Gold Section: Sugarbeet Weed Control

CONTROLLING COMMON RAGWEED IN FIELDS PLANTED TO SUGARBEET

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Summary

1. For common ragweed that is 0- to 2-inches tall, make a single application of Stinger at 3 fl oz/A plus glyphosate at 0.98 lb ae/A (equivalent to Roundup PowerMax at 28 fl oz/A). A second application of Stinger at 2 fl oz/A plus glyphosate may be needed 14 days after the first application. Herbicide application to small common ragweed provides the greatest control.
2. For common ragweed 2- to 4-inches tall, make a single application of Stinger at 4 fl oz/A plus glyphosate at 0.98 lb ae/A. A second application of Stinger at 3 fl oz/A plus glyphosate may be needed 14 days after the first application.
3. For common ragweed 4- to 6-inches tall, apply Stinger at 4 fl oz/A plus glyphosate. A second application of Stinger at 4 fl oz/A plus glyphosate may be needed 14 days after the first application.
4. Glyphosate resistant common ragweed greater than 6-inches tall can only be partially controlled with POST herbicides in sugarbeet. For maximum control, apply Stinger at 4 fl oz/A plus glyphosate followed by Stinger at 4 fl oz/A plus glyphosate plus high surfactant methylated seed oil concentrate (HSMOC) 14 days after the first application. While this herbicide combination will only provide partial control of common ragweed greater than 6-inches, maximizing spray coverage through increased spray volume and droplet quality may improve control.

Introduction

Common ragweed is a troublesome weed found in both Minnesota and North Dakota. Integrated strategies of cultural, mechanical, and chemical control options are required for controlling this species. Mowing can be an effective strategy, especially in ditches and grass waterways, if done on a regular basis. Two-inch common ragweed is very resilient, especially if only damaged above the seed leaves. Mowed common ragweed can grow new stems and flower just ten days later than plants not mowed. Longevity of common ragweed seed makes managing flushes or complete eradication of this species very difficult. Several soil-applied herbicides labeled for corn and soybean use have activity on common ragweed, however, few herbicides are labeled in sugarbeet that control this species.

Experiments were conducted on natural populations of common ragweed within a sugarbeet field near Mayville, North Dakota in 2014 (Peters and Carlson 2014). The field contained some glyphosate resistant common ragweed biotypes. Treatments included herbicide applications on June 10, 18, 24, and 26, and July 7 and 18, targeting 0-1, ≤2, and 4-inch common ragweed.

Negligible sugarbeet injury was observed in the 2014 experiment. Greatest injury occurred when treatments were applied to 4-inch common ragweed, however, injury was more likely from weed competition than herbicide treatments. Visual sugarbeet injury was greatest after sequential applications of Roundup PowerMax (glyphosate) at 28 fl oz/A plus Stinger at 4 fl oz/A. Visual sugarbeet injury in this experiment, as well as similar trials from 2009 and 2010, was commonly observed when Stinger was applied to cotyledon or 2-leaf sugarbeet at rates of 4 fl oz/A or greater. Sugarbeet injury was inconsistent among treatments and decreased over time.

Weed control in the 2014 study was greatest when treatments were applied to one-inch common ragweed compared to two- or four-inch common ragweed. Treatments containing Stinger averaged 95% ragweed control when applications were made to one-inch or smaller ragweed, 92% control when applications were made to ragweed up to 2-inches tall, and 86% control when applications were made on ragweed up to 4-inches tall. Treatments containing Stinger gave greater common ragweed control, regardless of weed height at time of application, compared to treatments containing only glyphosate.

Materials and Methods

Experiments were conducted on natural populations of common ragweed near Doran, Minnesota in 2018. Plot area was located in a commercial sugarbeet field under conventional tillage. "ACH 830" sugarbeet was seeded 1.25 inches deep in 22-inch spaced rows at 61,500 seeds per acre on May 6. Herbicide treatments were applied May 31, and June 13 and 27. All treatments were applied with a bicycle sprayer in 17 gpa spray solution through 8002 XR flat fan nozzles pressurized with CO_2 at 42 psi to the center four rows of six row plots 40 feet in length in a field with moderate levels of glyphosate-resistant common ragweed. Ammonium sulfate in all treatments was a liquid formulation from Winfield United called N-Pak AMS.

Sugarbeet injury was evaluated on June 21 and 28. Weed control was evaluated June 21 and 28, and July 11. All evaluations were a visual estimate of percent fresh weight reduction in the four treated rows compared to the adjacent untreated strip. Experimental design was randomized complete block with 4 replications. Data were analyzed with the ANOVA procedure of ARM, version 2018.4 software package.

Table 1. Application Information

Application Code	A	B	C	D
Date	May 31	June 13	June 13	June 27
Time of Day	4:30 PM	12:00 PM	12:15 PM	2:00 PM
Air Temperature (F)	82	74	75	85
Relative Humidity (%)	36	36	38	53
Wind Velocity (mph)	8	6	6	3
Wind Direction	N	S	S	SW
Soil Temp. (F at 6")	68	68	68	76
Soil Moisture	Fair	Good	Good	Good
Cloud Cover (%)	0	20	20	60
Sugarbeet stage (avg)	2-4 leaf	6-8 leaf	6-8 leaf	12-14 leaf
Ragweed (avg)	2"	6"	6"	10"

Results and Discussion

Sugarbeet Injury- Sugarbeet injury evaluation was difficult due to heavy common ragweed competition. Sugarbeet injury was generally greater when herbicide treatments were applied to 6-8 leaf sugarbeet and 6-inch common ragweed compared to applications made to 2-4 leaf sugarbeet and 2-inch common ragweed (Table 2). Of the treatments applied to 2-4 leaf sugarbeet, ethofumesate plus glyphosate gave the greatest injury at 15 to 18%. Sugarbeet injury was 10% or less from Stinger at 2 or 4 fl oz/A applied in either a single or repeat application and could be considered negligible. Sugarbeet injury was greatest when Stinger was applied with glyphosate to 6-8 leaf sugarbeet and 6-inch common ragweed. Two applications of Stinger at 4 fl oz/A plus glyphosate showed the greatest amount of injury at 23% to 28%.

Trials conducted in 2014 (Peters and Carlson 2014) had greater sugarbeet injury from Stinger at 2 to 4 fl oz/A plus glyphosate when applied to 4-8 leaf sugarbeet compared to 2-4 leaf sugarbeet (data not presented). Trials conducted in 2009 and 2010 had greater sugarbeet injury from two sequential applications of Stinger at 4 fl oz/A compared to a single application of Stinger at 8 fl oz/A (data not presented). The 2018 trial was similar in both regards with sugarbeet injury tending to be greater from two applications of Stinger compared to a single application and greater injury when applications were made to larger sugarbeet compared to smaller sugarbeet.

Common Ragweed Control- Common ragweed size impacted control from Stinger plus glyphosate. Herbicide treatments applied to 2-inch common ragweed generally provided greater control than the same treatments applied to 6-inch common ragweed (Table 2). On 2-inch common ragweed, sequential applications of Stinger + glyphosate tended to improve common ragweed control compared to a single application. A single application of Stinger at 4 fl oz/A + glyphosate to 2-inch common ragweed gave 93% control while two applications of Stinger at 4 fl oz/A plus glyphosate gave 100% control. Similarly, a single application of Stinger at 4 fl oz/A + glyphosate to 6-inch common ragweed gave 73% control while two applications of Stinger at 4 fl oz/A plus glyphosate gave 91% control.

Herbicide treatments containing Stinger usually improved common ragweed control compared to glyphosate alone (Table 2). Glyphosate alone gave 73% ragweed control compared to Stinger at 4 fl oz/A plus glyphosate showing 95% control. These results indicated the common ragweed biotype had some glyphosate resistance. The addition of ethofumesate to glyphosate did not improve control of 2-inch common ragweed.

Acceptable control can be achieved when herbicide applications are made to small common ragweed. Stinger rates should be 3-4 fl oz/A, plus glyphosate, to ensure greater than 90% control. Sequential application increases the likelihood of 100% control, even on small common ragweed. Two sequential applications of Stinger at 4 fl oz/A plus glyphosate will provide the greatest control on common ragweed, however, common ragweed that is 6-inches or greater is too big for a POST herbicide program in sugarbeet to provide acceptable control.

Table 1. Sugarbeet injury and common ragweed control near Doran, MN in 2018.

Treatment	Rate	Application Code[1]	June 21 sgbt injury	June 28 sgbt injury	June 21 cora cntrl	June 28 cora cntrl	July 11 cora cntrl
	fl oz/A		----------------	----------------	--%--	----------------	----------------
2" common ragweed							
PMax[2,3]	28	A	8	8	73	55	58
PMax+Etho[4]	28+4	A	18	15	73	55	53
PMax+Stinger	28+2	A	5	10	88	85	74
PMax+Stinger	28+4	A	8	5	95	94	93
2" + 14 days							
PMax+Stinger/ PMax+Stinger	28+2/ 28+2	A / B	10	5	99	98	100
PMax+Stinger/ PMax+Stinger	28+4/ 28+4	A / B	8	10	100	100	100
6" common ragweed							
PMax	28	C	5	15	71	78	66
PMax+Etho	28+4	C	18	15	76	71	65
PMax+Stinger	28+2	C	13	25	65	76	72
PMax+Stinger	28+4	C	23	23	65	75	73
6" + 14 days							
PMax+Stinger/PMax+Stinger	28+2/ 28+2	C / D	15	25	78	81	82
PMax+Stinger/ PMax+Stinger	28+4/ 28+4	C / D	28	23	70	76	91
LSD (0.05)			**13**	**14**	**11**	**13**	**15**

[1] Application information is listed in Table 1

[2] PMax=Roundup PowerMax

[3] PMax alone and PMax+Stinger treatments were applied with N-Pak AMS at 2.5% v/v and Prefer 90 NIS at 0.25% v/v.

[4] PMax+Etho treatments were applied with N-Pak AMS at 2.5% v/v and high surfactant methylated oil concentrate (HSMOC) at 1.5 pt/A.

Other Weeds- Common lambsquarters was also evaluated in this trial. Treatments applied to 2-inch common lambsquarters provided 95% control while treatments applied to 8-inch common lambsquarters gave 80% control when evaluated 21 days after application (data not shown). No differences were observed when evaluated 28 days after application.

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INTER-ROW CULTIVATION TIMING EFFECT ON SUGARBEET YIELD AND QUALITY IN 2018

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Summary

Field experiments were conducted to determine if cultivation at 1.5 to 2 inches deep at 4 MPH negatively affects sugarbeet root yield and quality. Cultivation did not affect sugarbeet density, root yield, sucrose content, or recoverable sucrose per acre at three environments in 2018.

Introduction and Objectives

Sugarbeet producers have renewed their interest in inter-row cultivation due to the development of glyphosate resistant waterhemp (*Amaranthus tuberculatus)* in Minnesota and North Dakota. However, producers are concerned about how mid-season cultivation affects sugarbeet yield and disease pressure.

Research conducted by Alan Dexter and Joe Giles in the 1980s and 1990s generally demonstrated early-season cultivation has little effect on recoverable sucrose yield, but cultivation later in the season is detrimental to yield and quality (Dexter et al. 2000). Dexter (1983) reported sugarbeet yield tended to increase with up to three cultivations, but decreased after four cultivations. Giles et al. (1987) reported increasing cultivation number from one to four numerically reduced yield in one of two environments. Giles et al. (1990) reported one to three cultivations had no effect on sugarbeet yield, but there was an increasingly negative effect on sugarbeet yield as cultivation number increased from four to seven in one of two environments.

Sugarbeet producers frequently used inter-row cultivation to control herbicide-resistant weeds in 2018 (Peters et al. 2018). Many producers currently consider one to two mid-season cultivation passes a "rescue" strategy rather than a primary weed control method. The objectives of this experiment were to 1) evaluate the effect of inter-row cultivation timing and number of passes on sugarbeet yield and quality and 2) evaluate if inter-row cultivation timing and number of passes increases severity of *Rhizoctonia solani* on sugarbeet.

Materials and Methods

Site Description. Field experiments were conducted in three environments in 2018. The three environments were on producer fields near Glyndon, MN (46°51'52.7"N, 96°31'15.5"W), Hickson, ND (46°42'18.9"N, 96°48'08.1"W), and Amenia, ND (47°00'10.4"N, 97°06'21.9"W). Previous crop grown in fields were soybean, sugarbeet, and wheat at the Glyndon, Hickson, and Amenia fields, respectively. Soil descriptions for each environment can be found in Table 1.

Table 1. Soil descriptions for trial environments in 2018.

Environment	Soil series & texture	Organic matter	Soil pH
Amenia, ND	Bearden & Lindass silty clay loam mix	3.9%	8.0
Hickson, ND	Fargo silty clay	6.0%	7.5
Glyndon, MN	Wyndmere fine sandy loam	2.6%	8.2

Experimental Procedures. The experimental design was a randomized complete block with four replicates. Plots were 11 feet wide (6 rows) and 30 feet long. Treatments were applied every two weeks though the growing season starting June 21 and ending August 16. Treatments were cultivation dates with a maximum of three dates and an untreated control. Inter-row cultivation was performed to the center 4 rows of each plot using a modified Alloway 3130 cultivator (Alloway Standard Industries, Fargo, ND) with 15-inch sweep shovels spaced at 22 inches with a ground depth of 1.5 to 2 inches at 4 MPH.

