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Sugarbeet tolerance when dimethenamid-P follows soil-applied ethofumesate and *S*-metolachlor

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Research Article

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Abstract

Sugarbeet growers only recently have combined ethofumesate, *S*-metolachlor, and dimethenamid-P in a weed control system for waterhemp control. Sugarbeet plant density, visible stature reduction, root yield, percent sucrose content, and recoverable sucrose were measured in field experiments at five environments between 2014 and 2016. Sugarbeet stand density and stature reduction occurred in some but not all environments. Stand density was reduced with PRE application of *S*-metolachlor at 1.60 kg ai ha^{-1} and *S*-metolachlor at 0.80 kg ha^{-1} + ethofumesate at 1.68 kg ai ha^{-1} alone or followed by POST applications of dimethenamid-P at 0.95 kg ai ha^{-1}. Sugarbeet visible stature was reduced when dimethenamid-P followed PRE treatments. Stature reduction was greatest with ethofumesate at 1.68 or 4.37 kg ha^{-1} PRE and *S*-metolachlor at 0.80 kg ha^{-1} + ethofumesate at 1.68 kg ha^{-1} PRE followed by dimethenamid-P at 0.95 kg ha^{-1} POST. Stature reduction ranged from 0 to 32% 10 d after treatment (DAT), but sugarbeet recovered quickly and visible injury was negligible 23 DAT. Although root yield and recoverable sucrose were similar across herbicide treatments and environments, we caution against the use of *S*-metolachlor at 0.80 kg ha^{-1} + ethofumesate at 1.68 kg ai ha^{-1} PRE followed by dimethenamid-P at 0.95 kg ha^{-1} in sugarbeet.

Introduction

Ethofumesate is applied preplant or PRE at rates ranging from 1.12 to 4.37 kg ai ha^{-1} for control of monocotyledonous and dicotyledonous weeds in sugarbeet. Weed control following PRE application requires timely and adequate precipitation to activate herbicide into the weed seedling layer, because ethofumesate has low water solubility and is strongly adsorbed to soil (Shaner 2014; Schweitzer 1975). Ethofumesate uptake by weeds occurs by shoot (coleoptile or hypocotyl) and root adsorption and is rapidly translocated to foliage of susceptible weed species, remaining as ethofumesate through adsorption and translocation (Duncan et al. 1982a; Eshel et al. 1978). Several observations concluded that ethofumesate may affect surface waxes by inhibition of very-long-chain fatty acids, although the specific mechanism of herbicidal action is not fully known (Abulnaja et al. 1992; Devine et al. 1993). Ethofumesate soil-applied alone, soil-applied in mixtures, or mixed with glyphosate and applied POST controls agronomically and economically important weeds in sugarbeet across a range of environments (Dexter 1975; Ekins and Cronin 1972; Peters et al. 2016a; Schweizer 1979; Sullivan 1973; Sullivan and Fagala 1970). Field research from Kansas and Colorado in 1970 reported that 'NC 8438' (ethofumesate) controlled green foxtail [*Setaria viridis* (L.) P. Beauv.], barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], redroot pigweed (*Amaranthus retroflexus* L.), and common lambsquarters (*Chenopodium album* L.) (Sullivan and Fagala 1970). Likewise, ethofumesate controlled common lambsquarters and Pennsylvania smartweed [*Persicaria pensylvanica* (L.) M. Gomez] in Ohio and redroot pigweed and *Setaria* species in Idaho (Ekins and Cronin 1972).

One would anticipate a strong technical fit with ethofumesate in sugarbeet in Minnesota and eastern North Dakota, in that full-season residual activity of the herbicide (Elkins and Cronin 1972) is well suited for prairie soils. Still, ethofumesate has not been widely used. Survey of weed control and production practices indicated that the percentage of soil-applied ethofumesate use ranged from 1% to 22% in 2005 to 2014, with average annual use of 9% during that period (Carlson et al. 2015). Several factors may contribute to low adoption of ethofumesate. Ethofumesate is a relatively expensive treatment, especially at rates required for adequate weed control in Minnesota and eastern North Dakota soils (A. Dexter 2017, personal communication). Moreover, mechanical incorporation is often required to activate ethofumesate to achieve consistent weed control (Entz 1982). Additionally, McAuliffe and Appleby (1981) reported significant chemical degradation losses when ethofumesate was applied directly to the surface of dry soils without an activating precipitation event or irrigation event within 4 d of application.

Precipitation to activate soil-applied herbicides is inconsistent or limiting in May within the sugarbeet-producing region of Minnesota and eastern North Dakota. For example, average total May precipitation in Fargo, ND, is 66 mm, with daily precipitation totaling 6.4 mm or greater occurring only 3 d during the month (D. Ritchison 2017, personal communication). Growers typically use spring tillage, but the intended purpose is to create a smooth and firm seedbed at seeding depth to ensure successful stand establishment rather than herbicide incorporation (Cattanach 1995; Smith et al. 1990). Finally, ethofumesate potentially reduces stand density of spring-seeded barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), or wheat (*Triticum aestivum* L.) seeded as a companion crop with sugarbeet on 55% of the sugarbeet acreage in 2017 (Peters et al. 2016b; T. Grove, 2017, personal communication).

Waterhemp is a dioecious *Amaranthus* species spreading from its epicenter in the flood plains of southern and western Illinois (Sauer 1957) to many regions in the Midwest (Horak and Peterson 1995; Hinz and Owen 1997; Steckel et al. 2002). Glyphosate-resistant waterhemp populations were initially reported in Minnesota in 2007 and were reported across substantial sugarbeet acres in southwestern Minnesota in 2011 (Heap 2018; Stachler and Luecke 2011), as growers were slow to adopt alternative waterhemp control practices, increasing the incidence and severity of waterhemp infestation. Strategies to control glyphosate-resistant waterhemp biotypes included traditional soil-applied herbicides followed by POST herbicide mixtures with glyphosate. Treatments combining cycloate, ethofumesate, desmedipham, and phenmedipham with or followed by glyphosate improved waterhemp control compared to glyphosate alone (Stachler and Luecke 2011). However, sugarbeet injury was greater compared to glyphosate alone in the Roundup Ready® sugarbeet system, especially in west central Minnesota fields with variable soil textures.

