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Cultivation and Reduced-Rate Herbicides Weed Control in Sugarbeet Grown for Biofuel

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Abstract

Sugarbeet, grown for biofuel, is being considered as an alternate cool-season crop in the southeastern United States. Previous research identified ethofumesate PRE and phenmedipham + desmedipham POST as herbicides that controlled troublesome cool-season weeds in the region, specifically cutleaf evening-primrose. Research trials were conducted from 2014 through 2016 to evaluate an integrated system of sweep cultivation and reduced rates of ethofumesate PRE and/or phenmedipham + desmedipham POST for weed control in sugarbeet grown for biofuel. There were no interactions between the main effects of cultivation and herbicides for control of cutleaf evening-primrose and other cool-season species in two out of three years. Cultivation improved control of cool-season weeds, but the effect was largely independent of control provided by herbicides. Of the herbicide combinations evaluated, the best overall cool-season weed control was from systems that included either a 1/2X or 1X rate of phenmedipham + desmedipham POST. Either rate of ethofumesate PRE was less effective than phenmedipham + desmedipham POST. Despite improved cool-season weed control, sugarbeet yield was not affected by cultivation each year of the study. Sugarbeet yields were greater when treated with any herbicide combination that included either a 1/2X or 1X rate of phenmedipham + desmedipham POST compared with either rate of ethofumesate PRE alone or the nontreated control. These results indicate that cultivation has a very limited role in sugarbeet grown for biofuel. The premise of effective weed control based on an integration of cultivation and reduced herbicide rates does not appear to be viable for sugarbeet grown for biofuel.

Introduction

In the United States, the majority of the sugarbeet plantings are in the northern regions from Washington to Michigan, grown as a summer crop (Finkenstadt 2014; Khan 2015). Additionally, sugarbeet are grown in the Imperial Valley of California as a cool-season crop (Kaffka and Tharp 2013). In these areas, sugarbeet supply the edible sugar market and account for approximately half of the U.S. edible sugar production, with the remainder produced from sugarcane (*Saccharum* spp.). Federal regulations limit sales of edible sugar to maintain an economically sustainable balance between domestic supply and consumption (McMinimy 2016). Excess sugar from either crop can be stored until marketing conditions are favorable for sale or immediately used for alternative industrial products. There are many industrial products that are normally derived from petroleum that can be produced from excess sugar, including biofuels (Finkenstadt 2014). To produce biofuels, sucrose extracted from either sugarcane or sugarbeet is fermented to produce ethanol. Direct fermentation adds efficiency to ethanol produced from sugarbeet or sugarcane. In contrast, biofuels generated from grain crops require the additional process of enzymatic conversion of starches to sugars before fermentation (Panella 2010).

In Georgia, only 10.5% of the available cropland is planted to crops from December through February (USDA-NASS 2014), with the remainder winter-fallow. Webster et al. (2016) demonstrated that sugarbeet could be grown in the subtropical southeastern United States during winter months and produce yields comparable to traditional sugarbeet production areas. Optimum planting dates were determined to be mid-autumn with harvest occurring the following spring from April through June. In this production system, sugarbeet planting would theoretically begin in the autumn after the harvest of a summer crop, with sugarbeet harvested the following spring on a schedule that would allow ample time for planting peanut (*Arachis hypogaea* L.) or cotton (*Gossypium hirsutum* L.).

In traditional sugarbeet production regions of the United States, weeds were primarily controlled with ethofumesate, phenmedipham + desmedipham, clopyralid, and triflusulfuron until 2005. The commercialization of glyphosate-resistant varieties allowed for glyphosate to be applied directly to sugarbeet (Armstrong and Sprague 2010; Khan 2015; Kemp et al. 2009; Kniss et al. 2004; Wilson and Sbatella 2011). Glyphosate use in sugarbeet greatly simplified and improved weed management over previous systems and was heralded as a significant milestone (Morishita 2018). However, there are widespread incidences of weeds resistant to glyphosate throughout the United States, including the southeastern region. An important practice to lessen selection pressure is to develop diverse and integrated weed management programs that minimize glyphosate use across the cropping system, including alternative crops (Owen 2016; Shaner 2014).

