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Herbicide Programs Utilizing Halauxifen-Methyl for Glyphosate-Resistant Horseweed (*Conyza canadensis*) Control in Soybean

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Abstract

Evolution of glyphosate-resistant (GR) weeds, such as horseweed, presents major challenges in no-till soybean production systems. Effective GR horseweed control with preplant burndown applications is necessary to prevent potential soybean yield losses due to competition and to manage the soil weed seedbank. Halauxifen-methyl is a new synthetic auxin herbicide for broadleaf weed control in preplant burndown applications for soybean and other crops at low use rates (5 g ae ha^{-1}). Experiments were conducted to evaluate the efficacy of herbicide treatments containing halauxifen-methyl for control of GR horseweed in comparison to existing herbicide treatments utilized in no-till GR soybean systems. Glyphosate alone controlled horseweed 33%. Herbicide treatments that included halauxifen-methyl, dicamba, or saflufenacil in combination with glyphosate controlled horseweed 87% to 96%, 89%, and 93%, respectively, 35 d after burndown application (DAB). Horseweed control, horseweed density reduction, and ground cover reduction by halauxifen-methyl plus glyphosate was similar to dicamba plus glyphosate. Horseweed control was greater for halauxifen-methyl plus glyphosate than for 2,4-D plus glyphosate. Cloransulam, cloransulam plus flumioxazin, and cloransulam plus sulfentrazone added to halauxifen-methyl plus glyphosate increased horseweed control and reduced horseweed density. No herbicide injury or soybean yield reduction was observed for treatments containing halauxifen-methyl.

Introduction

The evolution of herbicide-resistant weeds represents a major challenge in no-till crop production systems (Bhowmik 2010; Duke and Powles 2009). Horseweed is one of the most troublesome weeds to control in broadleaf crops such as soybean because of the widespread occurrence in the United States of populations with resistance to acetolactate synthase–inhibiting herbicides and glyphosate (Gibson et al. 2005; Heap 2017; Kruger et al. 2009; VanGessel et al. 2009; Van Wychen 2016; Weaver 2001; Zheng et al. 2011).

Control of GR horseweed with effective preplant burndown applications is necessary to protect yield potential and to manage the weed seedbank as a result of the lack of POST herbicide options in no-till soybean systems (Kruger et al. 2008; Loux and Johnson 2014; Loux et al. 2006). Synthetic auxin herbicides such as 2,4-D and dicamba, as well as contact herbicides such as glufosinate, saflufenacil, and paraquat, can be used for GR horseweed control in preplant burndown applications. In general, spring burndown applications of these herbicides in Indiana occur from early April to early May, depending on appropriate weather conditions for entering the field. However, research has shown that herbicides such as 2,4-D, glufosinate, and paraquat can result in variable GR horseweed control in the spring depending on environmental conditions and horseweed size at the time of application (Brown et al. 2016; Byker et al. 2013; Davis et al. 2010; Kruger et al. 2008, Kruger et al. 2010; Loux et al. 2006; Loux and Johnson 2014; Mahoney et al. 2017; Mellendorf et al. 2013; Montgomery et al. 2017). Research has also shown that saflufenacil and dicamba are effective herbicides for GR horseweed control in burndown applications (Brown et al. 2016; Byker et al. 2013; Kruger et al. 2008; Mellendorf et al. 2013; Montgomery et al. 2017).

Halauxifen-methyl is a new synthetic auxin herbicide for broadleaf weed control in preplant burndown applications in soybean and other crops at a low use rate (5 g ha^{-1}) (Anonymous 2017a, b; Schmitzer et al. 2015; Switalski et al. 2017). Experiments were conducted to evaluate the efficacy of herbicide treatments containing halauxifen-methyl for GR horseweed control in comparison to existing herbicide treatments used in no-till GR soybean systems.

Materials and Methods

Field experiments were conducted in 2015 and 2016 at three locations in Indiana with GR horseweed populations (Brookston: 40.58°N, 86.78°W; Lafayette: 40.27°N, 86.88°W; and Cortland: 38.98°N, 85.94°W). Trials were established in no-till fields using a randomized complete block design with four replications. Plots measured 3 m wide and 9 m in length. GR soybean (Asgrow® 2933, Monsanto Co., 800 N. Lindbergh Boulevard, St Louis, MO 63167, USA) was planted in 76-cm rows at a seeding rate of 345,800 seeds ha^{-1}.