Waterhemp germinates in spring or summer, develops through the summer, and sets seed to complete its life cycle in fall (Radosevich et al. 1997). However, waterhemp may emerge later in the growing season than other summer annual weeds, and the duration of emergence period is longer than most other annual broadleaf weeds. Hartzler et al. (1999) reported that the emergence characteristics of waterhemp are distinctly different from two historically important Iowa weeds, giant foxtail (*Setaria faberi* Herrm.) and velvetleaf (*Abutilon theophrasti* Medik.). Waterhemp emergence was 5 to 25 d later than velvetleaf emergence, and period of emergence was 8 to 13 d longer than that of giant foxtail. Werle et al. (2014) reported that waterhemp and redroot pigweed germinated later [10% emergence at 230 growing degree days (GDD)] and for an extended period (766 GDDs accumulated between 10% and 90% emergence) than common ragweed (*Ambrosia artemisiifolia* L.) and kochia [*Bassia scoparia* (L.) A.J. Scott] (10% emergence at 19 GDD and 108 GDDs accumulated between 10% and 90% emergence), two additional important weeds in sugarbeet production areas in Minnesota and eastern North Dakota.

Waterhemp control has been shown to extend later into the growing season, with sequential (often referred to as layered) applications of soil-residual herbicides compared to single applications. Steckel et al. (2002) reported that acetochlor, dimethenamid-P, or *S*-metolachlor PRE at the 0.66× rate in corn (*Zea mays* L.) followed by (fb) acetochlor, dimethenamid-P, or *S*-metolachlor POST at the 0.34× rate improved common waterhemp control compared to PRE only treatments at the 1× rate. Aulakh and Jhala (2015) reported that PRE application of sulfentrazone plus metribuzin fb glufosinate late POST in soybean [*Glycine max* (L.) Merr.] controlled common lambsquarters, waterhemp, eastern black nightshade (*Solanum ptychanthum* Dunal), and velvetleaf 69% to 78% at harvest. Broadleaf control improved to greater than 90% when acetochlor, pyroxasulfone, or *S*-metolachlor was mixed with glufosinate early POST following sulfentrazone + metribuzin PRE.

Single or layered application of chloroacetamide herbicides applied with glyphosate and ethofumesate POST improved waterhemp control in sugarbeet compared to three POST glyphosate and ethofumesate applications on approximately 14-d intervals (Peters et al. 2016a, 2017). However, chloroacetamide herbicides must be properly timed to sugarbeet growth stage and waterhemp emergence. Acetochlor, dimethenamid-P, and *S*-metolachlor are labeled for application at the two-leaf sugarbeet stage (Anonymous 2014, 2017, 2018), respectively. Sugarbeets seeded in early April reach the two-leaf stage on approximately May 10 in the southern Red River Valley and southwestern Minnesota or 5–10 d before waterhemp germination and emergence according to a waterhemp GDD model (Peters 2016). A layered chloroacetamide application may follow 14–21 d after the two-leaf stage application or when sugarbeets are at the six- to eight-leaf sugarbeet stage. Glyphosate and ethofumesate at 0.14 kg ha^{-1} are usually mixed with chloroacetamide herbicides for control of emerged weeds. Layered application of chloroacetamide herbicides at reduced rates in combination with glyphosate and ethofumesate improved waterhemp control 16% when evaluated in July and August compared to a single application of chloroacetamide herbicides at full rates in experiments averaged across three locations in 2016 and 2017 in sugarbeet in Minnesota and eastern North Dakota. (Peters et al. 2018).

A late spring may delay sugarbeet planting from mid-April until mid-May to early June in Minnesota and eastern North Dakota in some years. In this scenario, single or layered chloroacetamide application is not an effective weed management strategy, as waterhemp will emerge before sugarbeets reach the two-leaf stage or labeled timing for chloroacetamide POST application. Sugarbeet growers are advised to use cycloate or ethofumesate PPI or PRE. Additionally, growers may register with Syngenta (Syngenta Crop Protection LLC, Greensboro, NC) to use *S*-metolachlor (Dual Magnum®) PRE using a Section 24(c) Special Local Need label, whereby sugarbeet growers assume all risk of sugarbeet injury, sugarbeet root yield loss, and loss of sugarbeet crop at rates from 1.07 to 2.14 kg ha^{-1}, depending on soil organic matter (OM) content and soil texture (Pusino et al. 1992; Shaner et al. 2006).

Sugarbeet tolerance to soil-applied *S*-metolachlor has been inconsistent. Growth reduction of sugarbeet with *S*-metolachlor 2.25 kg ha^{-1} applied PPI averaged 6% and ranged from 0 to 14% in five environments between 1997 and 2002 (Dexter and Luecke 2004). However, injury averaged 44% and ranged from 20% to 73% in 2003. Injury was attributed to cool soils that slowed sugarbeet emergence plus abundant precipitation patterns immediately following sugarbeet planting and before sugarbeet emergence.

Research investigated sugarbeet tolerance from *S*-metolachlor PRE at reduced rates. Lueck (2017) reported that sugarbeet stand density (number of plants per 31-m row) decreased as *S*-metolachlor rate increased from 0.54 to 2.15 kg ha^{-1} across nine

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Table 1. Soil descriptions for environments in 2014, 2015, and 2016.

Environment	Soil series and texture	Soil subgroup	Organic matter	Soil pH
			%	
Amenia-2014	Bearden-Lindaas clay loam	Aerie Calciaquolls / Typic Argiaquolls	3.4	7.1
Amenia-2015	Bearden-Lindaas clay loam	Aerie Calciaquolls / Typic Argiaquolls	4.1	8.0
Belgrade-2015	Osakis loam	Oxyaquic Hapludalfs	3.2	6.6
Crookston-2015	Wheatville loam	Frigid Aeric Calciaquolls	2.6	8.5
Amenia-2016	Bearden-Lindaas clay loam	Aerie Calciaquolls / Typic Argiaquolls	2.7	7.4

environments. However, stand density with *S*-metolachlor at 0.54 kg ha^{-1} across environments or *S*-metolachlor across rates in a high-OM soils cohort was the same as stand density with the untreated control when environments were grouped according to OM as described by Pusino et al. (1992) and Shaner et al. (2006). Lueck (2017) surmised that *S*-metolachlor was adsorbed more greatly by high organic matter soils across climatic conditions. *S*-metolachlor at rates greater than 0.54 kg ha^{-1} reduced sugarbeet stand density, especially with precipitation greater than 40 mm 7 d after seeding (Bollman and Sprague 2008) in soil cohorts with less than 3.5% OM.

