ENVIRONMENTAL CONDITIONS, VARIETY, AND APPLICATION TIMING INFLUENCE ON S-METOLACHLOR SUGARBEET CROP SAFETY

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Andrew Bruce Lueck

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Andrew Bruce Lueck

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Thomas Peters
Chair

Dr. Thomas DeSutter

Dr. Ted Helms

Dr. Kirk Howatt

Dr. Rich Zollinger

Approved:

4-17-17
Date

Dr. Harlene Hatterman-Valenti
Department Chair

ABSTRACT

Glyphosate-resistant weeds in North Dakota and Minnesota sugarbeet growing regions have necessitated research on S-metolachlor. S-metolachlor can be applied early-postemergence in sugarbeet but has not been labeled preemergence as reductions in sugarbeet safety have been observed. Field and growth chamber experiments were conducted to determine crop safety from S-metolachlor applied preemergence. S-metolachlor readily bonds to soil clay and organic matter. High clay and organic matter soils buffer S-metolachlor from soil solution and increase crop safety. Sugarbeet emergence was affected by soil series, temperature, and soil water, but was not affected by S-metolachlor or S-metolachlor rate. S-metolachlor affected sugarbeet growth, but a rate of 0.54 kg ai ha^{-1} was safe across soils and growing conditions. No differences in varietal tolerance were observed. S-metolachlor applied immediately after planting or at the cotyledon and two-leaf stage injured sugarbeet less than application 3, 5, or 7 d after planting.

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF FIGURES

Figure Page

LIST OF APPENDIX TABLES

INTRODUCTION

Herbicides affect crop yield by reducing or eliminating competition from weeds. The effects of herbicide on yield are positive in most situations, but may also negatively affect crop yield through reduced crop safety. Herbicides used in sugarbeet (*Beta vulgaris L.*) are commonly adapted from other crops and do not always have adequate crop safety. Residual herbicides are soil-applied herbicides used to control emerging weeds. Residual herbicides can be applied preplant-incorporated, preemergence, or early-postemergence. S-metolachlor (Dual Magnum, Syngenta Crop Protection, LLC, Regional Headquarters, P.O. Box 18300, Greensboro, NC 27409) is one of two herbicides applied preemergence in sugarbeet.

S-metolachlor was approved for preplant-incorporated, preemergence, and early-postemergence use on sugarbeet in 2003 (Dexter 2004). However, use preplant-incorporated or preemergence in sugarbeet was temporary due to excessive sugarbeet injury observed in 2003 in some fields treated with S-metolachlor. As a result, Syngenta, manufacturer of S-metolachlor, withdrew preplant-incorporated and preemergence use of S-metolachlor on sugarbeet from the master label. S-metolachlor is currently approved for preemergence use in sugarbeet through a section 24C state local needs supplemental label in Minnesota and North Dakota whereby the farmer assumes liability for product performance.

The presence of glyphosate-resistant common and tall waterhemp (*Amaranthus rudis Sauer*) and (*Amaranthus tuberculatus (Moq.) Sauer*) in sugarbeet, and possible introduction of glyphosate-resistant palmer amaranth (*Amaranthus palmeri S. Wats.*), may require greater use of soil-applied herbicides for control of amaranth species in sugarbeet. Universities advocate the use of chloroacetamide herbicides preemergence followed by a repeat application early postemergence for season-long waterhemp control.