'Crystal 355RR' sugarbeet seed (American Crystal Sugar Company, Moorhead, MN) was planted 1.25 inches deep at a density of 61,000 (+/- 1,000) seeds per acre in six rows spaced 22 inches apart. Planting dates were May 3, 2018 at Glyndon, May 7, 2018 at Hickson, and May 14, 2018 at Amenia. Sugarbeet seeds were treated with penthiopyrad (Kabina ST, Sumitomo Corporation, New York, NY). Nitrogen, phosphorus, and potassium fertilizer was applied based on spring soil tests and incorporated prior to planting. Weeds and disease were controlled so that crop injury from cultivation could be detected without interference from other yield-limiting factors. Weeds were controlled using glyphosate (Roundup PowerMAX, Monsanto Company, St. Louis, MO) at 32 oz per acre. No more than three glyphosate applications were made at each location and herbicide resistant waterhemp were removed by hand weeding. Root disease pressure from *Rhizoctonia solani* was controlled with soil-applied applications of azoxystrobin (Quadris, Syngenta Crop Protection, Greensboro, NC) at Amenia and Hickson. Disease pressure from *Cercospora beticola* was controlled with foliar applications of triphenyltin hydroxide (Super Tin 4L, United Phosphorus, Inc., King of Prussia, PA), thiophanate methyl (Topsin 4.5FL, United Phosphorus, Inc., King of Prussia, PA), and difenoconazole / propiconazole (Inspire XT, Syngenta Crop Protection, Greensboro, NC).

Data Collection and Analysis. Sugarbeet stand counts were collected in the center two rows of each plot prior to the start of cultivation treatments and prior to harvest to determine percent stand mortality throughout the season. Harvest dates were September 17, 2018 at Glyndon, September 11, 2018 at Hickson, and September 18, 2018 at Amenia. At harvest, sugarbeet was defoliated with a four-row topper and harvested with a two-row sugarbeet harvester. The sugarbeet roots harvested from the center two rows of each plot were weighed and a 20-lb sample was analyzed by American Crystal Sugar Company, East Grand Forks, ND for percent sucrose. Sugarbeet roots were visually analyzed for *Rhizoctonia* root and crown rot, but no visual infection was observed from any treatment at any location.

Data was subjected to analysis of variance using the MIXED procedure in SAS 9.4 (SAS Institute, Cary, NC) to test for treatment differences among means at $P \leq 0.05$. Cultivation treatment was considered a fixed effect, while environment and replicate were considered random effects. Environments were combined for analysis when mean square error values between environments were within a factor of ten. Single-cultivation and double-cultivation treatments were subject to regression analysis ($P \leq 0.05$) to detect relationships between cultivation timing and sugarbeet stand, yield, and quality, but no significant relationships were detected.

Results and Discussion

Field Growing Conditions. Field planting ranged between May 3 and May 14 across all environments (Table 2), which is typical for sugarbeet production in eastern North Dakota and Minnesota. Season-long precipitation at Amenia was slightly below the 30-year average, while Hickson and Glyndon received slightly above the 30-year average. However, sugarbeet at Amenia still had the greatest sucrose yield of all environments. Hickson received excessive hail on August 26 that destroyed 90% of the crop canopy which likely reduced root yield and sucrose content at harvest. Glyndon received only 0.6 inches of precipitation in the month following planting, which led to an erratic and non-uniform crop stand. Glyndon soil texture was a fine sandy loam with low organic matter, which likely contributed to moisture stress throughout the growing season. Sugarbeets at Glyndon were also noted to exhibit foliar potassium deficiency throughout the season, which was possibly due to inadequate fertilization rate, poor crop uptake, or both.

Table 2. Dates of planting and harvest, previously crop grown, and sugarbeet density at three environments in 2018.

Environment	Planting date	Harvest date	Previous crop	Sugarbeet density[a]
				# per 100 row-feet
Amenia, ND	May 14	September 18	Wheat	185
Hickson, ND	May 7	September 11	Sugarbeet	190
Glyndon, MN	May 3	September 17	Soybean	152

[a] Sugarbeet stand was counted prior to first treatment.

Sugarbeet Stand Density. Cultivation did not affect sugarbeet density at any environment in 2018 (Table 3). Environments were analyzed separately for stand mortality because mean square error values between environments were not within a factor of ten. Stand mortality at Amenia was relatively low, ranging from 11% to 21%, but no patterns were observed. The stand mortality at Hickson was relatively high, ranging from 30 to 40% (Table 3), but the stand mortality was consistent between treatments. The relatively high stand mortality at Hickson is probably due to sugarbeet being the previous crop grown on the field site. Planting sugarbeet into sugarbeet residue highly increases chance of infection from *Rhizoctonia solani* (Windels and Brantner 2008). Sugarbeet stand mortality was not observed at Glyndon (Table 3). Some sugarbeet roots at Glyndon were small and 6 to 8 leaves at harvest, indicating they had emerged mid-season. Sugarbeet were counted a just prior to the first cultivation on June 21, but sugarbeets continued to emerge randomly into the summer at Glyndon, making the stand mortality measurement negative in some treatments.

Table 3. Sugarbeet stand mortality affected by cultivation timing in 2018.

	Stand mortality[a]		
Cultivation timing	Amenia	Hickson	Glyndon
	--------------------------%--------------------------		
Control	15	32	-14
June 21	20	37	-1
July 5	15	37	4
July 19	20	41	-10
August 2	11	32	-1
August 16	13	30	10
June 21 + July 19	13	31	-7
July 5 + Aug 2	19	36	4
July 19 + Aug 16	21	39	7
June 21 + July 19 + Aug 16	16	37	7
ANOVA	----------------------*p value*----------------------		
Treatment	0.082	0.435	0.848

[a] Percent stand mortality is calculated by multiplying the ratio of harvest stand and pre-treatment stand by 100.

Harvested sugarbeet roots were visually inspected for root and crown rot from *R. solani*, but no infection was observed at any environment. Inter-row cultivation has historically been associated with root and crown rot since cultivation may physically deposit soil onto a beet crown, moving soil-borne pathogens nearer their host. Schneider et al. (1982) reported covering sugarbeet roots with soil via a cultivator moving 8 MPH in mid-August resulted in greater root rot due to *R. solani* in two of three field environments. Windels and Lamey (1998) reported reducing cultivation ground speed reduces chance of infection from *R. solani.* Some soil movement onto beet crowns was observed in this experiment, but the cultivation speed of 4 MPH used in this experiment was possibly not fast enough to cause significant root rot infection in these environments in 2018.

Sugarbeet Root Yield. Cultivation did not affect root yield at any environment (Table 4). Root yields were 37 to 40 tons/acre at Amenia, 16 to 23 tons/acre at Hickson, and 10 to 15 tons/acre at Glyndon. No statistical differences among treatments were measured across environments (P = 0.944). Inter-row cultivation only disturbs soil between the sugarbeet rows and does not significantly affect root growth or yield. Giles et al. (1990) conducted root excavations on sugarbeet in late-July and reported less root development and yield with treatments receiving five to seven weekly cultivations throughout the season in one of two environments. Giles et al. (1990) cultivated to a similar depth of 1.5 to 2 inches, but a ground speed of 3 MPH. Significant root yield reduction was not observed with up to three cultivations in this experiment cultivating 1.5 to 2 inches deep and 4 MPH. The yield loss Giles et al. (1990) reported in one of two environments was likely due a greater number of cultivations (five to seven) as compared to one, two, or three cultivations in the trials conducted in 2018.

Percent Sucrose Content. Cultivation did not affect sucrose content at any environment (Table 4). Sucrose percentages ranged from 15.7 to 16.3% in Amenia, 14.1 to 14.9% in Hickson, and 13.6 to 14.2% in Glyndon, with no significant differences among treatments. Combined analysis tended to demonstrate treatment differences between cultivation number and dates (P = 0.062), but no trends were observed. Regression analysis to determine if sucrose content was affected by cultivation timing was not significant (data not shown). Cultivator shanks traveling between sugarbeet rows during cultivation were observed to cause foliar damage, especially at later cultivation dates. Sugarbeet plants compensate for the foliar damage by producing new leaves, potentially lowering sucrose content, but this data demonstrates no reduction in sucrose content. Foliar damage was also noted from the tractor wheels traveling between plot rows. The tractor wheels in this experiment traveled on the outside of the plot area to remove the effect of the wheels from the results.

Table 4. Root yield, sucrose content, and recoverable sucrose per acre (RSA) affected by cultivation timing averaged across Amenia, Hickson, and Glyndon in 2018.

	Yield Components		
Cultivation timing	Root yield	Sucrose content	RSA
	Ton/acre	%	Lb/acre
Control	24.3	15.0	6,817
June 21	24.1	14.8	6,773
July 5	24.7	14.9	6,934
July 19	23.5	14.9	6,563
August 2	25.4	14.7	6,899
August 16	24.4	14.5	6,529
June 21 + July 19	24.3	14.5	6,679
July 5 + Aug 2	24.7	14.6	6,698
July 19 + Aug 16	23.5	14.8	6,472
June 21 + July 19 + Aug 16	23.5	14.8	6,540
ANOVA		*p value*	
Treatment	0.944	0.062	0.947

Recoverable Sucrose per Acre. Cultivation did not affect recoverable sucrose per acre at any environment (Table 4). Recoverable sucrose per acre (RSA) is a calculation derived from root yield and sucrose content. RSA ranged from 10,600 to 11,700 at Amenia, 4,500 to 6,000 at Hickson, and 2,400 to 3,900 at Glyndon. No treatment differences were measured in the combined analysis ($P = 0.947$). This result was expected since treatment means for root yield and sucrose content were not significantly different (Table 4).

Conclusion

Inter-row cultivation did not affect sugarbeet density, root yield, or quality at any environment in this experiment. This data suggests up to three cultivations performed as late as August 16 will not negatively affect sugarbeet yield. Most producers in 2018 only used cultivation to remove weeds that glyphosate did not control, so it is unlikely that, under current production practices, any sugarbeet producer would cultivate a field more than three times in one season. Most cultivations in 2018 were also done after the sugarbeet canopy closed in mid-July. The effect of inter-row cultivation on yield is likely a complex interaction of cultivation timing, soil type, environmental conditions, disease pressure, cultivation speed, and cultivation equipment.

Sugarbeet producers are concerned about yield loss from inter-row cultivation partially due to the past work done by Dexter and Giles. While the cultivation methods and procedures used in our experiment are similar to what Dexter and Giles implemented in their experiments, our timing of cultivation was different. Dexter and Giles conducted their cultivations on weekly intervals with the same start date, while our cultivations were two weeks apart with staggered starting dates and timings as late as August 16. Furthermore, certain aspects of sugarbeet production that could affect disease pressure are different from the 1980s and 1990s such as diploid genetics, seed treatments, and soil-applied applications of azoxystrobin. Our results show cultivation 1.5 to 2 inches deep at 4 MPH with soil-applied applications of azoxystrobin did not affect sugarbeet yield in 2018, but further research is needed in future years with different ground speeds, cultivator configurations, fungicide applications, and environmental conditions to better determine if cultivation could affect sugarbeet yield.

Acknowledgements

We thank the Sugarbeet Research and Education Board of Minnesota and North Dakota for funding this research. We would like to thank the NDSU Ag Experiment Station, Amitava Chatterjee, and Mohamed Khan for providing land to conduct the trials. We would also like to thank Peter Hakk, Alexa Lystad, Norm Cattanach, Charles Tvedt, Jewel Faul, and Jeff Stith for their help with establishing and maintaining these trials. Also, thanks to the American Crystal Sugar Company, East Grand Forks, MN quality lab for quality analysis.

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DELAYED CULTIVATION TO SUPPLEMENT CHLOROACETAMIDE HERBICIDES IN SUGARBEET

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Summary

Sugarbeet producers have asked if cultivation a few weeks after applying chloroacetamide herbicides can remove glyphosate-resistant waterhemp without reducing the efficacy of their layby herbicides and without stimulating another flush of weeds. Field trials were conducted to evaluate the effectiveness of delayed cultivation and how cultivation affects weed emergence. Cultivation can remove 65% of herbicide-resistant waterhemp and have no effect on waterhemp emergence if timed at canopy closure. A repeat glyphosate application is cost effective and more reliable than cultivation to control common lambsquarters.

Introduction and Objectives

Many sugarbeet producers in 2018 applied glyphosate and chloroacetamide herbicides in layers until crop canopy closure. Inter-row cultivators are often used a few weeks after spraying to remove herbicide-resistant weed "escapes". Producers would like to know if inter-row cultivation is a viable tool to remove weeds that glyphosate did not control. Producers would also like to know how a delayed inter-row cultivation affects weed emergence and how it interacts with already-present chloroacetamide herbicides. Therefore, the objectives of this experiment were to 1) evaluate the effectiveness of cultivation at removing herbicide-resistant weeds in sugarbeet and 2) evaluate how delayed cultivation affects weed emergence.

Materials and Methods

Site Description. Field experiments were conducted at two locations in eastern North Dakota and Minnesota in 2017 and at two locations in 2018. Each site-year combination is considered an environment. Environments in 2017 were near Wheaton, MN (45°47'11.0"N, 96°21'15.4"W) and Renville, MN (44°47'07.5"N, 95°08'20.2"W). Environments in 2018 were near Galchutt, ND (46°21'31.7"N, 96°50'22.7"W), and Nashua, MN (46°02'43.2"N, 96°19'38.5"W). Excessive precipitation destroyed two of six replications for the last two evaluations at the Wheaton-2017 environment. Soil descriptions for each used environment can be found in Table 1. The dominant weed at the Renville-2017 and Nashua-2018 environments was waterhemp and the dominant weed at the Wheaton-2017 and Galchutt-2018 environments was common lambsquarters. The four environments were separated into two groups: waterhemp and common lambsquarters.