Preliminary weed control research on sugarbeet in Georgia identified broadcast applications of ethofumesate (1.3 kg ai ha^{-1}) PRE and a premix of phenmedipham (0.41 kg ai ha^{-1}) + desmedipham (0.41 kg ai ha^{-1}) POST as herbicides that offer potential in controlling troublesome cool-season weeds that may infest the crop (Johnson et al. 2018). The herbicide rates evaluated in the initial trials were at the low end of the labeled rate range due to the loamy sand soil of the region. Depending on rate, estimated herbicide costs range from US$185 to US$232 ha^{-1} for ethofumesate and US$128 to US$214 ha^{-1} for phenmedipham + desmedipham (Anonymous 2017b). In the absence of a crop production budget for sugarbeet grown for biofuel, it is intuitive that these potential herbicide costs are excessive in this production system.

Another concern is herbicide injury potential. Ethofumesate and phenmedipham + desmedipham injure sugarbeet if temperatures are >22 C at the time of application (Anonymous 2017a, 2017c; Winter and Weise 1978). This hazard was reported in the preliminary weed control studies, with significant phytotoxicity due to the ambient air temperature of 31 C when ethofumesate was applied PRE and 25 C when phenmedipham + desmedipham was applied POST in the 2015–2016 season (Johnson et al. 2018). Similar conditions for herbicide phytotoxicity are likely, as plantings will be throughout the autumn (Webster et al. 2016) and ambient temperatures often exceed the warm-temperature threshold for herbicide injury. Low rates of ethofumesate and phenmedipham + desmedipham lessen chances of herbicide phytotoxicity due to warm temperatures (Dale et al. 2006). However, control of troublesome cool-season weeds using ethofumesate PRE and phenmedipham + desmedipham POST was erratic at labeled rates (Johnson et al. 2018) and further reduction of herbicide rates would increase the likelihood of cool-season weeds escaping control.

Mechanical weed control using cultivation was a common practice in sugarbeet before the development of glyphosate-resistant cultivars (Hembree 2016). Surveys indicated that Ohio sugarbeet growers cultivated an average of four times per season in the late 1960s (Kroetz et al. 1973). Even after the development and adaptation of improved selective herbicides, the new herbicide developments had limited weed control efficacy, and surveys of sugarbeet growers indicated that up to 65% of the North Dakota and Minnesota plantings were cultivated from 2000 through 2007 (Carlson et al. 2007). In recent years, adoption of glyphosate-resistant cultivars changed weed management in sugarbeet (Khan 2015), and cultivation is not commonly used for weed control. However, precision guidance and robotics improved the weed control efficiency using cultivation, and those technological developments benefited European sugarbeet growers by reducing pesticide use (Melander et al. 2005; Wiltshire et al. 2003). These grower experiences demonstrate that cultivation can still be successfully used in sugarbeet as part of an integrated system to manage weeds.

It is plausible that cultivation could be integrated with low rates of ethofumesate and phenmedipham + desmedipham to control weed escapes in sugarbeet grown for biofuel and compensate for erratic cool-season weed control from these herbicides. Therefore, studies were initiated in 2014 to determine whether cultivation and reduced herbicide rates could be integrated into a weed management system for biofuel plantings of sugarbeet in the southeastern United States.

Materials and Methods

Research trials were conducted at the University of Georgia Ponder Research Farm near Ty Ty, GA (31.510884°N, 83.645913° W) for three seasons beginning in the autumn of 2014. The soil was a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 86% sand, 6% silt, 8% clay, 0.9% organic matter, and pH 5.9. The soil at this location is representative of soils in the southeastern U.S. lower coastal plain region and was naturally infested with cool-season weeds that are common to the region.