The herbicide programs tested in this study were either currently in use for weed control in GR soybean in Indiana or are new herbicide programs containing halauxifen-methyl (5 g ha^{-1}) suggested by the manufacturer for GR horseweed control (Tables 1 and 2). Burndown herbicide applications occurred 13 to 17 d before planting of soybean targeting horseweed plants 13 to 20 cm in height (average of the horseweed stand), followed by POST herbicide applications at the V2 to V4 growth stage of soybean (Table 3). Herbicides were applied using a handheld CO_2-pressurized spray boom equipped with four XR11002 or AIXR 110015 nozzles (TeeJet Technologies, 200 W. North Avenue, Glendale Heights, IL 60139, USA) for wind speeds below 10 mph or above 10 mph, respectively. Nozzles were spaced 50 cm apart and calibrated to deliver 140 L ha^{-1} while traveling at 4.8 km h^{-1} and operating at 165 kPa for XR11002 nozzles or 289 kPa for AIXR 110015 nozzles.

Data collection consisted of visual ratings of horseweed control and soybean phytotoxicity (0 to 100% scale in comparison to the nontreated control) at 34 to 35 d after burndown application (hereafter referred to as 35 DAB). Horseweed density (plants m^{-2}) and soybean stand (plants m^{-1} of row) were recorded 35 DAB using two 1.0-m^2 quadrats per plot. In addition, soybean grain yield was collected by harvesting the center two rows of each plot at the end of the growing season to evaluate potential yield loss due to competition.

Digital imagery analysis using the public-domain Java-based ImageJ software (W.S. Rasband, ImageJ, US National Institutes of Health, Bethesda, MD, USA) was implemented in 2016 to measure ground cover by weeds as additional information on efficacy of herbicide treatments (Ferreira and Rasband 2012). The parameters hue and brightness were adjusted (hue = 46 to 120, brightness = 20 to 255) for processing field images with the *Threshold colour* plugin written by Landini (2009) in ImageJ according to the methodology described by Ali et al. (2013) and allowed for distinguishing between ground cover by vegetation versus soil plus plant residue. Lower ground cover (%) corresponds to higher overall herbicide efficacy. Field images were captured under ambient daylight conditions in the field 35 DAB using a digital camera (COOLPIX 5700, Nikon, Inc.) with resolution 2,560 by 1,920 pixels. The camera was supported by a monopod at a constant height of 170 cm above the soil surface of each plot, and focal length settings adjusted to cover a ground area of approximately 163 by 122 cm. To facilitate the analysis, ground cover provided by soybean plants was assumed to be approximately uniform for all treatments at 35 DAB because of low interspecific competition early in the growing season.

Table 1. List of soybean foliar-applied herbicides and rates used in herbicide treatments, manufacturers, and websites.

Trade name	Common name	Rate[a]	Manufacturer and website
		g ai or ae ha^{-1}	
Classic®	Chlorimuron-ethyl	22	DuPont Crop Protection, Wilmington, DE http://www.cropprotection.dupont.com
Clarity®	Dicamba	280	BASF Ag Products, Research Triangle Park, NC http://www.agproducts.basf.us
Durango® DMA®	Glyphosate	1,120	Dow AgroSciences LLC, Indianapolis, IN http://www.dowagro.com/en-US
Elevore™	Halauxifen-methyl	5	Dow AgroSciences LLC, Indianapolis, IN http://www.dowagro.com/en-US
FirstRate®	Cloransulam-methyl	18	Dow AgroSciences LLC, Indianapolis, IN http://www.dowagro.com/en-US
Liberty® 280 SL	Glufosinate	594	Bayer CropScience, Research Triangle Park, NC http://www.cropscience.bayer.com/en
Tricor® DF	Metribuzin	210	United Phosphorus Inc., King of Prussia, PA http://www.upi-usa.com/
Sharpen®	Saflufenacil	37	BASF Ag Products, Research Triangle Park, NC http://www.agproducts.basf.us
Shredder™ 2,4-D LV4	2,4-D ester	560	Winfield Solutions LLC, St. Paul, MN http://www.winfieldunited.com
Sonic®	Cloransulam + sulfentrazone	25 + 195	Dow AgroSciences LLC, Indianapolis, IN http://www.dowagro.com/en-US
Surveil™	Cloransulam + flumioxazin	25 + 76	Dow AgroSciences LLC, Indianapolis, IN http://www.dowagro.com/en-US
Valor® SX	Flumioxazin	63	Valent U.S.A. LLC, Walnut Creek, CA http://www.valent.com/