Our research indicates that *S*-metolachlor 0.54 kg ha^{-1} PRE fb layered chloroacetamide herbicides POST at reduced rates provides the best waterhemp control, especially when spring planting is delayed (Peters et al. 2018). This waterhemp control management plan combining multiple reduced-rate treatments beginning PRE through POST is conceptually similar to the split application at reduced-rate strategy developed with desmedipham and phenmedipham in sugarbeet in the 1990s (Dexter 1994). However, some growers in Minnesota and eastern North Dakota are unwilling to use *S*-metolachlor PRE (at any rate) because of variable soil types and concerns with sugarbeet injury. They have inquired about ethofumesate at reduced rates PRE fb reduced rates of chloroacetamide herbicides. Tolerance of sugarbeet to ethofumesate is related to application rate and soil type (Schweizer 1975). Sugarbeet tolerance to ethofumesate in Minnesota and eastern North Dakota is excellent at rates up to 4.37 kg ha^{-1}. However, field and laboratory research concludes that ethofumesate interacts with POST herbicides, including increased absorption or efficacy with herbicides applied sequentially (Duncan et al. 1982b; Kniss and Odero 2013) or tank-mixed with ethofumesate (Eshel et al. 1976). Ethofumesate applied PRE reduced epicuticular wax in cabbage (*Brassica oleracea* L.) (Leavitt et al. 1979) and onion (*Allium cepa* L.) leaves (Rubin et al. 1986). Additionally, ethofumesate altered the structure of cuticular waxes, increasing transpiration losses from the leaf surfaces (Leavitt et al. 1979) and increasing uptake of herbicides that followed in sequence with ethofumesate (Devine 1993). Decrease in chain length and wax modification was attributed to herbicide concentration but occurred even at sublethal rates (Bolton and Harwood 1976). Investigating crop response and evaluating potential sugarbeet tolerance risks from combining ethofumesate, *S*-metolachlor, and dimethenamid-P will benefit growers as they adopt additional waterhemp control strategies in sugarbeet. Therefore, the objective of this research was to determine if full or reduced rates of ethofumesate, *S*-metolachlor, and reduced-rate mixtures of ethofumesate = *S*-metolachlor applied PRE increase sugarbeet injury from dimethenamid-P applied POST.

Materials and methods

Field experiments were conducted in Minnesota and eastern North Dakota in 2014, 2015, and 2016. Location-year combinations (herein referred to as an environment) were Amenia-2014, Belgrade-2015, Crookston-2015, Amenia-2015, and Amenia-2016. The experiment was a randomized complete block design with four to six replications depending on environment. Experiments evaluated sugarbeet tolerance to PRE applications of ethofumesate at 1.68 and 4.37 kg ha^{-1}, PRE applications of *S*-metolachlor at 0.80 and 1.60 kg ha^{-1}, and PRE applications of ethofumesate at 0.80 kg ha^{-1} + *S*-metolachlor at 1.68 kg ha^{-1} alone or fb a POST application of dimethenamid-P at 0.95 kg ha^{-1}. A nontreated control was nested in the design for comparison. Detailed soil descriptions for each environment can be found in Table 1. Herbicide rates for sugarbeet were consistent with label recommendations for soil texture and OM content. Herbicide formulations and application rates are listed in Table 2. All treatments within an environment were applied as a single PRE application date or the same PRE application date followed by a POST application. All PRE herbicide applications were made within 1 d following sugarbeet seeding. POST applications were made at the two- to four-leaf sugarbeet growth stage. All treatments were applied using a bicycle wheel sprayer with a shielded boom to reduce particle drift at 159 L ha^{-1} spray solution through 8002 XR flat-fan nozzles (TeeJet Technologies, Glendale Heights, IL) spaced 51 cm apart and pressurized with CO_2 at 207 kPa to the center four rows of each plot. Sugarbeet was planted approximately 3 cm deep at 152,000 (±1,000) seeds ha^{-1} after fall chisel plowing and a single pass with a field cultivator with rolling baskets in spring. Individual plots were 3.4 m by 9.1 m and contained six rows on 56-cm spacing. Entire trial sites were kept weed-free with applications of glyphosate 1.27 kg ae ha^{-1}. Diseases and insects were controlled season-long at each environment. Precipitation data were collected from nearby weather stations operated by the North Dakota Agricultural Weather Network, Community Collaborative Rain, Snow and Hail Network, and the University of Minnesota Experiment Station.

Sugarbeet tolerance was evaluated by counting sugarbeet at the six-leaf stage and before harvest and by assessing visible sugarbeet injury between 7 and 13 d after treatment (DAT) (hereafter referred to as 10 DAT) and between 17 and 29 DAT (hereafter referred to as 23 DAT). Evaluation was a visual estimate of percentage injury ranging from 0% (no injury) to 100% (all plants completely eliminated) relative to the untreated check rows between individual plots. At harvest, sugarbeet was defoliated and harvested mechanically from the center two rows of each plot and weighed. A 10-kg sample was collected from each plot and analyzed for sucrose content and sugar loss to molasses by American Crystal Sugar Company (East Grand Forks, ND). Root yield (kg ha^{-1}), purity (%), and recoverable sucrose (kg ha^{-1}) were calculated using Equations (1–3).

$$\text{Root yield(kg/ha)} = \frac{\text{harvested plot weight(kg)}}{\text{hectare area of harvested plot}} \qquad (1)$$

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Table 2. Herbicides, herbicide rates, and application timing for the experiments.[a]

Common name	Trade name	Rate and application timing	
		PRE	POST
		kg ai ha^{-1}	
Ethofumesate	Nortron[b]	1.68	–
Ethofumesate	Nortron	4.37	–
S-metolachlor	Dual Magnum[c]	0.80	–
S-metolachlor	Dual Magnum	1.60	–
Ethofumesate + *S*-metolachlor	Nortron + Dual Magnum	1.68 + 0.80	–
Dimethenamid-P	Outlook[d]	–	0.95
Ethofumesate fb dimethenamid-P	Nortron fb Outlook	1.68	0.95
Ethofumesate fb dimethenamid-P	Nortron fb Outlook	4.37	0.95
S-metolachlor fb dimethenamid-P	Dual Magnum fb Outlook	0.80	0.95
S-metolachlor fb dimethenamid-P	Dual Magnum fb Outlook	1.60	0.95
Ethofumesate + *S*-metolachlor fb dimethenamid-P	Nortron + Dual Magnum fb Outlook	1.68 + 0.80	0.95

[a] Abbreviations: fb, followed by.
[b] Bayer Crop Science, Research Triangle Park, NC.
[c] Syngenta Crop Protection, Greensboro, NC.
[d] BASF Corp., Research Triangle Park, NC.