S-metolachlor applied preemergence at 1.42 kg ai ha^{-1} provided 95% common waterhemp control 28 days after application in corn (Steckel et al 2002). S-metolachlor applied early-postemergence at 1.35 and 1.80 kg ai ha^{-1} in sugarbeet provided 65% and 93% waterhemp control, respectively (Peters et al. 2017). However, requirements are for sugarbeet to be at the 2-leaf stage and for S-metolachlor to be rain-fall activated for effective waterhemp control. A weed management system that combines preemergence and early-postemergence application of residual herbicide may provide moreconsistent and effective waterhemp control in sugarbeet. In the same experiment, Peters et al. (2017) found that waterhemp control increase from 64% to 100% when S-metolachlor was applied preemergence at 0.54 kg ai ha^{-1} followed by a repeat application of S-metolachlor at 1.35 kg ai ha^{-1} early-postemergence. Additionally, Peters et al. (2017) found that S-metolachlor applied preemergence followed sequentially by other chloroacetamide herbicides applied early-postemergence provided greater waterhemp control compared to a single early-postemergence application of other chloroacetamide herbicides. Sugarbeet injury from S-metolachlor was negligible from preemergence and early-postemergence applications alone and preemergence followed by early postemergence applications. Grower confidence in crop safety from S-metolachlor use preemergence, at 0.54 kg ai ha^{-1} is limited.

The purpose of this research was to evaluate crop safety from S-metolachlor applied preemergence in sugarbeet and determine biological and environmental influences that may increase S-metolachlor sugarbeet injury. Objectives were: a) to determine a preemergence S-metolachlor rate that provided adequate crop safety across different environments; b) investigate the contribution of temperature, soil water, soil texture, soil organic matter, and precipitation on S-metolachlor sugarbeet crop safety; c) determine sugarbeet varietal response to S-metolachlor;

and d) determine effects of S-metolachlor application timing on sugarbeet crop safety. The hypothesis was that S-metolachlor applied preemergence at rates between 0 and 2.15 kg ai ha^{-1} would not affect sugarbeet yield or quality across different soil textures and environments. The goal of the study was to provide a greater understanding of sugarbeet crop safety related to preemergence applied S-metolachlor.

CHAPTER 1. LITERATURE REVIEW

Sugarbeet is an economically important crop (Kniss et al. 2012). In 2014, 28.4 million tons of sugarbeet were produced from 464,260 hectares in ten states, including California, Colorado, Idaho, Michigan, Minnesota, Montana, Nebraska, North Dakota, Oregon, and Wyoming (USDA-ERS 2017). The Red River Valley region of western Minnesota and eastern North Dakota is the largest sugarbeet production area in the United States. Since 2010, the region has averaged 275,000 hectares of sugarbeet, or about 57% of the total planted sugarbeet acreage in the United States. In the 2016 crop year, sugarbeet annual cash receipts were 2.9 billion dollars as compared to sugar cane that had 1.0 billion dollars (USDA-ERS 2017).

Sugarbeet, like other cropping systems, has pests that reduce yield and quality which includes insects, diseases, and weeds. Weeds are present in most sugarbeet fields and cause significant yield loss when not controlled. Weeds that grow taller than sugarbeet cause greater yield loss than weeds that do not grow beyond the sugarbeet canopy and, if not removed, yield losses can be exceptional (Schweizer and Dexter 1987).

The extent of yield loss depends upon competitive ability of the weeds, weed density, and the length of time weeds compete with sugarbeet (Cioni and Maines 2010). Dense weed populations that are not controlled can out-compete sugarbeet and may result in total yield loss (Schweizer and Dexter 1987). The most competitive weeds are annual, broadleaf species that emerge before, simultaneously, or shortly after the sugarbeet and grow taller than the crop and produce dense shade (Cioni and Maines 2010). Weed species vary in competitive ability, with larger and taller weeds causing more loss per plant than smaller and shorter weeds (Dexter 2004). Weeds also vary in competitive ability in different environments, since one environment may favor the weed more than the sugarbeet, while another environment may favor the sugarbeet more than the weed. Consequently, as the density of weeds increases, light becomes more limited and sugarbeet root yield decreases (Cioni and Maines 2010). Evans (1983) found that redroot pigweed (*Amaranthus retroflexus L.*) at a density of 3 plants per meter of row caused a 42% decrease in sugarbeet root yield and extractable sucrose. A similar study by Schweizer and Lauridson (1985) concluded powell amaranth (*Amaranthus powellii S. Wats.*) at densities of 6, 12, 18, and 24 plants per 30 meters of row reduced sugarbeet yields 8, 14, 24, and 25%, respectively.