[a]Herbicide rate expressed as active ingredient or acid equivalent as appropriate.

Data were pooled across all six site-years for analysis to summarize data and infer which herbicide treatments were superior across all of the different environments tested in Indiana.

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Table 2. Soybean herbicide treatments evaluated for glyphosate-resistant horseweed control, including herbicide combinations and rates.[a]

Burndown treatment[b]	Burndown rate[c]	POST treatment	POST rate
	g ae or ai ha^{-1}		g ae or ai ha^{-1}
gly	1,120	gly	1,120
hal	5	gly	1,120
hal + dic	5 + 280	gly	1,120
hal + 2,4-D	560 + 5	gly	1,120
hal + gly	5 + 1,120	gly	1,120
hal + gly + clo	5 + 1,120 + 17.7	gly	1,120
hal + gly + clo + flumi	5 + 1,120 + 25 + 76	gly	1,120
hal + gly + clo + sulf	5 + 1,120 + 25 + 195	gly	1,120
2,4-D	560	gly	1,120
2,4-D + gly	560 + 1,120	gly + clo	1,120 + 18
2,4-D + gly + mtz	560 + 1,120 + 210	gly	1,120
2,4-D + saflu + gly	560 + 37 + 1,120	gly + chl	1,120 + 22
saflu + gly	37 + 1,120	gly + chl	1,120 + 22
dic	280	gly	1,120
dic + gly	280 + 1120	gly	1,120
gluf	594	gly	1,120
gluf + chl + flumi	594 + 21.9 + 63	gly	1,120
gluf + clo + flumi	594 + 25 + 76	gly	1,120

[a]Ammonium sulfate (N-Pak® AMS; Winfield Solutions LLC, St. Paul, MN) at 2.5% vol/vol was added to all burndown and POST herbicide applications. Methylated seed oil (MSO Ultra™; Precision Laboratories LLC, Waukegan, IL) at 1% vol/vol was added to all treatments containing halauxifen-methyl or saflufenacil, and to 2,4-D alone. Herbicide treatments containing dicamba without halauxifen-methyl had non-ionic surfactant (Activator 90; Loveland Products Inc., Greeley, CO) at 0.25% vol/vol added. Burndown applications occurred 13 to 18 d before planting of soybean, followed by POST herbicide applications at V2 to V4 soybean growth stage.
[b]Abbreviations: chl, chlorimuron; clo, cloransulam; dic, dicamba; flumi, flumioxazin; gluf, glufosinate; gly, glyphosate; hal, halauxifen-methyl; mtz, metribuzin; saflu, saflufenacil; sulf, sulfentrazone.
[c]Herbicide rate expressed as active ingredient or acid equivalent as appropriate.

Although glyphosate-, 2,4-D-, and glufosinate-based herbicide treatments were variable across different site-years (treatment by site-year interaction), these treatments were not the focus of this experiment. Treatment differences for horseweed control, horseweed density, ground cover, soybean phytotoxicity, and soybean stand counts were determined with one-way ANOVA using PROC GLIMMIX procedure in SAS (V. 9.4; SAS Institute Inc., SAS Campus Drive, Cary, NC 27513, USA) with mean separation using Tukey honest significant difference (HSD) test at $\alpha = 0.05$. Orthogonal contrast statements within PROC GLIMMIX were used to further compare the efficacy of halauxifen-methyl–based herbicide treatments with herbicide treatments containing dicamba, 2,4-D, glyphosate, and glufosinate. Treatment differences for soybean grain yield were determined using PROC GLIMMIX procedure in SAS with Fisher's protected LSD test at $\alpha = 0.05$.