The experimental design was a two by nine factorial arrangement of treatments in a randomized complete block design with four replications. Treatments were all possible combinations of two cultivation regimes and nine herbicide combinations for a total of 18 treatments. Cultivation treatments were cultivation three times with a sweep cultivator and a noncultivated control. Herbicide treatments were all possible combinations of three PRE ethofumesate (Nortron®, Bayer CropScience, P.O. Box 12014, Research Triangle Park, NC) treatments and three POST phenmedipham + desmedipham (Betamix®, Bayer CropScience) treatments. The three ethofumesate PRE treatments were 0.65 kg ai ha^{-1} and 1.3 kg ha^{-1} (1/2X and 1X, respectively) and a nontreated PRE control. The three phenmedipham + desmedipham POST treatments were 0.20 kg ai ha^{-1} plus 0.20 kg ai ha^{-1} (premixed) and 0.40 kg ha^{-1} plus 0.40 kg ha^{-1} (1/2X and 1X, respectively) and a nontreated POST control. PRE treatments were applied immediately after sugarbeet were planted and activated with overhead sprinkler irrigation (7.6 mm) the same day as application. POST treatments were applied when the majority of the emerged weeds were between the cotyledon and 2-leaf stages. All herbicide treatments were applied broadcast with a tractor-mounted CO_2-pressurized plot sprayer, calibrated to deliver 234 L ha^{-1} at 207 kPa using low-drift TT11003 Turbo TeeJet® spray tips (TeeJet® Technologies, 200 W. North Avenue, Glendale Heights, IL). Sweep cultivation regimes began 2 wk after POST treatments were applied and were repeated three times at biweekly intervals.

Plots measured 1.8-m wide and 6.1-m long. Land preparation included moldboard plowing in early October and seedbed conditioning using a field cultivator and power tiller. This seedbed preparation regime produced a seedbed without clods, and that facilitated sugarbeet stand establishment, which was identified as an important cultural practice for improved weed control

(Bollman and Sprague 2009). During seedbed preparation, 840 kg ha^{-1} of 10-10-10 fertilizer was applied broadcast and incorporated with a power tiller. Betaseed® ERR-303 (Betaseed, 5705 W. Old Shakopee Road, Suite 110, Bloomington, MN) were planted November 4, 2014, October 15, 2015, and November 8, 2016, in three evenly spaced rows 46 cm apart, and centered on a flat seedbed (1.8-m wide) using vacuum planters (Monosem, 1001 Blake Street, Edwardsville, KS) that placed seeds at a density of 8.7 seed m^{-1}, at a depth of 0.8 cm. The ERR-303 variety performed well in earlier trials in Georgia (Johnson et al. 2018; Webster et al. 2016). In January of each year, sugarbeet were side-dressed with 112 kg ha^{-1} 27-0-0 (calcium ammonium nitrate), which included 4% Ca and 1% Mg. Foliar and soil-borne diseases were managed by fungicide applications beginning in the early spring and repeated at 3-wk intervals. The first application was tetraconazole (Eminent 125SL®, Sipcam Agro USA, 2520 Meridian Parkway, Suite 525, Durham, NC) (0.11 kg ai ha^{-1}), followed by alternating applications of azoxystrobin (Quadris®, Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC) (0.28 kg ai ha^{-1}) and prothioconazole (Proline 480SC®, Bayer CropScience) (0.18 kg ai ha^{-1}).

Visible estimates of weed control and crop injury compared with nontreated plots were assessed in mid-March (approximately 6 wk after the last cultivation) using a scale of 0 to 100, where 0 = no weed control or crop injury and 100 = total weed control or crop mortality. Sugarbeet were harvested June 11, 2015, June 14, 2016, and June 27, 2017. Crop yields were obtained by preharvest flail mowing to cut tops of sugarbeet plants and tall weeds, followed by harvest of the entire plot using small-scale equipment based on commercial designs.

Data were analyzed using PROC GLIMMIX (SAS Institute, 100 SAS Campus Drive, Cary, NC). Degrees of freedom were partitioned to test singularly and in combination the effects of cultivation and herbicides on visible estimates of weed control, crop injury, and sugarbeet yield. Means were separated using Tukey-Kramer's LSD ($P \leq 0.05$).