Schweizer and Lauridson (1985) noted 61, 20, 21, and 12% sugarbeet yield reductions caused by common sunflower (*Helianthus annuus L.*), kochia (*Chenopodiaceae*), common lambsquarters (*Chenopodium album L.*), and velvetleaf (*Malvaceae*), respectively, at densities of 10 plants per 30 meters of row. Volunteer crops also affect sugarbeet extractable sucrose yield (Kniss et al. 2012). Kniss et al. (2012) indicated a reduction in sugarbeet extractable sucrose by 19% for each volunteer corn (*zea mays L.*) plant per meter squared up to 1.7 plants per meter squared.

Cioni and Maines (2010) indicated duration of weed infestations can also affect sugarbeet yield and, when present for the entire growing season, results in significant crop loss when no control measures are employed. Sugarbeet exposed to 30 weeks of uncontrolled common lambsquarters resulted in a 94% root yield reduction (Dawson 1965). Weeds that emerge eight weeks after planting, and particularly after the sugarbeet plants have eight or more leaves, reduce yield less (Scott et al. 1979). Weed control through 10 and 12 weeks after planting is critical, and any weed that emerges after the critical period compete with the sugarbeet canopy for light (Dawson 1965).

Weed control was a costly and necessary part of sugarbeet production before the introduction of glyphosate-resistant sugarbeet (Kniss et al. 2004). An economic analysis of conventional and glyphosate-resistant sugarbeet varieties indicated increased revenue of \$385 ha^{-1} with glyphosate-resistant varieties due to improved weed control, reduced herbicide cost, and increased sugarbeet yields (Kniss et al. 2004). Kniss et al. (2004) concluded introduction of glyphosate-resistant sugarbeet into the U.S. market would allow sugarbeet producers a new and effective weed management tool. Commercial planting of glyphosate-resistant sugarbeet began in 2008 and was rapidly adopted by growers in Minnesota and North Dakota (Carlson et al. 2008). Sugarbeet growers in Minnesota and North Dakota grew other glyphosate-resistant crops in rotation with glyphosate-resistant sugarbeet (Lueck et al. 2017). However, there were unintended effects from use of multiple glyphosate-resistant crops which included shifts in weed population and the onset of weed resistance in species such as waterhemp (Culpepper 2006; Wilson et al. 2007).

Glyphosate was the most common herbicide treatment used by sugarbeet growers in Minnesota and North Dakota in 2016 (Lueck et al. 2017). Sugarbeet growers in Minnesota and North Dakota averaged 2.38 applications of glyphosate products to glyphosate-resistant sugarbeet in 2016. Sugarbeet growers in Minnesota and North Dakota have relied on glyphosate for waterhemp control, not only in sugarbeet, but in crops grown in sequence or rotation with sugarbeet. However, there now are many fields with multiple biotypes of waterhemp with populations ranging from susceptible biotypes to biotypes with moderate or full resistance to glyphosate. The percentage of sugarbeet growers in Minnesota and North Dakota that indicated waterhemp as the worst weed problem in sugarbeet increased from 11% in 2011 to 37% and 46%, respectively, in 2014 and 2015 (Lueck et al. 2017). Glyphosate-resistant waterhemp populations were greatest in southern and west central Minnesota and in southeastern North Dakota in 2016.

Waterhemp is a troublesome weed in most crops in the midwestern United States and has developed resistance to glyphosate herbicide (Steckel et al. 2002). Waterhemp is difficult to control due to delayed emergence, genetic variability, and ability to readily adapt to changes in agronomic practices and weed control techniques. Waterhemp seed production from plants grown at low densities and in competition with soybean can produce over 50,000 seeds per plant (Bensch et al. 2003). Waterhemp seed production was dependent on emergence date and soil fertility conditions (Uscanga-Mortera et al. 2007).