Table 1. Soil descriptions across environments in 2017 and 2018.

Environment	Soil series & texture	Organic Matter	Soil pH
Wheaton-2017	Doran & Mustinka loam mix	5.1%	6.9
Renville-2017	Mayer silty clay loam	7.7%	7.9
Galchutt-2018	Wyndmere loam	5.0%	7.5
Nashua-2018	Croke sandy loam	3.5%	7.2

Experimental Procedures. The experiment was a 2x4 factorial split-block arrangement in a randomized complete block design with four to six replications depending on environment. Each replication (block) was two factors, cultivation and herbicide treatment. Untreated plots were included for comparison. Sugarbeet was planted on May 15, 2017 at Renville, May 8, 2017 at Wheaton, May 14, 2018 at Nashua, and May 14, 2018 at Galchutt to a density of 61,000 (+/- 1,000) seeds per acre in plots that were 11 feet wide (six rows spaced 22-inches apart) and 30 feet long. S-metolachlor (Dual Magnum, Syngenta Crop Protection) at 0.5 pts/A was applied preemergence (PRE) within 48 hours after planting across the entire trial area in all environments to minimize the effects of early season weed competition.

Herbicide treatments were applied to 3- to 4-inch weeds with a bicycle wheel-type sprayer with a shielded boom to reduce particle drift at a volume of 17 gal/A. The center four rows of each six-row plot were sprayed using pressurized CO_2 at 35 PSI through 8002XR nozzles (TeeJet Technologies, Glendale Heights, IL). Half of the treatments were cultivated approximately two weeks after herbicide application using a modified Alloway 3130 cultivator (Alloway Standard Industries, Fargo, ND) with 15-inch sweep shovels spaced at 22 inches with a ground depth of 1.5 to 2 inches at 4 MPH. Information and use rates of herbicide can be found in Table 2. Dates of planting, herbicide application, cultivation, and crop stage at herbicide application can be found in Table 3.

Table 2. Herbicide product information for treatments applied to 3- to 4-inch weeds.

Herbicide [a]	Product Rate	Trade name	Manufacturer [b]
	fl oz/A		
Glyphosate	28	Roundup PowerMAX	Monsanto
Glyphosate + S-metolachlor	28 + 20	Roundup PowerMAX + Dual Magnum	Monsanto + Syngenta
Glyphosate + dimethenamid-P	28 + 18	Roundup PowerMAX + Outlook	Monsanto + BASF
Glyphosate + acetochlor	28 + 52	Roundup PowerMAX + Warrant	Monsanto

[a] Adjuvants: All treatments included ethofumesate at 4 oz/A (Ethofumesate 4SC, Willowood LLC), high surfactant methylated oil concentrate at 1.5 pt/A (Destiny HC, Winfield Solutions LLC), and ammonium sulfate liquid solution at 2.5% v/v (N-Pak AMS liquid, Winfield Solutions LLC).

[b] Manufacturer information: Monsanto Company, St. Louis, MO; Syngenta Crop Protection, Greensboro, NC; BASF Corporation, Research Triangle Park, NC.

Table 3. Planting dates, herbicide application dates, cultivation dates, and crop stage of sugarbeet at environments in 2017 and 2018.

Environment	Planting date	Application date		Cultivation date	SGBT stage at POST
		PRE [a]	POST		
Renville, MN-2017	May 15	May 15	June 26	July 10	8-10 leaf
Wheaton, MN-2018	May 8	May 9	June 27	July 14	8-10 leaf
Nashua, MN-2018	May 14	May 15	June 12	June 26	6-8 leaf
Galchutt, ND-2018	May 14	May 15	June 21	July 5	6-8 leaf

[a] Abbreviations: PRE = preemergence; POST = postemergence; SGBT = sugarbeet.

Data Collection and Analysis. Percent weed control was evaluated as 'overall control' and 'new weed emergence control' at 14, 28, and 42 (+/- 3) days after the cultivation treatment (DAC). Evaluations were a scale of 0% (no control) to 100% (complete control) relative to the untreated check rows between treatments. 'New weed emergence control' evaluated weeds that emerged since the last treatment, while 'overall control' evaluated old and new growth. Waterhemp in the 7-foot by 30-foot treated area of each 11-foot by 30-foot plot were counted 14 and 28 DAC at the Renville-2017 and Nashua-2018 environments. Waterhemp plants counted were considered glyphosate resistant because only plants that had emerged prior to herbicide application were counted and all treatments included glyphosate. Seedlings were evaluated as part of 'new weed emergence control'. Sugarbeet density was determined by counting emerged sugarbeet in treated rows.

Statistical analysis was conducted using SAS 9.4 (SAS Institute, Cary, NC). Data was subjected to ANOVA using PROC MIXED to test for treatment differences and significant interactions. Data was analyzed as a split-block design with expected means squares recommended by Carmer et al. (1989). Significantly different treatment means were separated using t-tests when data was found to be significantly different at the $P \leq 0.05$. The cultivation and herbicide treatment factors were considered fixed effects, while replicate and environment were considered random effects. All environments were analyzed separately because of differences in primary weed species, precipitation, sugarbeet density, and sugarbeet stage at which the treatments were applied. Only main effects are presented when no significant cultivation by herbicide interaction was detected.

Results and Discussion

Field Growing Conditions. Precipitation in the weeks following planting in 2017 was close to the 30-year average, but 2018 was relatively dry. Stand establishment was one of the greatest production challenges for sugarbeet producers in 2018 because of this dry period immediately after planting. Sugarbeet density at Renville-2017, Wheaton-2017, and Galchutt-2018 was near the optimal range of 175 to 200 sugarbeet per 100 ft row (Cattanach 1994; Smith et al. 1990; M. Metzger 2018, personal communication), but sugarbeet density at Nashua-2018 was 50% of the recommended density (Table 4). Crop density is an important component of sugarbeet weed management (Dawson 1977) and the poor sugarbeet density at Nashua-2018 and Galchutt-2018 likely reduced the contribution of crop canopy on weed suppression.

Table 4. Primary weed species present and sugarbeet density across environments in 2017 and 2018.

Environment	Primary weed species	Sugarbeet density [a]
		# per 100 ft row
Renville-2017	Waterhemp	180
Wheaton-2017	Common lambsquarters	193
Nashua-2018	Waterhemp	85
Galchutt-2018	Common lambsquarters	162

[a] Sugarbeet density is number of sugarbeets per 100 ft of row.

Waterhemp density per plot. Delayed cultivation reduced the number of waterhemp plants per plot in one of two environments (Table 5). At Renville-2017, cultivation removed nearly 65% of the waterhemp plants from the cultivated plots when accessed 14 DAC. At Nashua-2018, cultivation numerically reduced waterhemp per plot by one third; however, waterhemp densities were as low as 2 to 3 plants per plot and were insufficient to detect a statistical difference ($P = 0.119$). Had waterhemp densities at Nashua-2018 been greater and more uniform, a 65 to 70% reduction in waterhemp plants per plot between cultivated and no cultivated plots would be expected. This is because the cultivator was equipped with 15-inch wide shovels and covered approximately 68% of the field surface area (sugarbeet were grown in 22-inch rows) to remove emerged weeds.

Waterhemp density was not affected by herbicide treatment at either location. (Table 5). Herbicide treatments were applied to actively growing waterhemp. Since chloroacetamide herbicides have no efficacy on emerged waterhemp, glyphosate was the only herbicide in the treatment that could have had efficacy (POST) on emerged plants. The glyphosate alone treatment had the least waterhemp density per plot, numerically, at both environments. This observation suggests antagonism between herbicide mixtures; however, past research does not indicate significant antagonism between chloroacetamide herbicides and glyphosate exists (Tharp and Kells 2002).

New waterhemp emergence control. Cultivation did not affect 'new waterhemp control' at Nashua-2018 but improved 'new waterhemp control' by 11% at Renville-2017 (Table 5). Only data from 14 DAC was reported for 'new waterhemp control' because chloroacetamide herbicides have an effective period of 2 to 3 weeks (Mueller et al. 1999), and 14 DAC was 28 days after spray application. Waterhemp control similar in cultivated and no-cultivated plots might be attributed to the timing of the cultivation. Cultivation disrupted the emerging growth of new weeds between the rows and crop canopy created shade, suppressing any further emergence when cultivation was timed near crop canopy closure. In addition, waterhemp emergence is triggered by changes in moisture and temperature near the soil surface. Oryokot et al. (1997) reported soil disturbance, for example, soil disturbance caused by inter-row cultivation, does not affect moisture or air temperature in the zone where *Amaranthus* species seeds germinate and emerge.

Cultivation likely reduced weed emergence at Renville-2017 due to an interaction between precipitation after the cultivation and the sugarbeet density in each environment. Nashua-2018 received over one inch of precipitation in the two weeks following cultivation while Renville-2017 received less than a half inch. Cultivation at Renville-2017 may have disrupted new weed growth and conditions between the time of cultivation and canopy closure were not conducive for further weed emergence. Conditions were conducive for weed growth at

Table 5. Effect of cultivation and herbicide on waterhemp density and new waterhemp control at Renville, MN-2017 and Nashua, MN-2018, 14 and 28 days after cultivation treatment (DAC). [a]

	Waterhemp counts, 14 DAC		Waterhemp counts, 28 DAC		New waterhemp control, 14 DAC	
Main effects	Renville	Nashua	Renville	Nashua	Renville	Nashua
Cultivation	-----# per plot-----		----# per plot----		----------%----------	
With cultivation	7 a	2 a	9 a	2 a	100 a	98 a
No cultivation	19 b	3 a	20 b	3 a	89 b	98 a
Herbicide						
Glyphosate	8 a	1 a	9 a	1 a	90 b	92 b
Glyphosate + S-metolachlor	21 a	2 a	23 a	2 a	95 a	100 a
Glyphosate + Outlook	9 a	3 a	11 a	4 a	97 a	100 a
Glyphosate + Warrant	15 a	3 a	16 a	3 a	95 a	100 a
ANOVA	--------*p value*--------		--------*p value*--------		--------*p value*-------	
Cultivation	0.013	0.379	0.026	0.119	0.007	1.000
Herbicide	0.062	0.739	0.069	0.576	0.028	0.022
Cultivation*herbicide	0.535	0.108	0.676	0.801	0.282	0.515

[a] Means of a main effect within an environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

Nashua-2018, regardless of cultivation. In addition, sugarbeet density at Nashua-2018 was 85 sugarbeet per 100 ft row, or half an optimal density (Table 4). Sugarbeet density at Renville-2017, meanwhile, was quite uniform at 180 sugarbeet per 100 ft row. This difference in density between the two environments would have affected the role of crop canopy on weed suppression, which is a crucial component of weed management in sugarbeet (Dawson 1977).

Chloroacetamide herbicides with glyphosate increased control of newly emerging waterhemp by 5 to 8% compared to glyphosate alone at both environments (Table 5. Chloroacetamide herbicides gave similar waterhemp control at both environments. This result was expected since chloroacetamide herbicides in sugarbeet provide residual control of emerging small-seeded broadleaf weeds. These results demonstrate the value of mixing chloroacetamide herbicides with glyphosate to reduce the number of emerging waterhemp seedlings. Chloroacetamide herbicides in sugarbeet can be applied in a 'layered' system where Dual Magnum is applied PRE and S-metolachlor, Outlook, or Warrant are tank mixed with glyphosate and applied up to twice POST to provide "layered" residual control of small-seeded broadleaves until crop canopy closure (Peters et al. 2017). The use of this 'layered' system is important component in providing season-long control of glyphosate resistant waterhemp.

Overall waterhemp control. Cultivation improved season-long 'overall waterhemp control' at Renville-2017 but did not affect season-long waterhemp control at Nashua-2018 (Table 6). Data from 14 DAC and 28 DAC is representative of early to mid-season control, while data from 42 DAC is representative of season-long control. Cultivation significantly increased waterhemp control 15 to 20% at 42 DAC at Renville-2017 but did not significantly affect waterhemp control at Nashua-2017 (Table 6). These results are similar to the waterhemp density results (Table 5) and new waterhemp control data (Table 5) previously described.

'Overall waterhemp control' was not affected by herbicide treatment at Nashua, but S-metolachlor plus glyphosate provided less season-long waterhemp control than other herbicides at Renville-2017 (Table 6). S-metolachlor plus glyphosate had less overall control at Renville-2017 because of coincidentally greater numbers of herbicide-resistant weeds in plots, as new weed emergence control was not different compared with other chloroacetamide herbicides (Table 5). Counted plants were considered glyphosate resistant because only plants emerged prior to herbicide application were counted. Numerically, there were 21 waterhemp plants per plot in the S-metolachlor with glyphosate treatment compared with eight waterhemp per glyphosate alone treatment, but the difference was not statistically significant (Table 5). This observation would imply antagonism between glyphosate and S-metolachlor, but past research does not indicate antagonism exists (Tharp and Kells 2002).