Results and Discussion

Glyphosate applied alone resulted in 33% horseweed control. Halauxifen-methyl applied alone controlled GR horseweed 90% at 35 DAB, similar to dicamba applied alone (89%), whereas glufosinate and 2,4-D alone resulted in lower GR horseweed control (59% and 72%, respectively) (Table 4). The efficacy of 2,4-D- and glufosinate-based herbicide treatments and glyphosate alone was variable across site-years (data not shown). Variable horseweed control observed with 2,4-D, glufosinate, and glyphosate due to differences in plant size and environmental conditions have been reported in previous research (Ge et al. 2011; Kruger et al. 2010; Mithila et al. 2011; Montgomery et al. 2017; Owen et al. 2009; Shrestha et al. 2007; Steckel et al. 2006; VanGessel et al. 2009).

Horseweed control by treatments containing saflufenacil was similar to control by halauxifen-methyl- and dicamba-based herbicide treatments (93% to 97% versus 90% to 96% control, respectively) at 35 DAB, except for halauxifen-methyl plus glyphosate versus 2,4-D plus glyphosate plus saflufenacil (87% versus 97% control, respectively) (Table 4).

Other researchers have shown similar results for horseweed control with preplant burndown applications of 2,4-D, dicamba, glyphosate, glufosinate, and saflufenacil (Brown et al. 2016; Byker et al. 2013; Davis et al. 2010; Eubank et al. 2008; Kruger et al. 2010; Mahoney et al. 2017; Mellendorf et al. 2013; Mithila et al. 2011; Montgomery et al. 2017; Owen et al. 2009; Shrestha et al. 2007; Steckel et al. 2006; VanGessel et al. 2009).

Table 3. Burndown application dates, soybean planting dates, and application parameters for all-site years in Indiana.

Site-year	Burndown date	Planting date	Horseweed height	Horseweed density	Temperature	Relative humidity	Wind speed
			cm	Plants m^{-2}	C	%	km h^{-1}
Brookston 2015	May 28	June 11	3 to 18	75	22	68	4
Brookston 2016	June 03	June 16	10 to 33	54 to 215	22	70	0
Cortland 2015	May 13	May 28	3 to 20	108 to 538	11	66	8
Cortland 2016	May 16	June 01	8 to 25	17 to 182	13	43	11
Lafayette 2015	June 09	June 23	8 to 25	215 to 538	24	80	5
Lafayette 2016	May 18	May 31	5 to 28	54 to 409	19	40	13

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Table 4. Glyphosate-resistant horseweed control, density, and ground cover at 35 d after burndown treatment.[a]

Treatment[b]	Control	Density reduction	Ground cover
	———————————————%———————————————		
Nontreated control	–	–	55 a
Gly	33 g	17 h	46 ab
Hal	90 a–c	76 b–f	20 ef
hal + dic	95 ab	86 a–e	14 f
hal + 2,4-D	93 ab	83 a–f	20 ef
hal + gly	87 b–d	63 fg	22 d–f
hal + gly + clo	94 ab	90 a–c	15 f
hal + gly + clo + flumi	96 ab	91 a–c	15 f
hal + gly + clo + sulf	94 ab	85 a–f	15 f
2,4-D	72 e	44 g	34 b–d
2,4-D + gly	80 c–e	67 d–f	29 c–e
2,4-D + gly + mtz	82 c–e	84 a–f	25 d–f
2,4-D + gly + saflu	97 a	99 a	15 f
saflu + gly	93 ab	96 ab	18 ef
Dic	89 a–c	71 c–f	16 ef
dic + gly	89 a–c	74 b–f	16 f
gluf	59 f	64 e–g	39 bc
gluf + chl + flumi	78 de	81 a–f	24 d–f
gluf + clo + flumi	82 c–e	89 a–d	22 d–f

[a]Treatment means of six field trials ($n = 24$) in 2015 and 2016 combined for horseweed control and density, and treatment means of three field trials in 2016 combined for ground cover ($n = 12$). Means within a column followed by same letter are not statistically different according to Tukey's honest significant difference (HSD) test ($P \leq 0.05$). Horseweed control as percentage of nontreated control. Horseweed density as percentage reduction of nontreated control. Ground cover as percentage of total ground area cover with green vegetation.
[b]Abbreviations: chl, chlorimuron; clo, cloransulam; dic, dicamba; flumi, flumioxazin; gluf, glufosinate; gly, glyphosate; hal, halauxifen-methyl; mtz, metribuzin; saflu, saflufenacil; sulf, sulfentrazone. Refer to Table 2 for herbicide rates and adjuvants.