Weed control recommendations in sugarbeet are based on the requirement that sugarbeet must maintain an advantage over weeds early in the season (Cioni and Maines 2010). In sugarbeet, current agronomic recommendations are to control weeds from planting until row-closure. Weed control is difficult during this period because sugarbeet seedlings have a low tolerance to most herbicides. However, herbicides continue to be an effective method for weed control in sugarbeet across the Minnesota and North Dakota sugarbeet growing region. One class of herbicides are the soil-applied residual herbicides which control emerging weeds.

Preemergence residual herbicides are applied to the soil surface after the sugarbeet is planted, but before the sugarbeet emerges (Cioni and Maines 2010). Several factors should be considered when selecting preemergence residual herbicides, and the spectrum of weeds to be controlled is the first factor to be considered. S-metolachlor and ethofumesate are the only residual preemergence herbicides labeled in sugarbeet for broadleaf weed control. Control of glyphosate-resistant waterhemp populations increased with the addition of S-metolachlor applied preemergence (Peters et al. 2017). S-metolachlor applied preemergence at 1.42 kg ai ha^{-1}

provided 95% waterhemp control 28 days after application in corn (Steckel et al 2002). Results also suggest waterhemp control can be extended later into the growing season with repeat applications of residual herbicides. Waterhemp density was reduced following a repeat application of S-metolachlor as compared to a single application. Preemergence applications of S-metolachlor at 1.4 kg ai ha^{-1} provided greater consistency and duration to overall weed control in sugarbeet as compared to no preemergence herbicide (Bollman and Sprague 2007; Bollman and Sprague 2009; Meyers et al. 2010).

Metolachlor has been widely used for selective weed control in more than 70 crops worldwide, including sugarbeet (O'Connell et al. 1998). Metolachlor is a selective preemergence herbicide structurally related to the class of chloroacetanilides (Pusino et al. 1992). Chloroacetanilide herbicides kill plants by inhibiting very long chain fatty acid biosynthesis (Shaner 2014). Metolachlor was commercialized in 1977 and provides control of grasses and small-seeded broadleaves in corn, soybean, and many other crops (Vencill 2002). Metolachlor is a chiral pesticide that consists of four stereoisomers, or two pair of enantiomers (Sekhon 2008). Enantiomers are two stereoisomers that are mirror images, often differing in rotational direction, and result in S- and R-isomers. Enantiomers of chiral pesticides are often metabolized at different rates and in agriculture the more active enantiomer of a pesticide has many advantages (Sekhon 2008). Metolachlors herbicidal activity is mainly from the S-isomer pair (Shaner 2014). S-metolachlor is physically and chemically equivalent to metolachlor. However, S-metolachlor is more active at the site of action in susceptible plants (Shaner 2014).

The resolved S-isomer of metolachlor, S-metolachlor, was registered in 1997 (Shaner et al. 2006). New formulations based on the S-metolachlor isomer are more active on a gram-for-gram basis compared to formulations based on a racemic mixture of metolachlor that contains a

50:50 ration of the S- and R- isomers. The ratio of S-isomers to R-isomers in S-metolachlor marketed products is 88:12 (Shaner et al. 2006). S-metolachlor sustains the biological performance of metolachlor (O'Connell et al. 1998). Data analysis done by O'Connell et al. (1998) confirmed that S-metolachlor at a 35 to 38% lower application rate gave equivalent weed control to metolachlor.