Table 6. Effect of cultivation and herbicide on overall waterhemp control at Renville-2017 and Nashua-2018, 14, 28, and 42 days after cultivation treatment (DAC). [a]

	Overall control, 14 DAC		Overall control, 28 DAC		Overall control, 42 DAC	
Main effects	Renville	Nashua	Renville	Nashua	Renville	Nashua
Cultivation	----------%----------		----------%----------		----------%----------	
With cultivation	86 a	91 a	80 a	88 a	76 a	87 a
No cultivation	71 b	89 a	63 b	82 a	57 b	82 a
Herbicide						
Glyphosate	83 a	88 a	77 a	86 a	74 a	84 a
Glyphosate + S-metolachlor	70 b	90 a	61 b	85 a	58 b	86 a
Glyphosate + Outlook	83 a	88 a	77 a	81 a	73 a	80 a
Glyphosate + Warrant	80 a	91 a	71 a	88 a	67 a	88 a
ANOVA	--------*p value*--------		--------*p value*--------		---------*p value*---------	
Cultivation	< 0.001	0.252	0.001	0.115	0.001	0.245
Herbicide	0.005	0.893	0.005	0.836	0.002	0.788
Cultivation*herbicide	0.915	0.134	0.744	0.524	0.716	0.144

[a] Means of a main effect within an environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

New common lambsquarters control. Cultivation improved 'new common lambsquarters control' at Wheaton-2017 but did not improve lambsquarters control at Galchutt-2018 (Table 7). Sugarbeet density and sugarbeet stage at application is likely the reason for this difference. Herbicide was applied to 8- to 10-leaf sugarbeet at Wheaton-2017 and 6- to 8-leaf sugarbeet at Galchutt-2018 (Table 3). Wheaton-2017 had a full and uniform density of 193 sugarbeet per 100 ft row, while the density at Galchutt-2018 was less than optimal at 162 sugarbeet per 100 ft row (Table 4). Sugarbeet density at Galchutt-2018 was also noted to be non-uniform with frequent and random gaps. The smaller and less dense/uniform sugarbeet stand at Galchutt-2018 would have reduced the contribution of canopy closure on weed emergence. At Wheaton-2017, cultivation disrupted weed growth and allowed the sugarbeet canopy to suppress further emergence, but the gaps in stand and canopy at Galchutt-2018 at the time of treatment created conditions conducive for further weed growth after the cultivation. This would imply

Table 7. Effect of cultivation and herbicide on new common lambsquarters control at Wheaton-2017 and Galchutt-2018, 14 days after cultivation treatment (DAC). [a]

	New common lambsquarters control, 14 DAC	
Main effects	Wheaton	Galchutt
Cultivation	-----------------%-----------------	
With cultivation	92 a	97 a
No cultivation	77 b	94 a
Herbicide		
Glyphosate	76 b	89 a
Glyphosate + S-metolachlor	87 a	98 a
Glyphosate + Outlook	92 a	98 a
Glyphosate + Warrant	82 ab	98 a
ANOVA	---------------*p value*---------------	
Cultivation	0.027	0.220
Herbicide	0.032	0.160
Cultivation * herbicide	0.991	0.106

[a] Means of a main effect within an environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

the optimal time to cultivate is mid-July or near canopy closure when a healthy crop canopy can provide shade and suppress further weed emergence.

Overall common lambsquarters control. 'Overall common lambsquarters control' was not affected by cultivation in neither environment (Tables 8 and 9). An increase of 10% lambsquarters control was observed 14 DAC at Wheaton-2017, but no statistical difference was observed 42 DAC due to variability. Overall common lambsquarters control was 7 to 19% greater from cultivation at 42 DAC compared to no cultivation (Table 8), but no statistical difference occurred at either environment.

Table 8. Effect of cultivation and herbicide on overall common lambsquarters control at Wheaton-2017 and Galchutt-2018, 14, 28, and 42 days after cultivation treatment (DAC). [a]

	Overall control, 14 DAC		Overall control, 28 DAC	Overall control, 42 DAC	
Main effects	Wheaton	Galchutt	Wheaton	Wheaton	Galchutt
Cultivation	----------%	----------	--%--	----------%	----------
With cultivation	95 a	99 a	96 a	92 a	94 a
No cultivation	85 b	96 a	81 a	73 a	87 a
Herbicide					
Glyphosate	83 a	95 a	92 a	87 a	83 a
Glyphosate + S-metolachlor	91 a	97 a	81 a	78 a	92 a
Glyphosate + Outlook	95 a	100 a	89 a	85 a	95 a
Glyphosate + Warrant	91 a	99 a	91 a	80 a	92 a
ANOVA	-------*p*	*value*-------	-*p value*-	-------*p*	*value*-------
Cultivation	0.046	0.058	0.108	0.060	0.060
Herbicide	0.110	0.106	0.393	0.504	0.055
Cultivation * herbicide	0.927	0.134	0.478	0.389	0.108

[a] Means of a main effect within an environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

Table 9. Interaction of cultivation by herbicide on overall common lambsquarters control at Galchutt-2018, 28 days after cultivation treatment (DAC). [a]

	Overall lambsquarters control, 28 DAC
Cultivation * herbicide interaction	Galchutt
With cultivation	--%--
Glyphosate	88 b
Glyphosate + S-metolachlor	92 ab
Glyphosate + Outlook	100 a
Glyphosate + Warrant	98 a
No cultivation	
Glyphosate	72 c
Glyphosate + S-metolachlor	93 ab
Glyphosate + Outlook	93 ab
Glyphosate + Warrant	98 a
ANOVA	-*p value*-
Cultivation	0.067
Herbicide	0.013
Cultivation * herbicide	0.042

[a] Means not sharing any letter are significantly different by the t-test at the 5% level of significance.

'Overall common lambsquarters control' did not improved with chloroacetamide herbicides plus glyphosate compared to glyphosate alone (Tables 8 and 9). An interaction between cultivation and herbicide 28 DAC at Galchutt-2018 indicated lambsquarters control from glyphosate alone increased 16% by cultivation (Table 9). This interaction demonstrates cultivation benefitted glyphosate but cultivation was not necessary when glyphosate was combined with residual herbicides. Cultivation and tank-mixing a chloroacetamide herbicide with glyphosate are probably not necessary to manage common lambsquarters, as glyphosate provides excellent common lambsquarters control alone (Sivesend et al. 2011). A repeat glyphosate application probably is more effective than cultivation.

Conclusion: Should I follow herbicide application with a delayed cultivation pass?

Inter-row cultivation two weeks after herbicide application improved overall waterhemp control because it physically removed glyphosate resistant waterhemp. The cultivator removed 65% of herbicide-resistant waterhemp, which translated to 20% greater season-long overall control at Renville-2017 (Tables 5 and 6). At Nashua-2018, no benefit from cultivation was observed because of low waterhemp densities and thin/non-uniform sugarbeet densities. Many producers have asked if cultivation is a viable option to control herbicide-resistant waterhemp escapes without disrupting an activated herbicide barrier. This data suggests cultivation will effectively remove two thirds of weed escapes with no apparent deleterious effects. Cultivation timed two weeks after residual herbicide application or near canopy closure will disrupt weed growth and allow the crop canopy to suppress further emergence. Delayed cultivation is not necessary to control glyphosate-susceptible common lambsquarters because a repeat glyphosate application is cost effective and usually provides near 100% common lambsquarters control.

Acknowledgements

We thank the Sugarbeet Research and Education Board of Minnesota and North Dakota for funding this research. We would like to thank the Southern Minnesota Beet Sugar Cooperative, Tim Backman, Mike Moen, and Troy Koltes for providing land to conduct the trials. We would also like to thank Peter Hakk, Alexa Lystad, Norm Cattanach, Charles Tvedt, Jewel Faul, and Jeff Stith for their help with establishing and maintaining these trials.

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SUGARBEET SENSITIVITY TO DICAMBA AT LOW DOSE

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SUMMARY

1. Sugarbeet is not as sensitive to dicamba as some other rotational crops.
2. Sugarbeet leaves will lay flat on the ground within a few hours of exposure to dicamba.
3. Leaves may remain more prostrate than normal for the remainder of the growing season.
4. New leaf growth will generally resume around 6 to 10 days after exposure.
5. Dicamba accumulates in roots but metabolizes over time.
6. 1/10x rate (0.05 lb ai/A) was the dicamba rate at which sugarbeet root yield and quality losses were typically observed.

INTRODUCTION

Dicamba is a growth-regulator herbicide consisting of the auxin transport inhibitor compound benzoic acid. It is widely used to control perennial and annual broadleaf weeds in agricultural crops, fallow land, pastures, turfgrass, and rangeland. Dicamba can move in the xylem and phloem to areas of new plant growth; herbicide uptake is primarily through the foliage, but root uptake can occur as well. Dicamba was first registered for use in the United States in 1967. Common formulations of dicamba currently in use include Engenia by BASF, FeXapan plus VaporGrip by DuPont Crop Protection, and XtendiMax plus VaporGrip by Bayer Crop Protection.

The Environmental Protection Agency (EPA) first registered dicamba formulations for 'over-the-top' use on dicamba-tolerant cotton and soybean in 2016. An alarming number of complaints alleging dicamba off-target movement from dicamba tolerant soybean to neighboring sensitive crops were reported to Minnesota and North Dakota Department of Agriculture officials in 2017. To minimize potential future damage to neighboring sensitive crops, EPA and registrants agreed on label changes, implementation of detailed record keeping requirements, and implementation of additional spray drift mitigation measures for the 2018 growing season.

Dicamba-tolerant soybean are commonly grown in the sugarbeet growing areas of the Red River Valley in Minnesota and eastern North Dakota. However, information on the effect of dicamba off-target movement on sugarbeet is insufficient. Experiments were conducted to determine sugarbeet sensitivity to dicamba at low doses simulating off target movement. Experiment objectives were a) to determine sugarbeet injury from dicamba at low doses to simulate off-target movement; b) to determine if dicamba residues accumulate in leaf or root tissue and if they are present at harvest, and c) to determine the impact of dicamba dose on root yield and sugarbeet quality.

MATERIALS AND METHODS

Amenia, North Dakota

Sugarbeet experiments were conducted near Amenia, ND, in 2017 and 2018. The experimental area was prepared with a Kongskilde 's-tine' field cultivator with rolling baskets before sugarbeet planting. 'SES 36271RR' sugarbeet on May 2, 2017 and 'Crystal 981RR' sugarbeet on May 14, 2018 were seeded 1.25-inch-deep in 22-inch rows at 60,825 seeds per acre. Sugarbeet seed was coated with seed treatments for control of soil borne insects and diseases. Dicamba treatments were applied on August 11, 2017 and June 26, 2018 with a backpack sprayer in 17 gpa spray solution through 11002 Turbo Tee (TT) nozzles in 2017 and 11002 Turbo Tee Induction (TTI) nozzles in 2018 pressurized with CO_2 at 40 psi in 2017 and 50 psi in 2018 to the center four rows of six row plots 30 feet in length. For these experiments, the 1x rate of dicamba was 0.5 lb ai/A.

Sugarbeet visual growth reduction and /or malformation injury was evaluated approximately weekly after application. Evaluations were a visual estimate of sugarbeet injury in the four treated rows compared to the adjacent untreated strip. Sugarbeet leaf blade and petiole (plant) and root samples were collected at two time points to simulate preharvest and harvest. Samples were collected beginning with the untreated check plot and ending with the highest dicamba rate to prevent contamination. Five roots were randomly sampled from the treated area of the plot and cleaned with water. The largest and smallest roots were discarded. Roots were cut into pieces and immediately stored in a cooler on wet ice. Samples were shipped in cooler with dry ice to SGS Brookings, Brookings, SD for analysis of dicamba residue.

Sugarbeet were harvested for yield and quality measurement in 2018. Sugarbeet were defoliated with a four-row topper and harvested with a two-row sugarbeet harvester. The sugarbeet roots were weighed to determine root yield (tons/acre). Approximately 25 lbs. of roots were then sampled from each plot and taken to American Crystal Sugar Company Quality Lab, East Grand Forks, MN and analyzed for percent sucrose and sugar loss to molasses (SLM). Purity (%) and recoverable sucrose (lb/acre) were then calculated. Experiment design was an unreplicated strip in 2017 and a randomized complete block design with two replications in 2018. Data were analyzed with the ANOVA procedure of ARM, version 2018.5 software package.

Comstock, Minnesota, and Norcross, Minnesota

Sugarbeet experiments were conducted near Comstock, MN, in 2017 and near Norcross, MN, in 2018. The experimental area was prepared with a King Kutter gear-driven rotary tiller. 'Hilleshög 4062RR' sugarbeet on May 13, 2017, and 'Betaseed 70RR99' sugarbeet on May 15, 2018, were seeded 1.25-inch-deep in 22-inch rows at 63,360 seeds per acre. Sugarbeet seed was coated with seed treatments for control of soil borne insects and diseases. Dicamba treatments were applied on June 19, 2017, and June 20, 2018, with a backpack sprayer in 15 gpa spray solution through XR8002 nozzles pressurized with CO_2 at 40 psi to the center four rows of six row plots 25 feet in length. For these trials, the 1x rate of dicamba was 0.5 lb ai/A.

Sugarbeet canopy was photographed using a DJI Phantom 3 Series drone within 72 hours of treatment and approximately two weeks after treatment. Images were used to calculate Leaf Area Index (LAI). LAI is a dimensionless quantity that characterizes plant canopies; it is defined as the one-sided green leaf area per unit ground surface area in broad leaf canopies (LAI = leaf area / ground area, m2 / m2). Sugarbeet leaf blade and petiole (plant) and root samples were collected at two time points to simulate preharvest and harvest in 2018. Samples were collected beginning with the untreated check plot and ending with the highest dicamba rate to prevent contamination. Three roots were randomly sampled from the treated area of the plot and cleaned with water. Roots were cut into pieces and immediately stored in a cooler on wet ice. Samples were shipped in cooler with dry ice to SGS Brookings, Brookings, SD for analysis of dicamba residue.