Table 5. Orthogonal contrasts for glyphosate-resistant horseweed control, density, and ground cover at 35 d after burndown treatment.[a]

Orthogonal contrast[b]	Control	Density	Ground cover
	——————————%————————————		
hal vs gly	90 vs 33*	76 vs 17*	20 vs 46*
hal vs 2,4-D	90 vs 72*	76 vs 44*	20 vs 34*
hal vs dic	90 vs 89	76 vs 71	20 vs 16
hal vs gluf	90 vs 59*	76 vs 64	20 vs 39*
hal vs hal + gly	90 vs 87	76 vs 63	20 vs 22
hal vs hal + 2,4-D	90 vs 93	76 vs 83	20 vs 20
hal vs hal + dic	90 vs 95	76 vs 86	20 vs 14
hal + gly vs 2,4-D + gly	87 vs 80*	63 vs 67	22 vs 29
hal + gly vs 2,4-D + gly + mtz	87 vs 82*	63 vs 84*	22 vs 25
hal + gly vs 2,4-D + gly + saflu	87 vs 97*	63 vs 99*	22 vs 15
hal + gly vs dic + gly	87 vs 89	63 vs 74	22 vs 16
hal + gly vs hal + gly + clo	87 vs 94*	63 vs 90*	22 vs 15
hal + gly vs hal + gly + clo + flumi	87 vs 96*	63 vs 91*	22 vs 15
hal + gly vs hal + gly + clo + sulf	87 vs 94*	63 vs 85*	22 vs 15*
hal + gly vs gluf + chl + flumi	87 vs 78*	63 vs 81*	22 vs 24
hal + gly vs gluf + clo + flumi	87 vs 82*	63 vs 89*	22 vs 22
hal + gly vs saflu + gly	87 vs 93*	63 vs 96*	22 vs 18

[a]Treatment means of six field trials ($n = 24$) in 2015 and 2016 combined for horseweed control and density, and treatment means of three field trials in 2016 combined for ground cover ($n = 12$). Horseweed control as percentage of nontreated control. Horseweed density as percentage reduction of nontreated control. Ground cover as percentage of total ground area cover with green vegetation. *Significance at $P \leq 0.05$.
[b]Abbreviations: chl, chlorimuron; clo, cloransulam; dic, dicamba; flumi, flumioxazin; gluf, glufosinate; gly, glyphosate; hal, halauxifen-methyl; mtz, metribuzin; saflu, saflufenacil; sulf, sulfentrazone; vs, versus. Refer to Table 2 for herbicide rates and adjuvants.

Orthogonal contrasts were used to further compare herbicide treatments (Table 5) and showed that adding glyphosate, 2,4-D, or dicamba to halauxifen-methyl did not significantly increase GR horseweed control compared to halauxifen-methyl alone. Furthermore, halauxifen-methyl plus glyphosate resulted in similar GR horseweed control compared to dicamba plus glyphosate (87% versus 89%), and greater GR horseweed control than 2,4-D plus glyphosate (80%). Halauxifen-methyl plus glyphosate resulted in lower GR horseweed control than saflufenacil plus glyphosate and 2,4-D plus saflufenacil plus glyphosate (87% versus 93% and 97%). However, halauxifen-methyl plus glyphosate resulted in greater GR horseweed control (87%) than all glufosinate- and 2,4-D-based herbicide treatments (59% to 82% control), except 2,4-D plus saflufenacil plus glyphosate.