$$\text{Purity}(\%) = \frac{\%\ \text{sucrose content} - \%\ \text{sugar loss to molasses}}{\%\ \text{sucrose content}} \times 100 \quad (2)$$

$$\textit{Recoverable sucrose}(\text{kg/ha}) = \left(\frac{[(\%\ \text{purity}/100)\ \%\ \text{sucrose content}]}{100}\right) \times \text{root yield} \quad (3)$$

Data were subjected to ANOVA using the MIXED procedure in SAS 9.4 (SAS Institute, Cary, NC) to test for treatment effects and interactions using the appropriate expected mean square values as recommended by McIntosh (1983). Each location-year combination was considered an environment at random from a population as suggested by Blouin et al. (2011). Environments, replications, and all interactions containing these effects were designated random effects in the model; herbicide treatment and application timing were designated as fixed effects. Significantly different treatment means were separated using *t*-tests when data were found to be significantly different at the $P \leq 0.05$ level. Single degree-of-freedom contrasts were used to compare the effect of herbicide, herbicide rate, and application timing on sugarbeet density at the six-leaf stage and at preharvest, sugarbeet visible injury 10 and 23 d after POST treatment, and sugarbeet root yield, percent sucrose content, and recoverable sucrose ha^{-1} averaged across five environments.

Table 3. Planting dates, average stand density, and harvest dates, across environments.

Environment	Planting date	Sugarbeet average density	Harvest date
		No. plants per 31-m row	
Amenia-2014	May 17	172	September 3
Amenia-2015	April 16	211	September 17
Belgrade-2015	April 23	218	September 16
Crookston-2015	May 4	191	September 24
Amenia-2016	May 2	204	September 13

Results and discussion

Field growing conditions

Sugarbeet planting dates ranged between April 16 and May 17 across environments (Table 3), as is typical for sugarbeet production in eastern North Dakota and Minnesota. Sugarbeet are usually planted in rows spaced 56 cm apart to a depth of approximately 3 cm, with 11.4-cm spacing within the row or a density of 265 seeds (±10 seeds) per 31-m row (M. Metzger, 2018 personal communication). Seed attrition occurs after germination and before emergence, usually as a result of environmental and edaphic factors (Cattanach 1995; Smith et al. 1990; Campbell and Enz 1991). Emergence ranging from 181 to 206 plants per 31 m and preharvest density ranging from 172 to 197 plants per 31 m are considered ideal. Precipitation following seeding was near the 30-yr average in three environments: Amenia-2014, Belgrade-2015, and Crookston-2015. Precipitation was greater than normal at Amenia-2016 and less than normal at Amenia-2017 (Table 4). Average overall density at the six-leaf sugarbeet stage in the untreated control across environments was 205 sugarbeet plants per 31-m row and ranged from 189 to 220 (Table 5). Thus, differences in density in this experiment probably were directly due to treatment or an interaction of environment and treatment rather than environmental factors.

Sugarbeet stand density

Sugarbeet stand density at the six-leaf stage was influenced by herbicide treatment in certain environments (Table 5). There were no statistical differences between herbicides, herbicide rate, and/or application timing at three environments: Amenia-2015, Belgrade-2015, and Amenia-2016. Single degree-of-freedom comparisons were incomplete in the Amenia-2014 environment, as ethofumesate at 1.68 kg ha^{-1} was added to the experimental design beginning in 2015 at that location. Herbicide treatments affected sugarbeet density at the six-leaf stage at Crookston-2015 (Table 5). Single degree-of-freedom contrasts averaged across all PRE-only treatments (193 sugarbeet in 31-m row) and compared with PRE fb dimethenamid-P treatments (183 sugarbeet in 31-m row) was significant ($P = 0.0010$). Single degree-of-freedom contrasts comparing PRE-only treatments found that differences in stand densities were more strongly related to *S*-metolachlor PRE ($P = 0.0002$) than ethofumesate PRE ($P = 0.0422$), although

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Table 4. Sugarbeet planting date, days from planting (DAP) to first precipitation, cumulative precipitation, DAP to sugarbeet emergence, and average air temperature from planting to emergence by environment.

Location[a]	Planting date	Precipitation event[b]	Precipitation[c] 0–14 DAP	Precipitation 0–28 DAP	Precipitation 0–56 DAP	Days to emergence[d]	Average temperature[e]
		d	————	mm	————	d	C
Amenia-2014	May 17	2	27.4	62.2	151.1	9	16.4
Amenia-2015	April 16	3	20.1	95.3	179.2	17	9.8
Belgrade-2015	April 23	2	29.2	47.5	208.0	14	9.4
Crookston-2015	May 4	7	57.7	63.8	160.5	17	9.1
Amenia-2016	May 2	22	1.3	78.8	119.7	10	15.1

[a] Thirty-year average precipitation in May and June was 155 mm at Amenia, 205 mm at Belgrade, and 162 mm at Crookston.
[b] Number of days to first precipitation event totaling greater than 6.4 mm.
[c] Climatic data at Amenia were collected by the North Dakota Agricultural Weather Network; Belgrade climate data were collected by a local observer, Community Collaborative Rain, Snow and Hail Network; Crookston climate data were collected by the University of Minnesota Experiment Station.
[d] Sugarbeet days to emergence predicted by growing degree days accumulation and verified by visual observation.
[e] Average daily air temperature during the interval between planting and sugarbeet emergence.

Table 5. Sugarbeet plant density in response to herbicide treatments and environment at six-leaf stage. Includes average density, density as a percent of untreated control, and standard deviation of the mean averaged across environments.