Sugarbeet were harvested for yield and quality measurement on September 29, 2017, and September 22, 2018. Sugarbeet were defoliated with a six-row topper and harvested with a three-row sugarbeet harvester. The sugarbeet roots were weighed to determine root yield (tons/acre). Approximately 30 lbs. of roots were then sampled from each plot and taken to Minn-Dak Farmers Cooperative Quality Lab, Wahpeton, ND, and analyzed for percent sucrose and percent purity. Recoverable sucrose as lb/ton and lb/acre were calculated. Experiment design was a randomized complete block design with four replications in 2017 and six replications in 2018. Data were analyzed with the ANOVA procedure of ARM, version 2018.5 software package.

RESULTS AND DISCUSSION

Sugarbeet Injury. Visual sugarbeet injury from dicamba treatments increased over time at Amenia, ND in 2017 (Table 1). Sugarbeet injury from the lowest dicamba rate (1/1000x) increased 6%, injury from 1/100x increased 15%, and injury from 1/10x increased 20%. At both evaluation timings, sugarbeet injury was greatest from the

Table 1. Sugarbeet malformation injury from XtendiMax at 10 days after treatment (DAT) and 35 DAT at Amenia, ND, 2017.

Dicamba Rate[1]	Percent of labeled rate	Sugarbeet injury – 10DAT	Sugarbeet injury – 35 DAT
lb ai/acre		%	%
0.05	1/10x[1]	35	55
0.005	1/100x	5	20
0.0005	1/1000x	0	6

[1] A 1x rate equals 0.5 lb ai/A dicamba.

highest rate and decreased as dicamba rate decreased. Likewise, visible sugarbeet malformation and growth reduction was greater with increased dicamba rate at Amenia in 2018 (Table 2). Plot canopy estimated as leaf area index (LAI) was greatest in the untreated control and with the lowest dicamba rate and was least with the highest dicamba rate. Plot canopy increased as dicamba rate decreased.

Table 2. Sugarbeet visible malformation and growth reduction injury in response to dicamba off-target movement, 12 DAT at Amenia, ND, and plot canopy, 15 DAT, Norcross, MN, 2018.

Dicamba Rate[1]	Malformation	Growth Reduction	Plot Canopy (LAI)
	%	*%*	*cm^2*
High	100 a	100 a	210,000 c
Medium	60 b	50 b	256,900 b
Low	0 c	15 c	289,100 a
Untreated	0 c	0 c	303,300 a
LSD (0.10)	**30**	**17**	**31,400**

[1]High = 1/2x or 1/10x rate; Medium = 1/20x or 1/33x rate; Low = 1/200x or 1/100x rate. A 1x rate equals 0.5 lb ai/A dicamba.

Root yield, sucrose content and recoverable sucrose. Sugarbeet were harvested approximately three months after dicamba application at each location except at Amenia in 2017. Root yield and quality decreased as dicamba rate increased across locations and years (Tables 3, 4 and 5). Differences in sucrose content were not statistically significant in 2017 (Table 3). However, yield and recoverable sucrose were affected by the 1/10x rate dicamba as compared to the untreated check and the 1/100 and 1/33 dicamba rate in 2017.

Table 3. Sugarbeet canopy, root yield, sucrose content and recoverable sucrose in response to dicamba off-target movement, Comstock, MN, 2017.

Treatment[1]	Percent of Labeled Rate	Plot canopy - July 5	Root Yield	Sucrose	Recoverable Sucrose
		cm^2	*ton/acre*	*%*	*lb/acre*
XtendiMax	1/10x	16,400 b	23.9 b	15.3	5,682 b
XtendiMax	1/33x	28,000 ab	27.7 a	15.8	6,889 a
XtendiMax	1/100x	32,500 a	29.9 a	16.1	7,678 a
Untreated		29,700 a	28.4 a	15.0	6,761 ab
LSD (0.10)		**12,900**	**2.6**	**NS**	**1,151**

[1]A 1x rate equals 0.5 lb ai/A dicamba.

Dicamba at 1/10x to 1/2x rate decreased sugarbeet root yield, sucrose content and recoverable sucrose compared to the untreated check at Amenia and Norcross in 2018. Dicamba at 1/00x and 1/33x rate reduced root yield and quality compared to the untreated check at Norcross (Table 5). However, dicamba at 1/200x and 1/20x rate did not affect root yield and quality compared to the untreated check at Amenia in 2017 (Table 4). Root yield and recoverable sugar losses were much greater between 1/10x and 1/2x rate than between 1/200x and 1/20x rate at Amenia and Norcross in 2018 (Tables 4 and 5).

Table 4. Sugarbeet root yield, sucrose content and recoverable sucrose in response to dicamba off-target movement, Amenia, ND, 2018.

Treatment[1]	Percent of Labeled Rate	Root Yield	Sucrose	Recoverable Sucrose
		ton/acre	*%*	*lb/acre*
XtendiMax	1/2x	20.9 c	13.3 b	4,597 c
XtendiMax	1/20x	39.1 a	15.6 a	10,666 a
XtendiMax	1/200x	35.8 b	15.4 a	9,639 b
Untreated		37.8 ab	15.4 a	10,121 ab
LSD (0.10)		**3.2**	**1.4**	**833**

[1]A 1x rate equals 0.5 lb ai/A dicamba.

Table 5. Sugarbeet root yield, sucrose content and recoverable sucrose in response to dicamba off-target movement, Norcross, MN, 2018.

Treatment[1]	Percent of Labeled Rate	Root Yield	Sucrose	Recoverable Sucrose
		ton/acre	*%*	*lb/acre*
XtendiMax	1/10x	9.2 d	16.2 b	2,452 d
XtendiMax	1/33x	22.7 c	17.6 a	6,755 c
XtendiMax	1/100x	25.3 b	17.7 a	7,578 b
Untreated		28.0 a	18.4 a	8,856 a
LSD (0.10)		**2.1**	**1.1**	**578**

[1] A 1x rate equals 0.5 lb ai/A dicamba.

Residue Analysis. Dicamba residue level in leaves and roots decreased as the dicamba rate decreased (Table 6). Leaf tissue had greater levels of dicamba residue than root tissue. Except for leaf tissue at the labeled dicamba rate, the amount of residue in tissues declined between the first and second sampling date. Dicamba treatments were not applied until August 11 at Amenia in 2017 or much later than mid to late June or typical soybean application timing.

Sampling was timed to simulate August sugarbeet preharvest (58 to 69 DAT) and full harvest in October (84 to 94 DAT) and followed dicamba application to simulated off target movement from application in soybean in 2018. Dicamba was virtually undetectable in leaf and root across sampling timings and locations in 2018 (Tables 7 and 8). There was no dicamba residue detected in the roots 84 to 94 DAT.

Table 6. Dicamba residue measured in sugarbeet leaf and root tissue, 17 and 38 DAT, Amenia, ND, 2017.

		17 DAT		38 DAT	
Rate	Percent of Labeled Rate	Leaf	Root	Leaf	Root
lb ai/acre		ppm			
0.5	1x	0.57	0.48	1.40	0.47
0.05	1/10x	0.11	0.07	0.07	0.06
0.005	1/100x	0.12	0.01	0.01	0
0.0005	1/1000x	0	0.001	0	0
0		0	0	0	0

Table 7. Dicamba residue measured in sugarbeet leaf and root tissue, 58 and 84 DAT, Amenia, ND, 2018.

		58 DAT		84 DAT	
Rate	Percent of Labeled Rate	Leaf	Root	Leaf	Root
lb ai/acre		ppm			
0.25	1/2x	0.165	0.110	0.027	0
0.025	1/20x	0.045	0	0	0
0.0025	1/200x	0	0	0	0
0	Untreated	0	0	0	0

Table 8. Dicamba residue measured in sugarbeet leaf and root tissue, 69 and 94 DAT, Norcross, MN, 2018.

		69 DAT		94 DAT	
Rate	Percent of Labeled Rate	Leaf	Root	Leaf	Root
lb ai/acre		ppm			
0.05	1/10x	0.014	0.030	0	0
0.165	1/33x	0.012	0	0	0
0.005	1/100x	0	0	0.003	0
0	Untreated	0	0	0	0

CONCLUSION

Sugarbeet is not as sensitive to dicamba as other crops including soybean or sunflower. Sugarbeet injury following dicamba off target movement will occur within a few hours of exposure. Sugarbeet leaves will lay flat on the ground, regardless of rate, but a higher dosage will lead to greater visible injury. Leaves may remain more prostrate than normal for the remainder of the growing season, especially if the injury is severe. Leaf petioles will exhibit twisting, also called epinasty. New leaf growth generally resumes six to ten days after exposure and the new leaves will often be malformed with wrinkled leaf margins, parallel veins, or leaf strapping. Dicamba is rapidly metabolized by sugarbeet and it is unlikely dicamba residue will be detected in the roots at harvest.

INTER-ROW CULTIVATION IMMEDIATELY FOLLOWING RESIDUAL HERBICIDE APPLICATION IN SUGARBEET

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Summary

Sugarbeet producers have asked if cultivation immediately after their application of chloroacetamide (or "layby") herbicides affects the activity of the herbicides in addition to removing weeds. Field trials were conducted to evaluate the effectiveness of early cultivation and how cultivation interacts with residual herbicides as an incorporation tool. Cultivation removed 50 to 75% of herbicide-resistant waterhemp and did not affect the activity of residual herbicides with our cultivator configurations. Early cultivation before canopy closure did not affect waterhemp emergence, but did increase common lambsquarters emergence in one environment. Cultivation is not currently the preferred means to control common lambsquarters as a repeat glyphosate application is cost effective and more reliable.

Introduction and Objectives

Many sugarbeet producers in 2018 applied glyphosate and chloroacetamide herbicides in layers until crop canopy closure. Many producers have used inter-row cultivation as a supplement to their weed control program to remove weeds that glyphosate did not control. One limitation of chloroacetamide herbicides is their requirement for precipitation to become active in the soil. Because of this limitation, producers have inquired if cultivation can be used to activate their herbicides through incorporation. Producers would also like to know how cultivation affects weed emergence. Therefore, the objectives of this experiment were to 1) evaluate the effectiveness of cultivation at removing herbicide-resistant weeds in sugarbeet and 2) evaluate how immediate cultivation affects weed emergence and interacts with soil-residual herbicides in sugarbeet.

Materials and Methods

Site Description. Field experiments were conducted at two locations in eastern North Dakota and Minnesota in 2017 and at three locations in 2018. Each site-year combination was considered an environment. Environments in 2017 were near Wheaton, MN (45°47'11.0"N, 96°21'15.4"W) and Renville, MN (44°47'07.5"N, 95°08'20.2"W). Environments in 2018 were near Hickson, ND (46°42'14.2"N, 96°48'09.3"W), Galchutt, ND (46°21'31.7"N, 96°50'22.7"W), and Nashua, MN (46°02'43.2"N, 96°19'38.5"W). Detailed soil descriptions for each environment can be found in Table 1. The dominant weed at the Renville-2017, Hickson-2018, and Nashua-2018 environments was waterhemp, while the dominant weed at the Wheaton-2017 and Galchutt-2018 environments was common lambsquarters. The five environments were separated into two groups: waterhemp and common lambsquarters.

Table 1. Soil descriptions for environments in 2017 and 2018.

Environment	Soil series & texture	Soil subgroup	Organic Matter	Soil pH
Wheaton-2017	Doran & Mustinka loam mix	Aquertic Argiudolls & Typic Argiaquolls	5.1%	6.9
Renville-2017	Mayer silty clay loam	Typic Endoaquolls	7.7%	7.9
Hickson-2018	Fargo silty clay	Typic Epiaquerts	6.0%	7.5
Galchutt-2018	Wyndmere loam	Aeric Calciaquolls	5.0%	7.5
Nashua-2018	Croke sandy loam	Oxyaquic Hapludolls	3.5%	7.2

Experimental Procedures. The experiment was a 2x6 factorial split-block arrangement in a randomized complete block design with six replications. Each replication (block) was two factors, cultivation and herbicide treatment. Untreated plots were nested in the design for comparison. Sugarbeet was planted on May 15, 2017 at Renville, May 8, 2017 at Wheaton, May 7, 2018 at Hickson, May 14, 2018 at Nashua, and May 14, 2018 at Galchutt at a density of 61,000 (+/- 1,000) seeds per acre in plots that were 11 feet wide (six rows spaced 22 inches apart) and 30 feet long. S-metolachlor (Dual Magnum, Syngenta Crop Protection) at 0.5 pt/A was applied preemergence (PRE) within 48 hours after planting across the entire trial area in all environments except Hickson-2018 to minimize the effects of early season weed competition.

Herbicide treatments were applied at 4- to 10-leaf sugarbeet with a bicycle wheel-type sprayer with a shielded boom to reduce particle drift at a volume of 17 gal/A. The center four rows of each six-row plot were sprayed using pressurized CO_2 at 35 PSI through 8002XR nozzles (TeeJet Technologies, Glendale Heights, IL). Half of the treatments were cultivated immediately after herbicide application using a modified Alloway 3130 cultivator (Alloway Standard Industries, Fargo, ND) with 15-inch sweep shovels spaced at 22 inches with a ground depth of 1.5 to 2 inches at 4 MPH. Information and use rates of herbicide can be found in Table 2. Dates of planting, herbicide application, and crop stage at herbicide application can be found in Table 3.