Results and Discussion

Experiments were conducted in different but adjacent fields each year, and the sites had similar cropping histories. However, weed species composition varied among years. Additionally, early-season temperatures and rainfall varied widely among years, particularly early-season temperatures (Table 1). Therefore, all data were analyzed by year.

Weed Control

Cutleaf evening-primrose was present each year at densities of approximately 5 plants m^{-2}. There were no interactions between cultivation and herbicides for cutleaf evening-primrose control in 2014–2015 and 2015–2016. The main effect of cultivation was significant in 2014–2015 and 2015–2016, with cutleaf evening-primrose control from cultivation greater compared with the noncultivated control in both years (Table 2). Of all the herbicide combinations in 2014–2015, the best control of cutleaf evening-primrose resulted from treatments that included either rate of phenmedipham + desmedipham POST. In the 2015–2016 growing season, all herbicide combinations controlled cutleaf evening-primrose similarly.

In 2016–2017, cultivation and herbicide treatments interacted in their control of cutleaf evening-primrose (Table 3). With

Table 1. Monthly daily temperature and rainfall summaries.[a]

	Average maximum temperature			Average minimum temperature			Monthly rainfall			Cumulative days of rainfall		
	— C —						— cm —					
	2014–2015	2015–2016	2016–2017	2014–2015	2015–2016	2016–2017	2014–2015	2015–2016	2016–2017	2014–2015	2015–2016	2016–2017
October	27	26	28	13	14	14	5.0	7.1	0.1	3	11	2
November	18	23	24	4	12	8	17.5	11.1	2.5	7	11	1
December	18	22	19	7	11	8	29.6	18.0	29.4	9	14	11
January	14	14	19	4	3	8	10.5	8.1	23.0	7	11	12
February	14	18	22	3	5	9	11.5	12.4	6.2	12	8	7
March	23	23	22	11	11	9	4.1	15.7	4.1	10	13	6
April	26	25	28	16	13	14	17.6	14.0	7.9	12	7	4
May	30	29	29	17	17	17	2.1	6.6	7.9	3	6	6
June	33	33	30	21	21	21	10.2	12.2	24.9	14	11	22

[a] Data were recorded at the University of Georgia Ponder Farm (known as "Ty Ty") station of the Georgia Automated Weather Network, approximately 200 m from the location of these experiments; www.georgiaweather.net.

Table 2. Main effects of cultivation and herbicides on visible estimates of weed control in sugarbeet, 2014–2015 and 2015–2016 growing seasons.

	Cutleaf evening-primrose[a]		Lesser swinecress[a]	Corn spurry[a]
	2014–2015	2015–2016	2014–2015	2015–2016
	———————————	——— %	———	———————————
Cultivation main effect[b,c]				
Cultivated	81 a	83 a	86 a	79 a
Not cultivated	69 b	70 b	72 b	72 b
Herbicide main effect[b,d]				
Ethofumesate PRE (1/2X)	64 c	79 a	65 c	78 ab
Ethofumesate PRE (1X)	68 bc	83 a	70 bc	87 a
Phenmedipham + desmedipham POST (1/2X)	82 ab	85 a	83 ab	72 b
Phenmedipham + desmedipham POST (1X)	86 a	82 a	88 a	77 ab
Ethofumesate PRE (1/2X)/phenmedipham + desmedipham POST (1/2X)	81 ab	78 a	88 a	72 b
Ethofumesate PRE (1X)/phenmedipham + desmedipham POST (1/2X)	84 a	77 a	94 a	86 a
Ethofumesate PRE (1/2X)/phenmedipham + desmedipham POST (1X)	84 a	78 a	88 a	82 ab
Ethofumesate PRE (1X)/phenmedipham + desmedipham POST (1X)	85 a	83 a	94 a	87 a
Nontreated	43 d	41 b	39 d	36 c

[a] Weed densities: corn spurry, 3 plants m^{-2}; cutleaf evening-primrose, 5 plants m^{-2}; lesser swinecress, 5 plants m^{-2}.

