glyphosate were applied at 5, 280, 533, 1,066, and 1,260 g ae ha^{-1}, respectively. Methylated seed oil at 1% vol/vol was included with halauxifen-methyl and glyphosate plus halauxifen-methyl, whereas nonionic surfactant at 0.25% vol/vol was included with 2,4-D and dicamba; no adjuvants were included with combinations of glyphosate and 2,4-D or dicamba.

[e] Average height of small horseweed: 5 cm.

[f] Average height of large horseweed: 15 cm.

of action (Bish and Bradley 2015; Scott et al. 1998). Dicamba and 2,4-D controlled curly dock 59% to 70%, respectively, and were more effective than halauxifen-methyl (5%). Likewise, 2,4-D and dicamba reduced curly dock density compared with the nontreated check, whereas halauxifen-methyl did not (data not shown).

Common chickweed and purple cudweed are also encountered burndown before planting cotton and other crops and can be difficult to control with auxin herbicides (Monning and Bradley 2007; York and Collins 2016). None of the auxin herbicides effectively controlled purple cudweed (control range, 7% to 21%) or common chickweed (control range, 6% to 12%). Compared with the nontreated check, 2,4-D, dicamba, and halauxifen-methyl did not reduce density of common chickweed or purple cudweed (data not shown).

Despite a history of GR horseweed in North Carolina and Virginia, GR biotypes only made up a small portion of the horseweed populations used for this experiment, as demonstrated by excellent horseweed control by glyphosate alone (Table 4). Furthermore, glyphosate applied alone controlled all weeds 95% or greater with the exception of cutleaf evening primrose (35%) and curly dock (37%). Compared with glyphosate alone, adding 2,4-D, dicamba, or halauxifen-methyl to glyphosate did little to improve control of horseweed (96% to 99%), henbit (100%), purple deadnettle (99%), purple cudweed (100%), and common chickweed (100%). In contrast, poor control of cutleaf evening primrose and curly dock by glyphosate was improved 30% to 58% and 35% to 41% with the addition of 2,4-D or dicamba, respectively. Culpepper et al. (2005) documented the addition of 2,4-D to glyphosate improved cutleaf evening primrose 37% at 4 WAT compared with glyphosate alone. Combining halauxifen-methyl with glyphosate did little to improve cutleaf evening primrose (46%) or curly dock (38%) control compared with glyphosate alone. Weed density data on glyphosate alone and glyphosate combinations reaffirm visual estimates of weed control (Table 5). This research confirms 2,4-D continues to be recommended for control of cutleaf evening primrose, whereas control by halauxifen-methyl is inadequate.

These data from North Carolina and Virginia, in addition to research from Indiana (Zimmer et al. 2018a, 2018b), indicate halauxifen-methyl effectively controls horseweed. In this experiment, halauxifen-methyl and dicamba controlled horseweed averaging 5 or 15 cm in height more effectively than did 2,4-D. Besides horseweed, information is limited on efficacy of halauxifen-methyl for control many other weed species. Steckel (2018) observed halauxifen-methyl plus florasulam (Anonymous 2018b) controlled henbit. However, it was not distinguished which active ingredient or if both were responsible for henbit control. In this experiment, halauxifen-methyl controlled henbit 90% and purple deadnettle 99%, whereas 2,4-D and dicamba controlled these weeds not greater than 8%. Despite effectiveness against horseweed, henbit, and purple deadnettle, halauxifen-methyl was less effective against other weeds in this experiment. Like 2,4-D and dicamba, purple cudweed and common chickweed control by halauxifen-methyl was inadequate (≤ 7%). Halauxifen-methyl controlled cutleaf evening primrose and curly dock less than dicamba and 2,4-D did. This is of particular concern because cutleaf evening primrose and curly dock are commonly encountered preplant burndown (York and Collins 2016) and glyphosate does not effectively control these species (Culpepper et al. 2005; Scott et al. 1998); 2,4-D or dicamba is often relied upon in combination with glyphosate to control these weeds. Replacing 2,4-D with halauxifen-methyl in preplant burndown applications may result in inadequate control of cutleaf evening primrose and curly dock.

In conclusion, halauxifen-methyl is a useful tool for horseweed, henbit, and purple deadnettle management. However, future research should address combinations of halauxifen-methyl with glyphosate and various rates of 2,4-D for broader-spectrum weed control where preplant intervals allow, especially where cutleaf evening primrose and curly dock are commonplace.

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