Table 2. Herbicide product information for treatments applied to 8- to 10-leaf sugarbeet in 2017 and 4- to 8-leaf sugarbeet in 2018.

Herbicide [a]	Product Rate	Trade name	Manufacturer [b]
	fl oz/A		
Glyphosate	28	Roundup PowerMAX	Monsanto
Glyphosate + S-metolachlor	28 + 20	Roundup PowerMAX + Dual Magnum	Monsanto + Syngenta
Glyphosate + dimethenamid-P	28 + 18	Roundup PowerMAX + Outlook	Monsanto + BASF
Glyphosate + acetochlor	28 + 52	Roundup PowerMAX + Warrant	Monsanto
Glyphosate + trifluralin	28 + 16	Roundup PowerMAX + Treflan HFP	Monsanto + Gowan
Glyphosate + cycloate	28 + 43	Roundup PowerMAX + Ro-Neet	Monsanto + Helm Agro

[a] Adjuvants: All treatments included ethofumesate at 4 oz/A (Ethofumesate 4SC, Willowood LLC), high surfactant methylated oil concentrate at 1.5 pt/A (Destiny HC, Winfield Solutions LLC), and ammonium sulfate liquid solution at 2.5% v/v (N-Pak AMS liquid, Winfield Solutions LLC).

[b] Manufacturer information: Monsanto Company, St. Louis, MO; Syngenta Crop Protection, Greensboro, NC; BASF Corporation, Research Triangle Park, NC; Gowan Company, Yuma, AZ; Helm Agro US, Tampa, FL.

Table 3. Planting dates, application dates, and crop stage of of sugarbeet across environments in 2017 and 2018.

Environment	Planting date	Application date		SGBT stage at POST
		PRE [a]	POST	
Renville, 2017	May 15	May 15	June 26	8-10 leaf
Wheaton, 2017	May 8	May 9	June 27	8-10 leaf
Hickson, 2018	May 7	-	June 20	6-8 leaf
Nashua, 2018	May 14	May 15	June 8	4-6 leaf
Galchutt, 2018	May 14	May 15	June 8	4-6 leaf

[a] Abbreviations: PRE = preemergence; POST = postemergence; SGBT = sugarbeet.

Data Collection and Analysis. Percent weed control was evaluated as 'overall control' and 'new weed emergence control' at 14, 28, and 42 (+/- 3) days after treatment (DAT). Evaluation was a scale of 0% (no control) to 100% (complete control) relative to the untreated check rows between treatments. 'New weed emergence control' evaluated weeds that emerged since the last treatment, while 'overall control' evaluated old and new growth. Waterhemp in the 7-foot by 30-foot treated area of each 11-foot by 30-foot plot was counted 14 and 28 DAT at the Renville-2017, Hickson-2018, and Nashua-2018 environments. Waterhemp plants counted were considered glyphosate resistant because only plants that emerged prior to herbicide application were counted and all herbicide treatments included glyphosate. Seedlings were evaluated as part of 'new weed emergence control'. Common lambsquarters density was determined by counting plants in a 1-m^2 quadrat 14 and 28 DAT at the Galchutt-2018 environment. Sugarbeet density was determined by counting stand in treated rows.

Statistical analysis was conducted using SAS 9.4 (SAS Institute, Cary, NC). Data was subjected to ANOVA using PROC MIXED to test for treatment differences and significant interactions. Data was analyzed as a split-block design with expected means squares as recommended by Carmer et al. (1989). Significantly different treatment means were separated using t-tests when data was found to be significantly different at the $P \leq 0.05$. The cultivation and herbicide treatment factors were considered fixed effects, while replicate and environment were considered random effects. All environments were analyzed separately because of differences in primary weed species, precipitation, sugarbeet density, and sugarbeet stage at which the treatments were applied. Only main effects are presented when no significant cultivation by herbicide interaction was detected.

Results and Discussion

Field Growing Conditions. Field planting ranged between May 8 and May 15 across all environments (Table 3), which is typical for sugarbeet production in eastern North Dakota and Minnesota. Precipitation in the weeks following planting in 2017 was near the 30-year average, but 2018 was dry in two of three environments. Stand establishment was a production challenge for sugarbeet producers in 2018 because of this dry period immediately following planting. Sugarbeet density in most environments were near the optimal range of 172 to 197 sugarbeets per 100 ft row (Cattanach 1994; Smith et al. 1990; M. Metzger 2018, personal communication), but the sugarbeet density at Nashua-2018 was 35% of the recommended density (Table 4). Sugarbeet density at Galchutt-2018 was non-uniform with frequent and random gaps, despite having a density at 85% of the recommended range. Hickson-2018 received 1/3rd inch of rain immediately after planting and one inch the week following planting that contributed to normal densities. Crop density is an important component of sugarbeet weed management (Dawson 1977) and the poor and non-uniform sugarbeet density at Nashua-2018 and Galchutt-2018 likely reduced the contribution of crop canopy for weed suppression.

Table 4. Primary weed species present and sugarbeet density at environments in 2017 and 2018.

Environment	Primary weed species	Sugarbeet density [a]
		# per 100 ft row
Renville-2017	Waterhemp	166
Wheaton-2017	Common lambsquarters	194
Hickson-2018	Waterhemp	187
Nashua-2018	Waterhemp	65
Galchutt-2018	Common lambsquarters	158

[a] Sugarbeet density is average number of sugarbeet plants per 100 ft of row.

Waterhemp density per plot. Cultivation immediately following herbicide application reduced waterhemp number of plants per plot by 50 to 75% across all environments when assessed 14 DAT (Table 5). Cultivated plots had 50 to 80% fewer waterhemp at 28 DAT per plot compared to non-cultivated plots across all environments. This result was expected because the cultivator with 15-inch wide shovels in 22-inch rows covered approximately 68% of field surface area. The primary value of cultivation is the physical removal of weeds that glyphosate will not control. Only plants that emerged prior to herbicide application were counted to determine the removal of herbicide resistant weeds. Herbicide treatment did not affect waterhemp counts in any environment season-long because most waterhemp biotypes in eastern North Dakota and Minnesota are glyphosate resistant.

Table 5. Effect of cultivation and herbicide on waterhemp density at Renville-2017, Hickson-2018, and Nashua-2018, 14 and 28 days after treatment (DAT). [a]

	Waterhemp counts, 14 DAT			Waterhemp counts, 28 DAT		
Main effects	Renville	Hickson	Nashua	Renville	Hickson	Nashua
Cultivation		------------# per plot------------			------------# per plot------------	
With cultivation	2 a	1 a	2 a	3 a	1 a	2 a
No cultivation	6 b	4 b	4 a	7 b	5 b	4 b
Herbicide						
Glyphosate	6 a	2 a	5 a	6 a	3 a	5 a
Glyphosate + S-metolachlor	3 a	1 a	3 a	5 a	3 a	3 a
Glyphosate + Outlook	3 a	3 a	1 a	3 a	2 a	2 a
Glyphosate + Warrant	4 a	2 a	3 a	5 a	2 a	4 a
Glyphosate + Treflan	5 a	4 a	1 a	7 a	3 a	3 a
Glyphosate + Ro-Neet	3 a	4 a	3 a	4 a	6 a	3 a
ANOVA		---------------*p value*---------------			-----------------*p value*---------------	
Cultivation	0.001	0.010	0.143	0.009	0.002	0.019
Herbicide	0.419	0.683	0.801	0.453	0.511	0.949
Cultivation * herbicide	0.118	0.534	0.950	0.170	0.667	0.985

[a] Means of a main effect within an environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

New waterhemp emergence control. Cultivation generally did not affect 'new waterhemp control' season-long at any environment (Table 6). Cultivation improved 'new waterhemp control' by 5% at Hickson-2018, 14 DAT, but had no effect 28 DAT. Cultivation improved 'new waterhemp control' by 4% at Renville-2017, 28 DAT, but had no effect 14 DAT. The differences were not considered season-long unless differences were seen at both evaluation dates because chloroacetamide herbicides have a 2 to 3 week effective period (Mueller et al. 1999). Cultivation did not affect 'new waterhemp control' at Nashua-2018. This occurrence is likely due to an interaction between sugarbeet stand density and the sugarbeet stage at which the treatments were applied. The treatments at Renville-2017 and Hickson-2018 were applied at the 8- to 10- and 6- to 8-leaf sugarbeet stages, respectively, while the treatments at Nashua-2018 were applied at the 4- to 6-leaf sugarbeet stage (Table 3). Sugarbeet density at Nashua-2018 was 65 sugarbeet per 100 ft row, while sugarbeet density at Renville-2017 and Hickson-2018 was 166 and 187 sugarbeet per 100 ft row, respectively (Table 4). The recommended sugarbeet density for optimal yield and weed suppression is 172 to 197 sugarbeet per 100 ft row (Cattanach 1994; Smith et al. 1990; M. Metzger 2018, personal communication). In an environment with a full and mature crop stand, cultivation would disrupt weed growth and allow the crop canopy to provide shade to suppress further weed emergence. While the crop canopy at Renville-2017 and Hickson-2018 were fuller and more mature than Nashua-2018, the differences were not sufficient to improve 'new waterhemp control' across both evaluation dates.

Residual herbicides applied with glyphosate generally improved 'new waterhemp control' relative to glyphosate alone in two of three environments (Table 6). Residual herbicides with glyphosate increased 'new waterhemp control' by 4 to 8% and Nashua-2018, 14 DAT and up to 13 to 15% at Renville-2017 and Nashua-2018, 28 DAT (Table 6). Herbicide treatment had no effect on 'new waterhemp control' at Renville-2017, 14 DAT or Hickson-2018 at any evaluation date. Herbicide treatment did not increase 'new waterhemp control' at Hickson-2018 at any evaluation date probably because the environment did not receive adequate precipitation until ten days after herbicide application. Chloroacetamide herbicides require 0.5 to 0.75 inches of precipitation to become activated into soil solution (Anonymous 2014, 2017). Chloroacetamide herbicides tended to provide numerically greater 'new waterhemp control' compared to Treflan and Ro-Neet, but statistical differences were not consistent. This is likely because chloroacetamide herbicides can be activated by rain alone, whereas Treflan and Ro-Neet require immediate soil-incorporation to become active.

Table 6. Effect of cultivation and herbicide on new waterhemp control at Renville-2017, Hickson-2018, and Nashua-2018, 14 and 28 days after treatment (DAT). [a]

	New waterhemp control, 14 DAT			New waterhemp control, 28 DAT		
Main effects	Renville	Hickson	Nashua	Renville	Hickson	Nashua
Cultivation		------------------%------------------			------------------%------------------	
With cultivation	89 a	100 a	97 a	91 a	96 a	95 a
No cultivation	91 a	95 b	96 a	87 b	96 a	93 a
Herbicide						
Glyphosate	83 a	97 a	91 b	81 c	97 a	83 c
Glyphosate + S-metolachlor	91 a	100 a	98 a	89 ab	99 a	96 ab
Glyphosate + Outlook	92 a	98 a	99 a	93 ab	100 a	98 a
Glyphosate + Warrant	88 a	100 a	99 a	94 a	98 a	98 a
Glyphosate + Treflan	92 a	98 a	95 ab	86 bc	94 a	89 bc
Glyphosate + Ro-Neet	94 a	94 a	99 a	92 ab	91 a	98 a
ANOVA		---------------*p value*----------------			-----------------*p value*-----------------	
Cultivation	0.082	0.009	0.328	0.006	0.867	0.423
Herbicide	0.061	0.150	0.004	0.011	0.066	0.004
Cultivation * herbicide	0.661	0.174	0.704	0.292	0.565	0.670

[a] Means within a main effect and environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

These results demonstrate the importance of mixing chloroacetamide herbicides with glyphosate to reduce the number of emerging waterhemp seedlings. Chloroacetamide herbicides in sugarbeet are applied in a 'layered' system where Dual Magnum is applied PRE and S-metolachlor, Outlook, or Warrant are tank mixed with glyphosate and applied twice POST to provide 'layered' residual control of small-seeded broadleaves until crop canopy closure (Peters et al. 2017). The use of this 'layered' system is important, as no herbicides currently labeled in sugarbeet provide season-long control of glyphosate-resistant waterhemp.

Sugarbeet producers have inquired if inter-row cultivation can be used to incorporate residual herbicides to improve their activity. Chloroacetamide herbicides need 0.5 to 0.75 inches of precipitation to become activated into soil solution (Anonymous 2014, 2017). In theory, cultivation could incorporate the herbicide into sub-surface soil moisture and activate the herbicide artificially in a dry season. Hickson-2018 received only 0.1 inches precipitation in the week following cultivation, while Renville-2017 and Nashua-2018 received over one inch. Cultivation did not enhance the activity of chloroacetamide herbicides at Hickson-2018 (Table 6) which had a dry period following herbicide application. More data is needed to form a reasonable conclusion, but this data suggests inter-row cultivation does not activate chloroacetamide herbicides and contribute to new waterhemp control in a dry season.