[b] Within each main effect, means in a column followed by the same letter are not different according to Tukey-Kramer's LSD ($P \leq 0.05$).

[c] Sweep cultivation three times at biweekly intervals beginning 2 wk after herbicide treatment.

[d] Ethofumesate PRE (1/2X): 0.65 kg ai ha^{-1}; ethofumesate PRE (1X): 1.3 kg ha^{-1}; phenmedipham + desmedipham POST (1/2X): 0.20 kg ai ha^{-1} + 0.20 kg ai ha^{-1}, premixed; phenmedipham + desmedipham POST (1X): 0.40 kg ha^{-1} + 0.40 kg ha^{-1}, premixed.

cultivation, all herbicide combinations equally controlled cutleaf evening-primrose (Table 3). In the absence of cultivation, herbicide treatments that included either rate of phenmedipham + desmedipham POST improved cutleaf evening-primrose control over the nontreated. Additionally, neither rate of ethofumesate PRE alone adequately controlled cutleaf evening-primrose unless cultivated.

Lesser swinecress (*Lepidium didymum* L.) was present only in 2014–2015 at densities of approximately 5 plants m^{-2}. There were no interactions between cultivation and herbicides for lesser swinecress control (Table 2). The cultivation main effect improved lesser swinecress control over plots not cultivated. Of the herbicide main effects, herbicide treatments that included either rate of phenmedipham + desmedipham POST improved lesser swinecress control over either rate of ethofumesate PRE alone or the nontreated.

Corn spurry (*Spergula arvensis* L.) was present only in 2015–2016 at densities of 3 plants m^{-2}. There were no interactions between cultivation and herbicides for corn spurry control (Table 2). The cultivation main effect improved corn spurry control over sugarbeet not cultivated. All herbicide treatments improved corn spurry control over the nontreated (Table 2). Of all herbicide combinations evaluated, treatments that included the 1X rate of ethofumesate PRE and/or the 1X rate of phenmedipham + desmedipham POST provided the best corn spurry control.

Cultivation and herbicide treatments interacted in the control of wild radish (*Raphanus raphanistrum* L.), which was present only in 2016–2017 at densities of 2 plants m^{-2} (Table 3). Herbicide treatments that included either rate of phenmedipham + desmedipham, with or without cultivation, provided the best wild radish control of all possible treatment combinations. Cultivation without herbicide treatment improved wild radish control compared with noncultivated/nontreated sugarbeet, and control was similar to the most effective herbicide combinations.

Visible Estimates of Injury

In the 2014–2015 and 2016–2017 seasons, there was no phytotoxicity observed in any of the cultivation and herbicide treatments (unpublished data). In 2015–2016, stunting of sugarbeet was observed and ranged from 12% to 25% when evaluated in mid-March (unpublished data). However, there were no significant effects of cultivation or herbicide treatments on phytotoxicity. While the cause of phytotoxicity was not related to cultivation or herbicide treatment, the exact cause is unknown.

Sugarbeet Yield

There were no interactions between cultivation and herbicides for sugarbeet yield (Table 4). Despite weed control benefits, the cultivation main effect had no effect on sugarbeet yield. In 2014–2015, herbicide treatments that included either rate of phenmedipham + desmedipham POST yielded more than the nontreated control. PRE applications of ethofumesate alone resulted in sugarbeet yields similar to the nontreated control, but yields were similar in most cases to treatments that included POST applications of phenmedipham + desmedipham. The highest yield in 2015–2016 was from sugarbeet treated with the 1X rate of ethofumesate PRE followed by the 1X rate of phenmedipham + desmedipham POST (Table 4). In 2016–2017, all

Table 3. Interaction of cultivation and herbicides on visible estimates of weed control in sugarbeet, 2016–2017 growing season.