Tank mixtures of acetolactate synthase–inhibiting (Group 2) and protoporphyrinogen oxidase–inhibiting (Group 14) herbicides such as cloransulam, cloransulam plus flumioxazin, or cloransulam plus sulfentrazone with halauxifen-methyl plus glyphosate resulted in greater GR horseweed control compared to halauxifen-methyl plus glyphosate (94%, 96%, 94% control versus 87% control, respectively) (Table 5). These tank mixtures resulted in similar GR horseweed control compared to 2,4-D plus glyphosate plus saflufenacil (97% control). Similarly, chlorimuron plus flumioxazin or cloransulam plus flumioxazin added to glufosinate resulted in greater GR horseweed control than glufosinate alone at 35 DAB (78% or 82% control versus 59% control, respectively) (Table 4).

Glyphosate alone was the only herbicide treatment that resulted in similar GR horseweed density compared to the nontreated control (17% reduction) at 35 DAB (Table 4). Halauxifen-methyl plus glyphosate resulted in 63% reduction in GR horseweed density. However, horseweed density counts 35 DAB did not reflect visual control of GR horseweed when comparing dicamba- and halauxifen-based treatments versus 2,4-D- and glufosinate-based treatments because of prolonged survival of GR horseweed plants up to 35 DAB with synthetic auxin treatments. Living horseweed plants were found in all these treatments at 35 DAB; however, only 2,4-D- and glufosinate-based treatments had actively growing plants in the plots. Furthermore, horseweed

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Table 6. Herbicide programs for glyphosate-resistant horseweed control and soybean grain yield in Indiana.[a,b]

Treatment	Yield
	kg ha^{-1}
Nontreated control	1,190 g
gly fb gly	2,750 f
hal fb gly	3,640 ab
hal + dic fb gly	3,560 a–e
hal + 2,4-D fb gly	3,450 a–e
hal + gly fb gly	3,610 a–c
hal + gly + clo fb gly	3620 a–c
hal + gly + clo + flumi fb gly	3,790 a
hal + gly + clo + sulf fb gly	3,590 a–d
2,4-D fb gly	3,340 b–e
2,4-D + gly fb gly + clo	3,570 a–e
2,4-D + gly + mtz fb gly	3,500 a–e
2,4-D + saflu + gly fb gly + chl	3,290 de
saflu + gly fb gly + chl	3,370 b–e
dic fb gly	3,500 a–e
dic + gly fb gly	3,490 a–e
gluf fb gly	3,300 c–e
gluf + chl + flumi fb gly	3,250 e
gluf + clo + flumi fb gly	3,470 a–e

[a]Treatment means of six field trials ($n = 24$) in 2015 and 2016 combined.
[b]Abbreviations: chl, chlorimuron; clo, cloransulam; dic, dicamba; fb, followed by; flumi, flumioxazin; gluf, glufosinate; gly, glyphosate; hal, halauxifen-methyl; mtz, metribuzin; saflu, saflufenacil; sulf, sulfentrazone. Refer to Table 2 for herbicide rates and adjuvants. Treatment means followed by same letter are not statistically different according to Fisher's protected LSD test ($P \leq 0.05$).

density did not account for plant height or regrowth of injured plants. Therefore, digital imagery analysis was utilized in 2016 to measure ground cover by weeds 35 DAB and provide additional information on efficacy of herbicide treatments.

Cloransulam, cloransulam plus flumioxazin, or cloransulam plus sulfentrazone added to halauxifen-methyl plus glyphosate resulted in lower GR horseweed density at 35 DAB compared to halauxifen-methyl plus glyphosate (90%, 91%, or 85% versus 63% reduction, respectively) (Table 5). Similarly, adding cloransulam plus flumioxazin to glufosinate reduced GR horseweed density compared to glufosinate alone (89% versus 64%) (Table 4).

Digital imagery analysis (ground cover) showed more similar trends to GR horseweed control than horseweed density counts (Tables 4 and 5). Glyphosate alone resulted in similar ground cover compared to the nontreated control (46% versus 55% ground cover, respectively) (Table 4). Halauxifen-methyl alone resulted in lower ground cover than glyphosate, glufosinate, and 2,4-D alone (20% versus 46%, 39%, and 34% ground cover, respectively). The addition of cloransulam plus flumioxazin or chlorimuron plus flumioxazin to glufosinate reduced ground cover compared to glufosinate alone (22% or 24% versus 39% ground cover, respectively).