<u>Overall waterhemp control.</u> Cultivation improved 'overall waterhemp control' 6 to 12% across all environments and evaluation dates (Table 7). Data from 14 DAT and 28 DAT is representative of early to mid-season control, while data from 42 DAT is representative of season-long control. Cultivation increased 'overall waterhemp control' by 6% at Renville-2017, and 9 to 13% at Hickson-2018 and Nashua-2018, 42 DAT (Table 7). This data mirrors the waterhemp counts (Table 5) and new waterhemp control (Table 6) data since overall control is a visual summation of the previous two dependent variables. Cultivation significantly increased overall waterhemp control because it physically removed 50 to 75% of waterhemp plants 14 DAT (Table 5) and generally did not affect new waterhemp control. The primary benefit of cultivation is the physical removal of glyphosate resistant waterhemp with no apparent deleterious effects on future weed emergence.

Herbicide treatment did not affect 'overall waterhemp control' season-long at any environment (Table 7). Chloroacetamide herbicides with glyphosate tended to improve overall waterhemp control as compared to glyphosate alone, but no statistical difference was detected. Trifluralin (Treflan) and cycloate (RoNeet) provided similar overall waterhemp control compared to chloroacetamide herbicides. Differences were probably not detected in this data because glyphosate resistant waterhemp had already emerged in all environments at the time of treatment and soil-applied seedling inhibitor herbicides are ineffective for control of emerged waterhemp. Past research indicated mixing a chloroacetamide herbicide with glyphosate can improve season-long overall waterhemp control (Peters et al. 2017), but only if chloroacetamide herbicides are applied prior to waterhemp emergence.

Table 7. Effect of cultivation and herbicide on overall waterhemp control at Renville-2017, Hickson-2018, and Nashua-2018, 14, 28, and 42 days after treatment (DAT). [a]

	Overall control, 14 DAT			Overall control, 28 DAT			Overall control, 42 DAT		
Main effects	Renville	Hickson	Nashua	Renville	Hickson	Nashua	Renville	Hickson	Nashua
Cultivation		--------------%--------------			--------------%--------------			--------------%--------------	
With cultivation	93 a	97 a	96 a	91 a	93 a	90 a	84 a	91 a	83 a
No cultivation	85 b	91 b	88 b	83 b	85 b	83 a	78 b	79 b	72 b
Herbicide									
Glyphosate	87 a	95 a	88 a	83 a	89 a	81 a	78 a	84 a	71 a
Glyphosate + S-metolachlor	89 a	95 a	93 a	87 a	90 a	89 a	80 a	85 a	90 a
Glyphosate + Outlook	91 a	95 a	93 a	90 a	94 a	92 a	83 a	90 a	83 a
Glyphosate + Warrant	89 a	95 a	96 a	88 a	87 a	88 a	82 a	88 a	77 a
Glyphosate + Treflan	87 a	93 a	93 a	85 a	92 a	87 a	80 a	85 a	78 a
Glyphosate + Ro-Neet	92 a	90 a	90 a	90 a	83 a	83 a	81 a	76 a	67 a
ANOVA		-----------*p value*-----------			-----------*p value*-----------			-----------*p value*-----------	
Cultivation	0.002	0.004	0.006	0.011	0.004	0.058	0.008	0.002	0.041
Herbicide	0.452	0.752	0.676	0.344	0.624	0.778	0.864	0.517	0.243
Cultivation * herbicide	0.157	0.762	0.919	0.245	0.732	0.533	0.087	0.425	0.723

[a] Means within a main effect and environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

New common lambsquarters control and density. Cultivation improved 'new common lambsquarters control' by 8 to 9% at Wheaton-2017, 14 and 28 DAT (Tables 8 and 9). An interaction of cultivation by herbicide at 14 DAT at Wheaton-2017 demonstrates control with chloroacetamide herbicides generally was not improved with cultivation, but new common lambsquarters control with trifluralin and cycloate was improved with cultivation (Table 9). This result was expected because Treflan and Ro-Neet require immediate incorporation to provide effective control, while chloroacetamide herbicides are effective with timely precipitation alone. In contrast, cultivation decreased 'new common lambsquarters control' at 14 and 28 DAT by 10 to 15% at Galchutt-2018 (Table 8). Weed density data shows an increase in new common lambsquarters emergence from cultivation as cultivated treatments had nearly 100% more common lambsquarters per m^2 compared to non-cultivated treatments at Galchutt-2018, 28 DAT (Table 10).

The difference in 'new common lambsquarters control' from cultivation between Wheaton-2017 and Galchutt-2018 was likely due to site differences in sugarbeet density, date of application, and the sugarbeet stage at which the treatments were applied. Sugarbeet density at Wheaton-2017 was full and uniform with 194 sugarbeet per 100 ft row, while sugarbeet density at Galchutt-2018 was non-uniform and with 158 sugarbeet per 100 ft row (Table 4). Treatments were applied to 8- to 10-leaf sugarbeet at Wheaton-2017 and 4- to 6-leaf sugarbeet at Galchutt-2018 (Table 3). This difference in crop maturity between environments likely affected the role of canopy coverage on new common lambsquarters control. Based on calendar date, Galchutt-2018 was treated 18 days before Wheaton-2017 (Table 3). A cultivation/herbicide treatment later in the season would most likely have had less lambsquarters emergence following cultivation because common lambsquarters is an early emerging, C3, summer annual weed. An early cultivation with little canopy coverage would also have exposed the tilled seeds to light. Buhler (1997) reported common lambsquarters emergence increased nearly 250% when tillage was performed in the light compared to the dark. This implies producers should avoid cultivation until the crop canopy can provide shade to reduce the stimulation of common lambsquarters emergence.

Residual herbicides applied with glyphosate improved 'new common lambsquarters control' compared to glyphosate alone in one of two environments (Tables 8 and 9). Chloroacetamide herbicides provided greater 'new common lambsquarters control' compared to glyphosate alone and glyphosate plus Treflan or Ro-Neet at Wheaton-2017, 14 DAT (Table 9), but no difference was detected 28 DAT (Table 8). Residual herbicides applied with glyphosate gave significantly greater control of emerging lambsquarters compared to glyphosate alone in terms of both visible control and density measurements at Galchutt-2018, 14 and 28 DAT (Tables 8 and 10). Common lambsquarters likely responded differently to herbicide treatments at Wheaton-2017 and Galchutt-2018 due to differences in crop stage at time of treatment. Herbicide treatments were applied to 8- to 10-leaf sugarbeet at Wheaton in 2017 compared to 4- to 6-leaf sugarbeet at Galchutt in 2018 (Table 3). Crop canopy at Wheaton-2017 likely provided shade and suppressed weed emergence, reducing the effect of herbicide treatment.

Table 8. Effect of cultivation and herbicide on new common lambsquarters control at Wheaton-2017 and Galchutt-2017, 14 and 28 days after treatment (DAT). [a]

	New common lambsquarters control, 14 DAT	New common lambsquarters control, 28 DAT	
Main effects	Galchutt	Wheaton	Galchutt
Cultivation	--%--	-------------%-------------	
With cultivation	80 b	91 a	65 b
No cultivation	90 a	83 b	80 a
Herbicide			
Glyphosate	70 b	87 ab	47 b
Glyphosate + S-metolachlor	89 a	89 ab	80 a
Glyphosate + Outlook	90 a	90 a	82 a
Glyphosate + Warrant	87 a	92 a	75 a
Glyphosate + Treflan	85 a	80 b	70 a
Glyphosate + Ro-Neet	90 a	81 ab	81 a
ANOVA	*-p value-*	*----------p value----------*	
Cultivation	0.003	0.007	0.001
Herbicide	< 0.001	0.010	< 0.001
Cultivation * herbicide	0.320	0.223	0.132

[a] Means within a main effect and environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

Table 9. Interaction of cultivation by herbicide on new common lambsquarters control at Wheaton-2017, 14 days after treatment (DAT). [a]

Cultivation * herbicide interaction	New common lambsquarters control, 14 DAT Wheaton
With cultivation	--%--
Glyphosate	92 ab
Glyphosate + S-metolachlor	92 ab
Glyphosate + Outlook	93 a
Glyphosate + Warrant	94 a
Glyphosate + Treflan	92 ab
Glyphosate + Ro-Neet	92 ab
No cultivation	
Glyphosate	83 cd
Glyphosate + S-metolachlor	90 ab
Glyphosate + Outlook	90 ab
Glyphosate + Warrant	87 bc
Glyphosate + Treflan	76 de
Glyphosate + Ro-Neet	69 e
ANOVA	*-p value-*
Cultivation	0.002
Herbicide	0.084
Cultivation * herbicide	0.010

[a] Means not sharing any letter are significantly different by the t-test at the 5% level of significance.

Table 10. Effect of cultivation and herbicide on common lambsquarters density at Galchutt-2017, 14 and 28 days after treatment (DAT). [a]

Main effects	Common lambsquarters density, 14 DAT Galchutt	Common lambsquarters density, 28 DAT Galchutt
Cultivation	# per m^2	# per m^2
With cultivation	20 a	48 a
No cultivation	18 a	25 b
Herbicide		
Glyphosate	25 a	80 b
Glyphosate + S-metolachlor	12 a	34 a
Glyphosate + Outlook	14 a	32 a
Glyphosate + Warrant	13 a	28 a
Glyphosate + Treflan	27 a	24 a
Glyphosate + Ro-Neet	20 a	20 a
ANOVA	*-p value-*	*-p value-*
Cultivation	0.217	0.018
Herbicide	0.098	< 0.001
Cultivation * herbicide	0.620	0.099

[a] Means within a main effect and evaluation date column not sharing any letter are significantly different by the t-test at the 5% level of significance.

[b] Cultivation treatments were cultivated immediately after spray treatment.

[c] All herbicide treatments included ethofumesate, high surfactant methylated oil concentrate, and liquid ammonium sulfate solution.

<u>Overall common lambsquarters control.</u> Season-long 'overall common lambsquarters control' was the same in cultivation and herbicide treatments across environment and evaluation date (Table 11). Overall lambsquarters control tended to be greater from cultivation compared to no cultivation at 42 DAT at Wheaton-2017, but the differences were not statistically significant (*P* = 0.069). Overall lambsquarters control tended to be less from cultivation compared to no cultivation at 42 DAT at Galchutt-2018, but the differences were not statistically significant (*P* = 0.127). Overall control was a visual summation of new emergence and old growth control, so this data is consistent with new emergence control and weed density data where cultivation reduced new common lambsquarters control and increased weed density 28 DAT at Galchutt-2018 (Table 9). Herbicide treatments did not provide satisfactory season-long overall common lambsquarters control at either environment (Table 11). There was a numerical trend at Galchutt-2018 for residual herbicides with glyphosate providing 11 to 27% greater control 42 DAT, but this difference was not statistically significant (*P* = 0.085). This trend was not present at Wheaton-2017 where glyphosate alone gave similar overall control compared to glyphosate mixed with a residual herbicide (Table 11).

Table 11. Effect of cultivation and herbicide on overall common lambsquarters control at Wheaton-2017 and Galchutt-2018, 14, 28, and 42 days after treatment (DAT). [a]

	Overall control, 14 DAT		Overall control, 28 DAT		Overall control, 42 DAT	
Main effects	Wheaton	Galchutt	Wheaton	Galchutt	Wheaton	Galchutt
Cultivation	----------%----------		----------%----------		----------%----------	
With cultivation	98 a	100 a	96 a	83 a	78 a	73 a
No cultivation	96 a	100 a	94 a	87 a	70 a	80 a
Herbicide						
Glyphosate	99 a	100 a	99 a	77 a	73 a	60 a
Glyphosate + S-metolachlor	99 a	99 a	98 a	88 a	77 a	80 a
Glyphosate + Outlook	97 a	100 a	97 a	88 a	86 a	87 a
Glyphosate + Warrant	98 a	100 a	96 a	89 a	77 a	81 a
Glyphosate + Treflan	93 a	100 a	89 a	82 a	68 a	71 a
Glyphosate + Ro-Neet	95 a	100 a	90 a	86 a	66 a	81 a
ANOVA	-------*p value*-------		-------*p value*-------		-------*p value*-------	
Cultivation	0.363	0.363	0.446	0.158	0.069	0.127
Herbicide	0.438	0.438	0.057	0.229	0.162	0.085
Cultivation * herbicide	0.438	0.438	0.467	0.114	0.645	0.902

[a] Means within a main effect and environment column not sharing any letter are significantly different by the t-test at the 5% level of significance.

Conclusion: Should I cultivate immediately after herbicide application?

Cultivation immediately after herbicide application can improve overall waterhemp control because it physically removes waterhemp that glyphosate will not control. The cultivator removed 50 to 75% of herbicide resistant waterhemp, which resulted in 6 to 12% greater waterhemp control at the end of the season compared to not using a cultivator (Tables 5 and 7). Sugarbeet producers have asked if cultivation can be used to activate chloroacetamide herbicides in a dry year. Hickson-2018 was the only environment without activating precipitation in the ten days following herbicide treatment and 'new waterhemp control' was not enhanced with cultivation in that environment (Table 6). Further research is needed to strengthen this conclusion, but these data suggest that chloroacetamide activation cannot be achieved with a cultivator in a dry environment. Cultivation after herbicide application reduced common lambsquarters control at Galchutt-2018 compared to herbicide treatments without cultivation (Table 8). This is most likely due to insufficient sugarbeet canopy at time of cultivation to adequately shade the soil surface and suppress further common lambsquarters emergence. Cultivation provides a means of removing glyphosate resistant weeds from sugarbeet, but does not improve weed control compared to glyphosate application when weeds are susceptible to glyphosate.