Cultivation[b]	Herbicides[c]	Visible estimates of weed control[a] Cutleaf evening-primrose[d]	 Wild radish[d]
		——— % ———	
Cultivated	Ethofumesate PRE (1/2X)	79 ab	67 bc
Cultivated	Ethofumesate PRE (1X)	79 ab	83 abc
Cultivated	Phenmedipham + desmedipham POST (1/2X)	85 a	86 abc
Cultivated	Phenmedipham + desmedipham POST (1X)	85 a	87 abc
Cultivated	Ethofumesate PRE (1/2X)/phenmedipham + desmedipham POST (1/2X)	89 a	80 abc
Cultivated	Ethofumesate PRE (1X)/phenmedipham + desmedipham POST (1/2X)	90 a	91 ab
Cultivated	Ethofumesate PRE (1/2X)/phenmedipham + desmedipham POST (1X)	85 a	95 a
Cultivated	Ethofumesate PRE (1X)/phenmedipham + desmedipham POST (1X)	80 a	93 ab
Cultivated	nontreated	53 bc	73 abc
Not cultivated	Ethofumesate PRE (1/2X)	37 c	56 c
Not cultivated	Ethofumesate PRE (1X)	53 bc	69 bc
Not cultivated	Phenmedipham + desmedipham POST (1/2X)	80 a	78 abc
Not cultivated	Phenmedipham + desmedipham POST (1X)	87 a	86 abc
Not cultivated	Ethofumesate PRE (1/2X)/phenmedipham + desmedipham POST (1/2X)	90 a	90 ab
Not cultivated	Ethofumesate PRE (1X)/phenmedipham + desmedipham POST (1/2X)	85 a	87 abc
Not cultivated	Ethofumesate PRE (1/2X)/phenmedipham + desmedipham POST (1X)	89 a	93 ab
Not cultivated	Ethofumesate PRE (1X)/phenmedipham + desmedipham POST (1X)	91 a	91 ab
Not cultivated	Nontreated	27 c	25 d

[a] Means in a column followed by the same letter are not different according to Tukey-Kramer's LSD ($P \leq 0.05$).

[b] Sweep cultivation three times at biweekly intervals beginning 2 wk after herbicide treatment.

[c] Ethofumesate PRE (1/2X): 0.65 kg ai ha^{-1}; ethofumesate PRE (1X): 1.3 kg ha^{-1}; phenmedipham + desmedipham POST (1/2X): 0.20 kg ai ha^{-1} plus 0.20 kg ai ha^{-1}, premixed; phenmedipham + desmedipham POST (1X): 0.40 kg ha^{-1} plus 0.40 kg ha^{-1}, premixed.

[d] Weed densities: cutleaf evening-primrose, 5 plants m^{-2}; wild radish, 2 plants m^{-2}.

plots treated with herbicides had similar yields. However, sugarbeet treated with the 1X rate of ethofumesate PRE followed by the 1X rate of phenmedipham + desmedipham POST was the only treatment with sugarbeet yields greater than the nontreated control.

The premise of these studies was that cultivation would control weed escapes and allow for reduced rates of ethofumesate and phenmedipham + desmedipham to be used for cool-season weed control in sugarbeet grown for biofuel. The only interaction in these experiments between cultivation and herbicides was with control of two weed species in only one out of three years. Otherwise, weed control was solely affected by the main effects of cultivation and herbicides. Cultivation and herbicide treatments did not injure sugarbeet, and the one incidence of crop stunting was not caused by either cultivation or herbicides. Sugarbeet yield responded similarly. It is worth noting that the main effect of cultivation improved weed control (Table 2), but not enough to increase sugarbeet yield (Table 4). For many years, cultivation was commonly used for weed control in sugarbeet in traditional production regions (Carlson et al. 2007; Hembree 2016; Kroetz et al. 1973). Despite the weed control benefits, Dexter et al. (1999) reported that cultivation reduced sugarbeet yield 3 years out of 10 and never increased yield. Their results parallel ours observation that sugarbeet yield was not increased by cultivation.