Treatment	Rate	Timing	Amenia-2014	Amenia-2015	Crookston-2015	Belgrade-2015	Amenia-2016	Average	Percent of untreated	SD[a]
	kg ai ha^{-1}		————	————	Sugarbeet plants per 31-m row	————	————	————	%	
Untreated			189	212	198	220	208	205	–	12.3
Ethofumesate	1.68	PRE	–	217	201	207	207	–	–	–
Ethofumesate	4.37	PRE	182	217	197	213	202	202	98.7	13.7
S-metolachlor	0.80	PRE	174	211	202	222	210	204	99.3	18.2
S-metolachlor	1.60	PRE	145	209	184	227	203	193	94.4	31.1
Ethofumesate + *S*-metolachlor	1.68 + 0.80	PRE	171	208	184	213	208	197	96.0	18.3
Dimethenamid-P	0.95	POST	186	202	204	215	203	202	98.4	10.4
Ethofumesate fb dimethenamid-P	1.68 / 0.95	PRE fb POST	–	206	202	220	207	–	–	–
Ethofumesate fb dimethenamid-P	4.37 / 0.95	PRE fb POST	180	222	186	217	200	201	98.1	18.5
S-metolachlor fb dimethenamid-P	0.80 / 0.95	PRE fb POST	181	204	186	235	200	201	98.1	21.2
S-metolachlor fb dimethenamid-P	1.60 / 0.95	PRE fb POST	155	214	163	218	197	190	92.4	29.0
Ethofumesate + *S*-metolachlor fb dimethenamid-P	1.68 + 0.80 / 0.95	PRE fb POST	155	217	180	213	207	195	94.9	26.4
Average			172	211	191	218	204	199		
P value			0.0017	0.7469	<0.0001	0.6189	0.8188	0.3115	0.4601	
Contrasts[b]										
Untreated vs. treated			–	NS	NS	NS	NS	NS		
All PRE vs. all PRE fb dimethenamid-P			–	NS	**	NS	NS	NS		
Ethofumesate PRE vs. ethofumesate PRE fb dimethenamid-P			NS	NS	NS	NS	NS	NS		
S-metolachlor PRE vs. *S*-metolachlor PRE fb dimethenamid-P			–	NS	**	NS	NS	NS		
Ethofumesate at 1.68 kg ai ha^{-1} vs. ethofumesate at 4.37 kg ai ha^{-1}			*	NS	*	NS	NS	NS		
S-metolachlor at 0.80 kg ai ha^{-1} vs. *S*-metolachlor at 1.6 kg ai ha^{-1}			–	NS	**	NS	NS	*		
Ethofumesate + *S*-metolachlor PRE vs. ethofumesate + *S*-metolachlor fb dimethenamid-P			–	NS	NS	NS	NS	NS		
Dimethenamid-P vs. all PRE fb dimethenamid-P			–	NS	**	NS	NS	NS		

[a] Abbreviations: fb, followed by; NS, not significant; SD, standard deviation.
[b] Significance at P < 0.05 and P < 0.01 levels denoted by * and **, respectively.

both contrasts were significant. Single degree-of-freedom contrast comparing *S*-metolachlor PRE rate (0.80 or 1.60 kg ha^{-1} alone or fb dimethenamid-P) was highly significant ($P < 0.0001$) and significant across all environments ($P = 0.0178$). Numerically, *S*-metolachlor at 1.68 kg ha^{-1} had 18 fewer sugarbeet plants in a 31-m row than *S*-metolachlor 0.8 kg ha^{-1} in the Crookston-2015 environment.

Average sugarbeet stand density was reduced by harvest compared to the six-leaf evaluation across environments (Table 6). This observation is not unusual in sugarbeet production. Sugarbeet mortality occurs primarily from soilborne diseases such as *Rhizoctonia* root and crown root and *Aphanomyces* root rot. Loss of stand also occurs from sugarbeet plants spaced too close together (doubles), that do not grow and are not collected by harvest equipment. Sugarbeet density at harvest was least at Amenia-2014 and Amenia-2016 and greatest at Belgrade-2015 and Amenia-2015. Although herbicide treatments resulted in reduced sugarbeet density, differences were not statistically different. Amenia-2016 was an exception, where PRE herbicides fb dimethenamid-P reduced density by 14 sugarbeet plants compared with

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Table 6. Sugarbeet plant density in response to herbicide treatments and environment at preharvest. Includes average density, density as a percent of untreated control, and standard deviation of the mean averaged across environments.

Treatment	Rate	Timing	Amenia-2014	Amenia-2015	Crookston-2015	Belgrade-2015	Amenia-2016	Average	Percent of untreated	SD[a]
	kg ai ha^{-1}		Sugarbeet plants per 31-m row						%	
Untreated			161	197	185	218	159	184	–	24.7
Ethofumesate	1.68	PRE	–	197	184	218	168	–	–	–
Ethofumesate	4.37	PRE	154	200	181	215	156	181	98.4	26.9
S-metolachlor	0.80	PRE	157	191	172	223	169	181	99.0	25.7
S-metolachlor	1.60	PRE	129	192	160	219	158	172	93.3	34.7
Ethofumesate + *S*-metolachlor	1.68 + 0.80	PRE	141	193	170	215	146	173	94.1	31.3
Dimethenamid-P	0.95	POST	154	192	186	212	145	178	96.5	27.8
Ethofumesate fb dimethenamid-P	1.68 / 0.95	PRE fb POST	–	185	182	212	145	–	–	–
Ethofumesate fb dimethenamid-P	4.37 / 0.95	PRE fb POST	151	207	171	208	150	177	96.3	28.5
S-metolachlor fb dimethenamid-P	0.80 / 0.95	PRE fb POST	159	200	172	222	152	181	98.2	29.5
S-metolachlor fb dimethenamid-P	1.60 / 0.95	PRE fb POST	138	200	160	215	146	172	93.4	33.8
Ethofumesate + *S*-metolachlor fb dimethenamid-P	1.68 +0.80 / 0.95	PRE fb POST	131	204	164	212	146	172	93.1	35.6
Average			147	196	174	216	153	177		
P value			0.0066	0.3468	0.0002	0.8531	0.1789	0.0595	0.1634	
Contrasts[b]										
Untreated vs. treated			–	NS	*	NS	NS	NS		
All PRE vs. all PRE fb dimethenamid-P			–	NS	NS	NS	*	NS		
Ethofumesate PRE vs. ethofumesate PRE fb dimethenamid-P			NS	NS	NS	NS	NS	NS		
S-metolachlor PRE vs. *S*-metolachlor PRE fb dimethenamid-P			–	NS	NS	NS	*	NS		
Ethofumesate at 1.68 kg ai ha^{-1} vs. ethofumesate at 4.37 kg ai ha^{-1}			NS	*	NS	NS	NS	NS		
S-metolachlor at 0.80 kg ai ha^{-1} vs. *S*-metolachlor at 1.6 kg ai ha^{-1}			–	NS	*	NS	NS	*		
Ethofumesate + *S*-metolachlor PRE vs. ethofumesate + *S*-metolachlor fb dimethenamid-P			–	NS	NS	NS	NS	NS		
Dimethenamid-P vs. all PRE fb dimethenamid-P			–	NS	*	NS	NS	NS		

[a] Abbreviations: fb, followed by; NS, not significant; SD, standard deviation.
[b] Significance at P < 0.05 and P < 0.01 levels denoted by * and **, respectively

PRE-only herbicides alone (P = 0.0153). Single degree-of-freedom contrasts comparing PRE herbicides indicated that *S*-metolachlor rate partially explained density differences (P = 0.0475).