Acknowledgements

We thank the Sugarbeet Research and Education Board of Minnesota and North Dakota for funding this research. We would like to thank the Southern Minnesota Beet Sugar Cooperative, Tim Backman, Mike Moen, and Troy Koltes for providing land to conduct the trials. We would also like to thank Peter Hakk, Alexa Lystad, Norm Cattanach, Charles Tvedt, Jewel Faul, and Jeff Stith for their help with establishing and maintaining these trials.

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SUGARBEET TOLERANCE AND ROTATIONAL CROP SAFETY FROM ETHOFUMESATE 4SC APPLIED POSTEMERGENCE

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Summary

1. Minimal to no visual sugarbeet injury was observed throughout the 2017 growing season. Sugarbeet growth, root yield, percent sucrose, and recoverable sucrose were not affected by ethofumesate or timing of ethofumesate application.
2. No adverse effects were observed throughout the 2018 growing season to rotational crop stand establishment or plant development from any treatment. Minimal to no visual crop injury was observed across all locations.
3. Environmental factors, such as weather, had a negative impact on yield at certain locations.
4. At Richville, MI, reduced grain moisture at harvest was observed in corn when ethofumesate was applied July 15 or later the previous growing season.

Introduction

Crop diversity is essential when practicing sustainable agriculture. Diversifying crop sequences introduces multiple growth cycles to a single field and aids in reducing inputs, such as pesticides, nutrients, etc. (Liebman and Dyck 1993). Decreased weed pressure is also a result of crop rotations, as well as increased crop yield (Peterson and Varvel 1989). Rotational benefits are evident when practicing a grass-legume rotation. In the Red River Valley, common rotational practices include alternating shallow and deep-rooted crops, as well as incorporating grain crops and legume crops (Tanner 1948). Sugarbeet is a deep-rooted crop grown in the Red River Valley. Herbicide residues from the previous growing season can potentially injure sensitive plants within the crop rotation (Sheets and Harris 1965). Ethofumesate is a herbicide labeled in sugarbeet for controlling grass and small-seeded broadleaf weeds (Peters and Lystad 2017) with historical reports of rotational crop injury (Schroeder and Dexter 1978). Willowood USA, a company that produces generic crop protection products for the agriculture industry, such as 'Ethofumesate 4SC', has increased the maximum label rates for post-emergence use in sugarbeet from 0.8 to 8 pt/A, along with decreasing the Pre-Harvest Interval (PHI) from 90 to 45 days.

The objective of this study was to evaluate crop safety from Ethofumesate 4SC at rates greater than 12 fl oz/A (0.8 pt/A) applied post-emergence in Roundup Ready (RR) sugarbeet in 2017 and the carry-over effects in wheat, corn, soybean, and dry bean in 2018.

Materials and Methods

Experiments were conducted near Crookston, Foxhome, and Lake Lillian, MN, Prosper, ND, and Richville, MI in 2017 and 2018. In 2017, the experimental area was prepared for planting by applying the appropriate fertilizer and tillage to each location. Sugarbeet was strategically planted at each location between the end of April and the beginning of May to achieve 9, 10, and 11-month crop rotation intervals in 2018 following ethofumesate treatment applications in 2017. Sugarbeet varieties included "SV36271RR", "BT80RR52", "HM4062", "BT9230", and "HM9619RR" at Prosper, ND, Crookston, MN, Foxhome, MN, Lake Lillian, MN, and Richville, MI, respectively.

Herbicide treatments included applications of ethofumesate at multiple rates and timings throughout the summer as well as an untreated control (Table 1). Applications made in June, July, and August simulated 11, 10, and 9-month crop rotation intervals, respectively. Applications at Prosper, ND were made with a bicycle sprayer early in the season and a backpack sprayer later in the season in 17 gpa spray solution through 8002 XR flat fan nozzles pressurized with CO_2 at 40 psi to all 6 rows of the 6-row plots 40 feet in length in each of 3 experimental areas. High-surfactant methylated oil concentrate (HSMOC) used in all treatments across all locations was a liquid formulation from Winfield United called 'Destiny HC'. Weeds, insects, and diseases were managed throughout the growing season.

Table 1. Treatment list in 2017.

Number	Treatment	Rate (fl oz)	Timing of application
1	Untreated control	0	
2	Etho[1]/etho/etho/etho	32/32/32/32	A=2-lf stage/ B=A+14 days / C=B+ 14 days / D=C+14 days
3	Ethofumesate	128	E=June 15
4	Ethofumesate	128	F=July 15
5	Ethofumesate	128	G=August 15

[1] Ethofumesate

Sugarbeet injury was a visual estimate of percent growth reduction of all 6 rows per plot. Sugarbeet was harvested from the experimental area in the fall and assessed for yield and quality. Sugarbeet that were not collected for yield assessment were removed from the experimental area to simulate harvest similar to a commercial field setting. Yield components were analyzed using SAS Data Management software PROC MIXED procedure to test for significant differences at p=0.05. Experimental design was randomized complete block with 6 replications.

Plots were prepared in the spring using a field cultivator. Tillage was applied in the same direction as the previous herbicide treatments to prepare the seed bed and incorporate recommended fertilizer for each crop. "DKC45-64RR2" corn, "AG0934RR2" soybean, and "Prosper" wheat was planted into three different experimental areas with planting rates of 31,000 seeds per acre, 150,000 seeds per acre, and 163 pounds per acre, respectively at Crookston, MN, Prosper, ND, Foxhome, MN, and Lake Lillian, MN. Crop varieties planted at Richville, MI were "Stine 9316" corn, "Stine 14RD16" soybean, and "Zenith" dry bean with planting rates of 32,000, 150,000, and 106,000 seeds per acre, respectively. Weeds, insects, and disease were managed throughout the 2018 growing season.

Crop injury was evaluated on May 29, June 9, and June 20, 2018 at Prosper; June 5, June 14, June 25, and July 9, 2018 at Crookston; May 31, June 14, and July 12, 2018 at Lake Lillian; and May 31, June 15, June 29, July 16, and August 14 at Richville, MI. All evaluations were a visual estimate of percent fresh weight reduction in the six treated rows compared to the untreated control. Stand was collected at the same time as the first visual injury evaluations by counting the first 10 feet of the middle two rows in each plot. The first 30 feet of each plot was counted in Richville, MI. Plant height was collected at the same time as the last visual injury evaluation by averaging multiple measurements recorded throughout the plot. Data were analyzed as previously described.

Results and Discussion

Sugarbeet Results:

Visual sugarbeet injury was negligible at any location throughout the growing season. Yield data were combined across locations (Table 2). No differences were observed across all locations. The average root yield, extractable sucrose, and percent sugar across locations were 28.5 ton/A, 8,499 pounds per acre (lb/A), and 16.6%, respectively.

Table 2. Ethofumesate effects on sugarbeet yield across locations in 2017.

Treatment[1]	Root Yield	Extractable Sucrose	Sugar
	-------------ton/A-----------	-------------lb/A-------------	--------------%---------------
Untreated Check	28.7	8,485	16.6
32 / 32 / 32 / 32 fl oz/A	28.4	8,532	16.7
June 15 at 128 fl oz/A	28.4	8,513	16.6
July 15 at 128 fl oz/A	28.9	8,610	16.6
Aug 15 at 128 fl oz/A	28.3	8,356	16.4
LSD (0.05)	NS	NS	NS

[1] Treatment – ethofumesate was applied at the rates given and at the timings referenced in Table 1.

Rotational Crop Results:

Wheat, soybean, corn and dry bean stand and development were not impacted by ethofumesate at 9, 10, and 11 months after application (Table 3). Neither a single application of ethofumesate at 128 fl oz/A nor 4 applications at 32 fl oz/A impacted crop injury or stand establishment at any location, regardless of crop.

Table 3. Ethofumesate impact on stand and development across rotational crops in 2018.

	Wheat		Soybean		Corn		Dry Bean	
Treatment[1]	Stand	Injury	Stand	Injury	Stand	Injury	Stand	Injury
	---yd^2---	---%---	---30'---	---%---	---30'---	---%---	---30'---	---%---
Untreated Check	63	0	159	0	44	0	157	0
32 / 32 / 32 / 32 fl oz/A	61	0	155	2	44	5	158	0
June 15 at 128 fl oz/A	60	3	155	2	45	0	153	0
July 15 at 128 fl oz/A	63	3	157	0	45	5	153	0
Aug 15 at 128 fl oz/A	62	0	160	2	45	5	154	0
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

[1]Treatment – ethofumesate was applied at the rates given and at the timings referenced in Table 1.

Wheat yield components were unaffected by ethofumesate at all rates and timings and were combined across all locations (Table 4). Test weight averaged 56.4 pounds per bushel (lb/bu) with moisture and yield averaging 14.1% and 40.6 bushels per acre (bu/A), respectively.

Table 4. Ethofumesate carry-over impact on wheat yield across locations in 2018.

Treatment[1]	Test Weight	Moisture	Yield
	---------------lb/bu------------	---------------%----------------	--------------bu/A------------
Untreated Check	56.7	13.7	40.0
32 / 32 / 32 / 32 fl oz/A	55.7	13.7	41.6
June 15 at 128 fl oz/A	57.0	14.1	40.1
July 15 at 128 fl oz/A	56.8	13.8	40.0
Aug 15 at 128 fl oz/A	55.6	14.1	41.4
LSD (0.05)	NS	NS	NS

[1]Treatment – ethofumesate was applied at the rates given and at the timings referenced in Table 1.

Ethofumesate had no effect on soybean yield at all rates and timings evaluated across all locations. Soybean grown at Lake Lillian, MN, Foxhome, MN and Richville, MI locations had an average moisture and yield of 13.3% and 64.6 bu/A, respectively (Table 5). Soybean yield data from Crookston, MN and Prosper, ND were evaluated separately due to hail storms in June and September, respectively, which decreased the average yield to 37.7 bu/A. However, analyzing soybean yield data when combined across all locations did not reveal any treatment differences.

Table 5. Ethofumsate carry-over impact on soybean yield in 2018.

	Foxhome, MN; Lake Lillian, MN; Richville, MI			Prosper, ND; Crookston, MN		
Treatment[1]	Test Weight	Moisture	Yield	Test Weight	Moisture	Yield
	-------lb/bu------	-----%-----	------bu/A------	-----lb/bu----	-------%------	----bu/A---
Untreated Check	54.3	13.3	63.6	55.4	13.6	38.0
32 / 32 / 32 / 32 fl oz/A	53.8	13.2	65.6	54.8	13.6	38.0
June 15 at 128 fl oz/A	54.2	13.2	64.0	54.4	13.6	36.9
July 15 at 128 fl oz/A	54.1	13.3	62.4	54.6	13.6	39.1
Aug 15 at 128 fl oz/A	55.2	13.3	67.4	54.8	13.5	36.6
LSD (0.05)	NS	NS	NS	NS	NS	NS

[1]Treatment – ethofumesate was applied at the rates given and at the timings referenced in Table 1.

Corn yield components were generally unaffected by ethofumesate at the rates and timings evaluated (Table 6). Corn in Richville, MI showed decreased grain moisture when ethofumesate applications of 128 fl oz/A were made in July and August. Corn grain from these two treatments averaged 15.7% moisture, compared to 16.5% in the untreated check plots. Corn yield data from Crookston, MN was not included in the combined location analysis due to damage from the hail storm in June. Crookston corn yield was 143 bu/A when averaged across treatments versus 229 bu/A when averaged across treatments and the other four locations. This was likely due to weather.

Table 6. Ethofumesate carry-over impact on corn yield in 2018.

	Prosper, ND, Foxhome, MN, Lake Lillian, MN, Richville, MI			Crookston, MN		
Treatment[1]	Test Weight	Moisture	Yield	Test Weight	Moisture	Yield
	--------lb/bu-------	---------%---------	-------bu/ac-------	-----lb/bu-----	-----%-----	--bu/A--
Untreated Check	54.8	18.4	231.8	61.7	15.5	136.7
32 / 32 / 32 / 32 fl oz/A	54.5	18.4	227.4	62.6	16.5	150.2
June 15 at 128 fl oz/A	55.2	18.3	226.2	61.6	15.6	156.1
July 15 at 128 fl oz/A	54.9	18.2	228.9	61.8	15.2	137.0
Aug 15 at 128 fl oz/A	55.3	17.9	229.2	62.6	16.1	136.7
LSD (0.05)	NS	NS	NS	NS	NS	NS

[1] Treatment – ethofumesate was applied at the rates given and at the timings referenced in Table 1.

Dry bean at Richville did not show any growth or developmental reductions from ethofumesate throughout the growing season. Moisture and yield, when averaged across treatment, were 15% and 31.1 bu/A, respectively (data not presented).

Conclusion

Previous studies report ethofumesate residue damaging rotational crops, especially wheat (Schweizer 1975). Ethofumesate in sugarbeet did not damage narrow leaf crops including wheat and corn planted in sequence with sugarbeet in our experiments. However, crop residue at application in previous experiments were different from our experiment. Ethofumesate was applied to bare soil in Schweizer's experiment, which differs from our experiment where ethofumesate was applied post-emergence to sugarbeet from 2- to 22-leaves. The lack of injury observed throughout the growing season is, however, consistent with ethofumesate applied post-emergence literature. Wang P et al. (2005) reported degradation of ethofumesate soil-applied was significantly slower than through plant metabolism. Gardner and Branham (2001) conducted a similar study which found ethofumesate dissipated much faster in plots when applied to turf grass rather than bare soil.

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