It is unusual for consistent weed control benefits from cultivation to not result in corresponding yield increases. One reason might be that sugarbeet, being a root crop, does not tolerate frequent cultivation using sweeps (Dexter et al. 1999). Another possibility might be related to environmental conditions in our trials. There are distinct differences between sugarbeet production in the traditional regions versus biofuel plantings in the southeastern United States, with growing seasons being among the most striking contrasts. Sugarbeet grown for biofuel in the southeastern United States is a cool-season crop and would be typically cultivated from November through January, which is a period that tends to have extended periods of rainfall. For example, in our trials during December alone, there were 9, 14, and 11 rainfall events for 2014, 2015, and 2016, respectively, with monthly rainfall totals exceeding 29 cm in two out of three years (Table 1). During rainy periods, scheduled cultivations were delayed and implement performance was inhibited by moist soils. These factors may be the primary reasons for cultivation being marginally beneficial in our studies.

These studies also indicate that weed control in sugarbeet grown for biofuel in the southeastern United States should be based on

Table 4. Main effects of cultivation and herbicides on sugarbeet yield, 2014–2015, 2015–2016, and 2016–2017 growing seasons.

	Sugarbeet yield		
	2014–2015	2015–2016	2016–2017
	——————— ($kg\ ha^{-1}$) ———————		
Cultivation main effect[a,b]			
Cultivated	53,590 a	61,160 a	72,140 a
Not cultivated	41,920 a	58,490 a	73,470 a
Herbicide main effect[a,c]			
Ethofumesate PRE (1/2X)	39,610 bcd	45,790 b	76,670 ab
Ethofumesate PRE (1X)	36,440 cd	48,970 b	67,930 ab
Phenmedipham + desmedipham POST (1/2X)	45,740 abc	72,900 ab	68,260 ab
Phenmedipham + desmedipham POST (1X)	58,140 abc	73,610 ab	65,660 ab
Ethofumesate PRE (1/2X)/phenmedipham + desmedipham POST (1/2X)	47,750 abc	43,650 b	72,160 ab
Ethofumesate PRE (1X)/phenmedipham + desmedipham POST (1/2X)	60,580 ab	67,920 ab	80,560 ab
Ethofumesate PRE (1/2X)/phenmedipham + desmedipham POST (1X)	57,120 abc	59,540 ab	75,290 ab
Ethofumesate PRE (1X)/phenmedipham + desmedipham POST (1X)	64,950 a	87,660 a	97,200 a
Nontreated	19,460 d	38,400 b	51,540 b

[a] Within each main effect, means in a column followed by the same letter are not different according to Tukey-Kramer's LSD ($P \leq 0.05$).
[b] Sweep cultivation three times at biweekly intervals beginning 2 wk after herbicide treatment.
[c] Ethofumesate PRE (1/2X): 0.65 kg ai ha^{-1}; ethofumesate PRE (1X): 1.3 kg ha^{-1}; phenmedipham + desmedipham POST (1/2X): 0.20 kg ai ha^{-1} plus 0.20 kg ai ha^{-1}, premixed; phenmedipham + desmedipham POST (1X): 0.40 kg ha^{-1} plus 0.40 kg ha^{-1}, premixed.

herbicides, specifically phenmedipham + desmedipham POST. This is in agreement with Johnson et al. (2018), who identified sugarbeet herbicides that controlled cool-season weeds and those that did not. In the previous studies, ethofumesate (1.3 kg ha^{-1}) PRE and phenmedipham (0.41 kg ha^{-1}) + desmedipham (0.41 kg ha^{-1}) POST were evaluated at the low end of the labeled rate range due to soil type. In the present studies, the same rates were evaluated (1X), along with a reduced rate (1/2X). In most cases, weed control from the 1/2X rate of phenmedipham + desmedipham was equivalent to the 1X rate, including the problematic cutleaf evening-primrose. However, applications were made to small weeds, and that is certainly a factor for successful weed control using the 1/2X rate of phenmedipham + desmedipham and equally important for weed control in sugarbeet grown for edible sugar in conventional production regions (Dale et al. 2006). It is evident that sugarbeet grown as a biofuel crop will also require a high level of management and attentiveness to minimize production costs without sacrificing yield potential.

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