No soybean injury was observed for any treatment containing halauxifen-methyl (data not shown). Soybean was planted 13 to 17 DAB. The current product label requires at least 14 d between halauxifen-methyl application and soybean planting (Anonymous 2017a). Soybean yield for all treatments is presented in Table 6. The nontreated control and glyphosate alone resulted in lower soybean grain yield than all other treatments.

In conclusion, herbicide treatments containing either halauxifen-methyl, dicamba, or saflufenacil resulted in the greatest control of GR horseweed. Therefore, halauxifen-methyl is a valuable addition for use in preplant burndown treatments for control of GR horseweed in soybean. Further research looking into the weed control spectrum of halauxifen-methyl compared to other synthetic auxin herbicides, preplant intervals for soybean crop safety, herbicide fate, and tank mix interactions is necessary to increase understanding of this new active ingredient.

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References

Ali A, Streibig JC, Duus J, Andreasen C (2013) Use of image analysis to assess color response on plants caused by herbicide application. Weed Technol 27:604–611

Anonymous (2017a) Elevore™ herbicide product label. Dow AgroSciences LLC. LOES No. 010-02340. Indianapolis, IN: Dow AgroSciences LLC. 5 p

Anonymous (2017b) Introducing Elevore™ herbicide – Elevate your perception of burndown with Elevore herbicide, offering thorough control of labeled broadleaf weeds, including superior control of marestail up to 8 inches tall. http://msdssearch.dow.com/PublishedLiteratureDAS/dh_0997/0901b803809973ab.pdf?filepath=pdfs/noreg/010-43764.pdf&fromPage=GetDoc. Accessed: September 13, 2017

Bhowmik PC (2010) Current status of herbicide resistant weeds around the globe. J Crop Weed 6:33–43

Brown LR, Shropshire C, Sikkema PH (2016) Control of glyphosate-resistant Canada fleabane in corn with preplant herbicides. Can J Plant Sci 96:932–934

Byker HP, Soltani N, Robinson DE, Tardif FJ, Lawton MB, Sikkema PH (2013) Control of glyphosate-resistant horseweed (*Conyza canadensis*) with dicamba applied preplant and postemergence in dicamba-resistant soybean. Weed Technol 27:492–496

Davis VM, Kruger GR, Young BG, Johnson WG (2010) Fall and spring preplant herbicide applications influence spring emergence of glyphosate-resistant horseweed (*Conyza canadensis*). Weed Technol 24:11–19

Duke SO, Powles SB (2009) Glyphosate-resistant crops and weeds: now and in the future. AgBioForum 12:346–357

Eubank TW, Poston DH, Nandula VK, Koger CH, Shaw DR, Reynolds DB (2008) Glyphosate-resistant horseweed (*Conyza canadensis*) control using glyphosate-, paraquat-, and glufosinate-based herbicide programs. Weed Technol 22:16–21

Ferreira T, Rasband W (2012) ImageJ user guide (IJ 1.46r). https://imagej.nih.gov/ij/docs/guide/user-guide.pdf. Accessed October 9, 2017

Ge X, d'Avignon DA, Ackerman JJ, Duncan B, Spaur MB, Sammons RD (2011) Glyphosate-resistant horseweed made sensitive to glyphosate: low-temperature suppression of glyphosate vacuolar sequestration revealed by ^{31}P NMR. Pest Manag Sci 67:1215–1221

Gibson KD, Johnson WG, Hillger DE (2005) Farmer perceptions of problematic corn and soybean weeds in indiana. Weed Technol 19:1065–1070

Heap I (2017) The international survey of herbicide resistant weeds. http://www.weedscience.org. Accessed: September 13, 2017

Kruger GR, Davis VM, Weller SC, Johnson WG (2008) Response and survival of rosette-stage horseweed (*Conyza canadensis*) after exposure to 2,4-D. Weed Sci 56:748–752

https://doi.org/10.1017/wet.2018.60 Published online by Cambridge University Press

Kruger GR, Davis VM, Weller SC, Johnson WG (2010) Control of horseweed (*Conyza canadensis*) with growth regulator herbicides. Weed Technol 24:425–429

