INTER-ROW CULTIVATION IMMEDIATELY FOLLOWING RESIDUAL HERBICIDE APPLICATION IN SUGARBEET

Nathan H. Haugrud[1] and Thomas J. Peters[2]

[1] Graduate Research Assistant, [2] Extension Sugarbeet Agronomist and Weed Control Specialist, North Dakota State University and University of Minnesota, Fargo, ND

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.

<u>New common lambsquarters control and density.</u> 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.

Overall common lambsquarters control. 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.

Literature Cited

Anonymous (2014) Warrant® herbicide product label. Monsanto Company Publication. St. Louis, Missouri.

Anonymous (2017) Outlook® herbicide product label. BASF Corporation Publication. Research Triangle Park, North Carolina.

Buhler DD (1997) Effects of tillage and light environment on emergence of 13 annual weeds. Weed Technol 11:496-501

Carmer SG, Nyquist WE, Walker WM (1989) Least significant differences for combined analyses of experiments with two- or three- factor treatment designs. Agron J 81:665-672

Cattanach AW (1994) Effect of greater than recommended plant populations on sugarbeet yield and quality in 1992 and 1993. Sugarbeet Research and Extension Reports 24:314-319

Dawson JH (1977) Competition of late-emerging weeds with sugarbeets. Weed Sci 25:168–170

Peters TJ, Lueck AB, Groen C (2017) Continued evaluation of the strategy for managing waterhemp in sugarbeet. Sugarbeet Research and Extension Reports 47:30-38

Smith LJ, Cattanach AW, Lamb JA (1990) Uniform vs variable in-row spacing of sugarbeet. Sugarbeet Research and Extension Reports 20:151-156