DELAYED CULTIVATION TO SUPPLEMENT CHLOROACETAMIDE HERBICIDES 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 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.

<u>Overall waterhemp control.</u> 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.

<u>*New common lambsquarters control.*</u> 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.

Literature Cited

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

Mueller TC, Shaw DR, Witt WW (1999) Relative dissipation of acetochlor, alachlor, metolachlor, and san 582 from three surface soils. Weed Technol 13:341-346

Oryokot JOE, Murphy SD, Swanton CJ (1997) Effect of tillage and corn on pigweed (*Amaranthus* spp.) seedling emergence and density. Weed Sci 45:120-126

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

Sivesend EC, Gaska JM, Jeschke MR, Boerboom CM, Stoltenberg DE (2011) Common lambsquarters response to glyphosate across environments. Weed Technol 25:44-50

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

Tharp BE, Kells JJ (2002) Residual herbicides used in combination with glyphosate and glufosinate in corn (*Zea mays*). Weed Technol 16:274-281