Kruger GR, Davis VM, Weller SC, Stachler JM, Loux MM, Johnson WG (2009) Frequency, distribution, and characterization of horseweed (*Conyza canadensis*) biotypes with resistance to glyphosate and ALS-inhibiting herbicides. Weed Sci 57:652–659

Landini G (2009) Threshould colour: ImageJ. http://www.mecourse.com/landinig/software/software.html. Accessed: October 13, 2017

Loux M, Johnson B (2014) Control of marestail in no-till soybeans. https://ag.purdue.edu/btny/weedscience/Documents/marestail fact 2014 latest.pdf. Accessed: October 19, 2017

Loux M, Stachler J, Johnson B, Nice G, Davis V, Nordby D (2006) Biology and management of horseweed. The glyphosate, weeds, and crops series. Purdue Extension. https://www.extension.purdue.edu/extmedia/gwc/gwc-9-w.pdf. Accessed: September 11, 2017

Mahoney KJ, Shropshire C, Sikkema PH (2017) Post-emergence herbicides for control of glyphosate- resistant Canada fleabane in corn. Can J Plant Sci 97:206–209

Mellendorf TG, Young JM, Matthews JL, Young BG (2013) Influence of plant height and glyphosate on saflufenacil efficacy on glyphosate-resistant horseweed (*Conyza canadensis*). Weed Technol 27:463–467

Mithila J, Hall JC, Johnson WG, Kelley KB, Riechers DE (2011) Evolution of resistance to auxinic herbicides: historical perspectives, mechanisms of resistance, and implications for broadleaf weed management in agronomic crops. Weed Sci 59:445–457

Montgomery GB, Treadway JA, Reeves JL, Steckel LE (2017) Effect of time of day of application of 2,4-D, dicamba, glufosinate, paraquat, and saflufenacil on horseweed (*Conyza canadensis*) control. Weed Technol 31:550–556

Owen LN, Steckel LE, Koger CH, Main CL, Mueller TC (2009) Evaluation of spring and fall burndown application timings on control of glyphosate-resistant horseweed (*Conyza canadensis*) in no-till cotton. Weed Technol 23:335–339

Schmitzer PR, Balko TW, Daeuble JF, Epp JB, Satchivi NM, Siddall TL, Weimer MR, Yerkes CN (2015) Discovery and SAR of halauxifen methyl: a novel auxin herbicide. Pages 247–260 *in* Maienfisch P, Stevenson TM, eds. Discovery and synthesis of crop protection products. ACS Symposium Series, Vol. 1204. Washington, DC: American Chemical Society

Shrestha A, Hembree KJ, Va N (2007) Growth stage influences level of resistance in glyphosate-resistant horseweed. Calif Agric 61:67–70

Steckel LE, Craig CC, Hayes RM (2006) Glyphosate-resistant horseweed (*Conyza canadensis*) control with glufosinate prior to planting no-till cotton (*Gossypium hirsutum*). Weed Technol 20:1047–1051

Switalski D, Rutter B, Hecht L (2017) Elevore™ herbicide receives federal EPA registration. http://www.dowagro.com/en-us/usag/news-and-resources/newsroom/2017/august/30/elevore-herbicide-receives-federal-epa-registration. Accessed: September 13, 2017

VanGessel MJ, Scott BA, Johnson QR, White-Hansen SE (2009) Influence of glyphosate-resistant horseweed (*Conyza Canadensis*) growth stage on response to glyphosate applications. Weed Technol 23:49–53

Van Wychen L (2016) 2016 Survey of the most common and troublesome weeds in broadleaf crops, fruits, & vegetables in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. http://wssa.net/wp-content/uploads/2016-Weed-Survey_Broadleaf-crops.xlsx. Accessed: October 15, 2017

Weaver SE (2001) The biology of Canadian weeds. 115. *Conyza canadensis*. Can J Plant Sci 81:867–875

Zheng D, Kruger GR, Singh S, Davis VM, Tranel PJ, Weller SC, Johnson WG (2011) Cross-resistance of horseweed (*Conyza canadensis*) populations with three different ALS mutations. Pest Manag Sci 67: 1486–1492