Herbicide treatment affected sugarbeet stand density at Crookston-2015 the most. Soil and climatic features occurred in Crookston-2015 that did not occur in the other environments. Soil OM was 2.6% at Crookston-2015, the lowest in the experimental area across environments. Average 24-h air temperature between planting and sugarbeet emergence was coldest (9.1 C), and the experimental area received the most precipitation from planting to 14 d after seeding (57.7 mm). Consequently, sugarbeet took a relatively long 17 d from seeding to emergence. Herbicide treatment also affected sugarbeet density at Amenia-2014 (numeric treatment means only). Planting date at Amenia-2014 was the latest, and neither soil OM nor climatic variables could explain sugarbeet stand loss.

Sugarbeet injury from *S*-metolachlor was previously reported by other researchers. Dexter and Luecke (2004) reported that sugarbeet injury in 2003 was greater than injury observed in the previous 11 yr of research (29 environments). The researchers did not identify a soil or climatic variable clearly linked to sugarbeet injury in 2003 but concluded that cold air temperatures (days from planting to two-leaf stage) and abundant precipitation may have contributed to injury.

Sugarbeet stand density and density reduction due to herbicide treatment were compared using numeric averages across environments. Density was measured by comparing number of sugarbeet in herbicide treatment and untreated control and averaged across

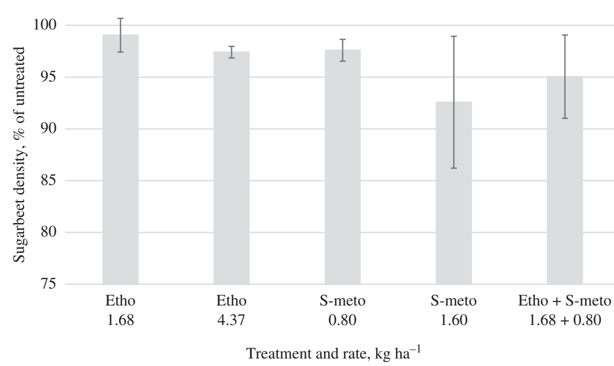

Figure 1. Comparison of sugarbeet density as a percent of untreated control (bar graph) and standard deviation of a sample mean (error bars), six-leaf stage, averaged across application timing and five environments. Etho, ethofumesate; *S*-meto, *S*-metolachlor.

environments (Tables 5 and 6). Stand density at both measurement intervals was least with *S*-metolachlor 1.60 kg ha^{-1} fb dimethenamid-P. Variation in sugarbeet density across environments and estimated as standard deviation of the mean ranged from 10.4 to 31.1 at the six-leaf stage and from 24.7 to 35.6 at harvest (Tables 5 and 6) and was greatest with *S*-metolachlor 1.60 kg ha^{-1} alone or *S*-metolachlor 1.60 kg ha^{-1} fb dimethenamid-P at the six-leaf stage and *S*-metolachlor 1.60 kg ha^{-1} alone or *S*-metolachlor 0.8 at kg ha^{-1} + ethofumesate at 1.68 kg ha^{-1} fb dimethenamid-P, preharvest. These results demonstrate that stand loss is not a

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Table 7. Sugarbeet visible stature reduction in response to herbicide treatment and environments 7 to 13 d after treatment (DAT).[a]

Treatment	Rate	Timing	Amenia-2014	Amenia-2015	Crookston-2015	Belgrade-2015	Amenia-2016	Average
	kg ai ha^{-1}		% Visible injury					
Untreated			0	0	3	9	8	4
Ethofumesate	1.68	PRE	–	0	0	11	13	–
Ethofumesate	4.37	PRE	18	8	5	17	5	10
S-metolachlor	0.80	PRE	14	8	0	16	10	9
S-metolachlor	1.60	PRE	23	18	17	16	20	18
Ethofumesate + *S*-metolachlor	1.68 + 0.80	PRE	21	11	0	7	13	10
Dimethenamid-P	0.95	POST	0	20	3	4	20	9
Ethofumesate fb dimethenamid-P	1.68 / 0.95	PRE fb POST	–	14	25	13	23	–
Ethofumesate fb dimethenamid-P	4.37 / 0.95	PRE fb POST	24	25	13	17	13	18
S-metolachlor fb dimethenamid-P	0.80 / 0.95	PRE fb POST	10	19	8	11	18	13
S-metolachlor fb dimethenamid-P	1.60 / 0.95	PRE fb POST	24	18	19	17	13	18
Ethofumesate + *S*-metolachlor fb dimethenamid-P	1.68 +0.801/ 0.95	PRE fb POST	19	32	23	27	18	24
P value			0.0030	<0.0001	<0.0001	0.0086	0.6020	<0.0001
Contrasts[b]								
Untreated vs. treated			–	**	*	NS	NS	**
All PRE vs. all PRE fb dimethenamid-P			–	**	**	NS	NS	**
Ethofumesate PRE vs. ethofumesate PRE fb dimethenamid-P			NS	**	**	NS	NS	**
S-metolachlor PRE vs. *S*-metolachlor PRE fb dimethenamid-P			–	NS	NS	NS	NS	NS
Ethofumesate at 1.68 kg ai ha^{-1} vs. ethofumesate at 4.37 kg ai ha^{-1}			NS	*	NS	NS	NS	NS
S-metolachlor at 0.80 kg ai ha^{-1} vs. *S*-metolachlor at 1.6 kg ai ha^{-1}			–	NS	**	NS	NS	*
Ethofumesate + *S*-metolachlor PRE vs. ethofumesate + *S*-metolachlor fb dimethenamid-P			–	*	**	**	NS	**
Dimethenamid-P vs. all PRE fb dimethenamid-P			–	NS	**	*	NS	**

[a] Abbreviations: fb, followed by; NS, not significant.
[b] Significance at P < 0.05 and P < 0.01 levels denoted by * and **, respectively.

treatment effect that will occur generally across environments. Rather, stand loss is an outcome from treatment that occurs in environmental conditions we do not fully understand. For example, sugarbeet density with herbicide treatments was greater than 93% when averaged across application timing. However, standard deviation of the sample ranged from 0.6 to 6.4 across environments (Figure 1), indicating that treatment interacted differently with features of the environment at each location.

Sugarbeet stature reduction

Sugarbeet visible stature reduction was evaluated 7–13 DAT (hereafter referred to as 10 DAT) and 17 to 29 DAT (hereafter referred to as 23 DAT) across environments (Tables 7 and 8). Stature reduction ranged numerically from 0 to 32%, 10 DAT and from 0 to 23%, 23 DAT. Injury was symptomology associated with chloroacetamide herbicides in sugarbeet including plant-to-plant variation in color and size of the foliage. Visual chlorosis occurred in moderately injured sugarbeet. Growth reduction was the more severe injury response relative to chlorosis especially 10 DAT. Although herbicide treatments caused stature reduction at each environment, treatment differences measured by single degree-of-freedom contrasts were environment dependent and were greatest at Amenia-2015 and Crookston-2015.