Physical and chemical properties of S-metolachlor impact the extent of injury to sugarbeet. The adsorption of residual herbicides to soil can determine environmental fate, biological activity, and persistence of the herbicide in soil (Pusino et al. 1992). S-metolachlor's environmental fate, biological activity, and persistence in the soil is greatly influenced by the herbicides adsorption to soil clay and organic matter contents. S-metolachlor is moderately adsorbed to soil, more readily adsorbed to high clay soils than to soils with low clay content, and more readily adsorbed to organic matter than to clay (Shaner 2014). S-metolachlor adsorption to soil can be quantified as a K_d value (Shaner et al. 2006). The K_d value is the adsorption coefficient of herbicide adsorbed to the soil over herbicide in solution, and the greater the K_d value of the herbicide, the more adsorbed the herbicide is to soil. K_d values for herbicides differentiate based on soil properties being evaluated. Across five soils, the S-metolachlor K_d value ranged from 1.6 in a sandy-loam with 1.5% organic matter to 6.9 in a clay-loam with 5.6% organic matter indicating S-metolachlor more readily adsorbs to soil rather than desorbing into soil solution (Shaner et al. 2006). The K_d value is dependent on the soil evaluated, but a value that is used to calculate K_{oc}. The K_{oc} value normalizes the organic matter content across evaluated soils. S-metolachlor has an average K_{oc} value of 200 mL/g, which is the organic carbon to water coefficient (Shaner 2014). The greater the K_{oc} value, the greater the adsorption to the soil. A study done by Pusino et al. (1992) indicated that organic matter, rather than clay complexes, was more responsible for S-metolachlor adsorption in soil. Organic matter may be the main factor that regulates S-metolachlor adsorption to soil (Pusino et al. 1992). According to Shaner et al. (2006), the extent of soil binding for S-metolachlor was highly correlated to soil organic matter (R^2=0.98). The recommended S-metolachlor application rate varies with soil texture and organic matter (Shaner et al. 2006).

S-metolachlor is a non-ionizable herbicide which indicates that soil pH has no effect on the herbicide (Shaner 2014). S-metolachlor has a K_{ow} value of 794 at 25 C, which is the partition coefficient between octanol (octan-1-ol) and water as measurement of solubility. A K_{ow} value greater than one indicates the herbicide is not water soluble. The greater the K_{ow} value, the greater the adsorption capacity. The S-metolachlor K_{ow} value indicates the herbicide adsorbs to the soil more readily than being dissolved in the soil solution. Adsorption capacity of S-metolachlor is due to the large surface area of the molecule and the ability of the herbicide to displace many water molecules from soil surfaces (Torrents and Jayasundera 1997).

Photodegredation is a major contributor to dissipation in the field particularly under prolonged lack of precipitation and temperatures above 7 C when S-metolachlor remains on the soil surface (Shaner 2014). Microbial degradation is a major contributor to soil dissipation, especially where S-metolachlor has moved beneath the soil surface. Non-biological degradation is negligible. S-metolachlor residues do not persist to affect crops planted the next season. Half-life of S-metolachlor applied to soil was about 14 days (Cao et al. 2008). Cao et al. (2008) concluded a rapid decline of S-metolachlor concentration in soil occurred 21 days after treatment, and by 92 days after treatment the concentration of herbicide in soil was undetectable. Leaching generally is insignificant when soil organic matter is greater than 2%.

Most S-metolachlor susceptible weeds fail to emerge from the soil. Injury in grasses is expressed as malformed and twisted seedlings (Shaner 2014). Leaves tightly roll into a whorl and may not unroll properly. Injured broadleaf weeds have cupped or crinkled leaves with a draw-string or heart-shaped appearance. S-metolachlor is phytotoxic only to emerging weed seedlings and is absorbed by shoots and roots. S-metolachlor is metabolized and detoxified in the plant by cleavage of the methyl-ether group followed by conjugation with glucose; also detoxified by conjugation of the chloroacetyl group with glutathione (GSH) or, in certain legumes, with homoglutathione (Shaner 2014).

S-metolachlor absorption in sugarbeet is primarily through sugarbeet roots and secondarily though the sugarbeet hypocotyl (Bollman et al. 2008). Equal percentages of S-metolachlor were translocated in sugarbeet indifferent of sugarbeet variety evaluated. S-metolachlor was rapidly metabolized in sugarbeet roots and required less than 6 h from absorption for complete metabolization (Bollman et al. 2008). S-metolachlor metabolic rate may vary between varieties (Bollman et al. 2008; Rowe et al. 1990). Bollman et al. (2008) and Rowe et al. (1990) concluded that more rapid metabolism of S-metolachlor reduces exposure time to the active herbicidal compound and results in greater crop safety.