Single degree-of-freedom contrast indicated that visible stature reduction 10 DAT with PRE herbicide treatments followed by dimethenamid-P was greater than injury with PRE treatments alone, at Amenia-15 and Crookston-2015, highly significant ($P \leq 0.0001$ and $P \leq 0.0001$, respectively), and were highly significant across environments ($P \leq 0.0001$) (Table 7). Stature reduction was greatest with ethofumesate fb dimethenamid-P ($P = 0.0005$; $P \leq 0.0001$, and $P = 0.0006$) at Amenia-2016, Crookston-2015, and across environments, respectively, or ethofumesate + *S*-metolachlor PRE fb dimethenamid-P ($P = 0.0011$; $P = 0.0001$, and $P = 0.0005$) at Amenia-2016, Crookston-2015, and across environments, respectively. Stature reduction with ethofumesate occurred with the labeled and reduced labeled rates except at Amenia-2015 ($P = 0.037$), where ethofumesate 4.37 kg ha^{-1} caused greater visible injury than ethofumesate at 1.68 kg ha^{-1}. Stature reduction with *S*-metolachlor PRE fb dimethenamid-P was the same as *S*-metolachlor PRE alone. However, *S*-metolachlor at 1.6 kg ha^{-1} reduced sugarbeet stature compared with *S*-metolachlor at 0.8 kg ha^{-1} ($P = 0.01$) across environments.

Sugarbeet recovered rapidly from early-season growth inhibition. Sugarbeet injury 23 DAT ranged from 0 to 23% across treatments and averaged from 1% to 11% across environments (Table 8). As with evaluation 10 DAT, single degree-of-freedom contrasts indicated greater stature reduction with PRE herbicide treatments fb dimethenamid-P than with PRE herbicide treatments alone ($P = 0.0419$; $P = 0.0311$, and $P = 0.0334$ at Amenia-2015, Crookston-2015, and across environments, respectively. Stature reduction 23 DAT was mostly explained by the single degree-of-freedom contrast comparing *S*-metolachlor at the 1.60 kg ha^{-1} rate with *S*-metolachlor at the 0.80 kg ha^{-1} rate ($P = 0.0012$) across environments.

Ethofumesate PRE has a history of safe use in sugarbeet when rate is adjusted for soil texture (Dexter 1975; Ekins and Cronin 1972; Schweizer 1975,1979; Sullivan 1973; Sullivan and Fagala 1970).

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Table 8. Sugarbeet visible stature reduction in response to herbicide treatments and environments 17 to 29 d after treatment.[a]

Treatment	Rate	Timing	Amenia-2014	Amenia-2015	Crookston-2015	Belgrade-2015	Amenia-2016	Average
	kg ai ha^{-1}		% Visible injury					
Untreated			4	2	0	2	0	1
Ethofumesate	1.68	PRE	–	0	0	0	5	1
Ethofumesate	4.37	PRE	8	0	2	2	8	4
S-metolachlor	0.80	PRE	8	3	0	2	8	4
S-metolachlor	1.60	PRE	20	3	20	3	9	11
Ethofumesate + *S*-metolachlor	1.68 + 0.80	PRE	5	0	0	3	4	2
Dimethenamid-P	0.95	POST	10	5	2	0	15	6
Ethofumesate fb dimethenamid-P	1.68 / 0.95	PRE fb POST	–	3	0	3	16	6
Ethofumesate fb dimethenamid-P	4.37 / 0.95	PRE fb POST	21	4	4	2	9	8
S-metolachlor fb dimethenamid-P	0.80 / 0.95	PRE fb POST	11	3	2	0	6	5
S-metolachlor fb dimethenamid-P	1.60 / 0.95	PRE fb POST	20	7	23	3	4	11
Ethofumesate + *S*-metolachlor fb dimethenamid-P	1.68 +0.80 / 0.95	PRE fb POST	18	3	13	3	3	8
P value			0.0028	0.5176	<0.0001	0.9095	0.3392	0.0192
Contrasts[b]								
Untreated vs. treated			–	NS	*	NS	NS	*
All PRE vs. all PRE fb dimethenamid-P			–	*	*	NS	NS	*
Ethofumesate PRE vs. ethofumesate PRE fb dimethenamid-P			*	NS	NS	NS	NS	NS
S-metolachlor PRE vs. *S*-metolachlor PRE fb dimethenamid-P			–	NS	NS	NS	NS	NS
Ethofumesate at 1.68 kg ai ha^{-1} vs. ethofumesate at 4.37 kg ai ha^{-1}			NS	NS	NS	NS	NS	NS
S-metolachlor at 0.80 kg ai ha^{-1} vs. *S*-metolachlor at 1.6 kg ai ha^{-1}			–	NS	**	NS	NS	**
Ethofumesate + *S*-metolachlor PRE vs. ethofumesate + *S*-metolachlor fb dimethenamid-P			–	NS	*	NS	NS	NS
Dimethenamid-P vs. all PRE fb dimethenamid-P			–	NS	*	NS	NS	NS

[a] Abbreviations: fb, followed by; NS, not significant.
[b] Significance at $P < 0.05$ and $P < 0.01$ levels denoted by * and **, respectively.

Table 9. Sugarbeet root yield, sucrose content, and recoverable sucrose in response to herbicide treatment, averaged across five environments.[a]

Treatment	Rate	Timing	Root yield[b]	Sucrose	Recoverable sucrose
	kg ai ha^{-1}		Mg ha^{-1}	%	kg ha^{-1}
Untreated			65.9	15.4	9,327
Ethofumesate	1.68	PRE	67.2	15.6	8,598
Ethofumesate	4.37	PRE	66.7	15.7	8,611
S-metolachlor	0.80	PRE	67.3	15.3	8,431
S-metolachlor	1.60	PRE	65.9	15.3	8,228
Ethofumesate + *S*-metolachlor	1.68 + 0.80	PRE	66.1	15.4	8,377
Dimethenamid-P	0.95	POST	67.0	15.3	9,407
Ethofumesate fb dimethenamid-P	1.68 / 0.95	PRE fb POST	67.7	15.4	8,516
Ethofumesate fb dimethenamid-P	4.37 / 0.95	PRE fb POST	66.8	15.6	8,545
S-metolachlor fb dimethenamid-P	0.80 / 0.95,	PRE fb POST	68.5	15.6	8,792
S-metolachlor fb dimethenamid-P	1.60 / 0.95	PRE fb POST	67.3	15.4	8,494
Ethofumesate + *S*-metolachlor fb dimethenamid-P	1.68 +0.80 / 0.95	PRE fb POST	64.4	15.6	8,243
P value treatment			0.5474	0.1119	0.4790

[a] Abbreviations: fb, followed by.
[a] Root yield reported in megagrams (Mg) ha^{-1}; 1 Mg = 1,000 kg = one metric ton.

Likewise, dimethenamid-P POST alone at 0.72 to 1.43 kg ha^{-1} has been safely applied to sugarbeet at the two- to four-leaf stage (Rice et al. 2002; Bollman and Sprague 2008; Peters et al. 2017, 2018). However, previous research did not evaluate ethofumesate followed by dimethenamid-P as a weed control treatment. Sugarbeet stature reduction was observed when ethofumesate + desmedipham POST followed ethofumesate and trichloroacetic acid (TCA) PRE (Duncan et al. 1982b). Duncan et al. (1982b) reported that ethofumesate applications reduced deposition of major wax components, resulting in increased absorption of foliar-applied herbicides following ethofumesate PRE. Injury from herbicide combinations occurred with other herbicide chemicals. Dexter (1994) reported that sugarbeet treated with soil-applied EPTC and cycloate were more susceptible to injury from desmedipham than sugarbeet not treated with soil-applied herbicide. The authors did not indicate if sugarbeet injury was attributed to reduced wax in the cuticle or increased absorption but recommended PRE herbicide should be considered when selecting desmedipham rate POST to reduce the risk of excessive sugarbeet injury.

Sugarbeet stature reduction with herbicide treatments occurred primarily at the Amenia-2015 and Crookston-2015 environments, although visible injury was observed at every location in this experiment. Significance of the treatment effects at the

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Amenia-2015 and Crookston-2015 environments influenced stature reduction across all environments. Ethofumesate or ethofumesate + *S*-metolachlor PRE fb dimethenamid-P and *S*-metolachlor at 1.6 kg ha^{-1} PRE reduced sugarbeet stature 10 DAT across environments compared to ethofumesate or ethofumesate + *S*-metolachlor PRE alone and *S*-metolachlor at 0.8 kg ha^{-1} PRE. These herbicide treatments may cause significant sugarbeet stature reduction injury that should be considered when planning a weed management system, even though sugarbeet injury was less at 23 DAT.

Sugarbeet root yield, sucrose content, and recoverable sucrose

Sugarbeet root yield did not differ significantly across environments, so data were combined over environments. Herbicides applied PRE, POST, or PRE fb POST did not affect sugarbeet root yield, sucrose content, or recoverable sucrose (Table 9), even though herbicide treatments reduced early-season sugarbeet density in some environments and tended to reduce stature across all environments. However, reduced rates of *S*-metolachlor + ethofumesate fb dimethenamid-P tended to reduce root yield and recoverable sugar. Sugarbeet root yield and recoverable sucrose from *S*-metolachlor 0.8 kg ha^{-1} + ethofumesate 1.68 kg ha^{-1} PRE fb dimethenamid-P numerically was less at four of five environments compared to *S*-metolachlor + ethofumesate PRE alone.

Sugarbeet recovery from early-season stature reduction caused by soil-applied herbicide treatments has been reported by other researchers. Smith and Schweizer (1983) reported that sugarbeet can recover from stature reduction caused by herbicides applied PRE and POST in spring and early summer and yield similarly to weed-free treatments. Likewise, Bollman and Sprague (2007) reported that sugarbeet overcame injury caused by PRE herbicides applied under different tillage regimes and closed canopy and produced recoverable sucrose the same as untreated control comparisons. Sugarbeet also compensate for stand loss. Khan and Hakk (2016) reported no differences in root yield or recoverable sucrose among plant densities ranging from 100 to 250 sugarbeet plants per 31-m row at 56-cm spacing between rows. However, individual sugarbeet size and weight from treatments at 50 sugarbeet plants per 30-m row (1.86 kg) was greater than average mean root weight of individual sugarbeet treatments from 150 and 200 sugarbeet plants per 30-m row (0.88 kg). That being said, sugarbeet stand density loss or stature reduction delay row closure and presumably increase the likelihood of late-season weed germination and emergence that may indirectly affect root yield and recoverable sucrose (Wilson 1999).

Our research concludes that sugarbeet growers need to take precautions before using PRE and POST soil residual herbicides in a weed management system, even though sugarbeet tolerance generally has been acceptable with soil-residual herbicides applied singly. Our research supports the use of *S*-metolachlor PRE but at rates up to 0.80 kg ha^{-1} when dimethenamid-P at 0.95 kg ha^{-1} or greater follows in a weed control system. *S*-metolachlor at 1.60 kg ha^{-1} followed by dimethenamid-P reduced sugarbeet stand density in some environments. Unfortunately, we do not understand the environmental trigger causing sugarbeet stand loss from *S*-metolachlor at rates greater than 0.80 kg ha^{-1} when dimethenamid-P follows.

Our research suggests caution when using ethofumesate or ethofumesate + metolachlor PRE fb dimethenamid-P POST at 0.95 kg ha^{-1} or greater. Sugarbeet density loss and stature reduction generally was negligible with ethofumesate, ethofumesate + *S*-metolachlor PRE or with dimethenamid-P POST alone. However, stature reduction was consistently observed across environments, especially at 10 DAT, when dimethenamid-P at 0.95 kg ha^{-1} POST followed ethofumesate or ethofumesate + *S*-metolachlor. These observations of greater phytotoxicity are consistent with research documenting increased POST herbicide uptake when following (Devine et al. 1993; Duncan et al. 1982b; Rubin et al. 1986) or when tank-mixed with ethofumesate (Eshel et al. 1976). Whether observed increased absorption results in increased phytotoxicity probably depends on the herbicide mode of action or environmental conditions (Kniss and Odero 2013; Rubin et al. 1986).

Dimethenamid-P followed ethofumesate, *S*-metolachlor, or ethofumesate + *S*-metolachlor in these experiments. Sugarbeet tolerance from other chloroacetamide herbicides following ethofumesate, *S*-metolachlor, or ethofumesate + *S*-metolachlor was not evaluated in these experiments. Likewise, sugarbeet tolerance from dimethenamid-P or other chloroacetamide herbicides split-applied at reduced rates and following ethofumesate, *S*-metolachlor, or ethofumesate + *S*-metolachlor was not evaluated in these experiments.

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