S-metolachlor applied preplant-incorporated at a rate of 2.24 kg ai ha^{-1} was evaluated on sugarbeet between 1997 to 2002 by Dexter and Luecke (2004) and resulted in 6% average sugarbeet crop injury over those years, but did not exceed 14% injury. However, sugarbeet injury from S-metolachlor applied preplant-incorporated in 2003 averaged 44% and ranged from 20% to 73% across nine locations (Dexter and Luecke 2004). Dexter and Luecke (2004) concluded sugarbeet injury from S-metolachlor was more severe in 2003 than in the previous eleven years of testing metolachlor or S-metolachlor due to an unusual cold spring, early sugarbeet seeding date, and frequent precipitation events. These environmental conditions slowed sugarbeet emergence, which increased uptake of the herbicide by the sugarbeet plants and caused more sugarbeet injury than previously observed. Preemergence and early-postemergence applied S-metolachlor treatments caused less sugarbeet injury than preplant-incorporated S-metolachlor (Dexter and Luecke 2004).

Research done by Bollman et al. (2008) in sugarbeet indicated the primary site of S-metolachlor absorption was through the roots of the seedlings; however, some absorption occurred through the hypocotyl. Sugarbeet injury symptoms from S-metolachlor included plant stunting, reduced plant growth, and sugarbeet leaf crinkling. Bollman and Sprague (2008) also evaluated crop injury from 12 sugarbeet varieties treated with S-metolachlor at a 1.40 kg ai ha^{-1} rate at different sugarbeet growth stages. Results suggested S-metolachlor applied preemergence and to two-leaf sugarbeets caused sugarbeet leaf crinkling and reduced growth as compared to S-metolachlor applied to four-leaf sugarbeets (Bollman and Sprague 2008). S-metolachlor applied preemergence caused 23% sugarbeet injury based on leaf area reduction. Injury from S-metolachlor at two-leaf sugarbeet was less than injury from the preemergence application, and S-metolachlor applied at four-leaf sugarbeet caused the least amount of injury. Preemergence herbicide application followed by precipitation within seven days of application caused the greatest magnitude of sugarbeet injury. Bollman and Sprague (2008) observed that sugarbeet can recover from early season injury. However, sugarbeet stands were reduced after S-metolachlor preemergence application and reductions in extractable sucrose were likely in years with precipitation close to application.

Sugarbeet varieties can vary in response to S-metolachlor and differences were not related to the ploidy level of the varieties (Bollman et al. 2008). Sugarbeet variety tolerance to

S-metolachlor was likely due to differences in the genetics. The rate of S-metolachlor metabolism, as determined by placement of hydroponic grown sugarbeets in ^{14}C radio-labeled herbicide solutions, was a major factor to determine the differential tolerance of the most tolerant sugarbeet varieties, Hilleshog ‘2771RZ’ (Syngenta Crop Protection, LLC, Regional Headquarters, P.O. Box 18300, Greensboro, NC 27409) and Betaseed ‘5833R’ (Betaseed Inc., 5705 W. Old Shakopee Road, Suite 110, Bloomington, MN 55437), and the most susceptible sugarbeet variety, Hilleshog ‘7172RZ’, in the experiment.

Herbicides can be used as part of an integrated weed management strategy to achieve sustainable weed management (O’Connell et al. 1998). S-metolachlor allows growers to exploit crop system and crop selection as a way of managing weeds without reliance on row-cultivation. Furthermore, S-metolachlor can be used to enhance crop establishment and early season crop competitiveness.

CHAPTER 2. S-METOLACHLOR SUGARBEET SAFETY FIELD EXPERIMENTS

Field experiments were conducted at multiple locations relevant to sugarbeet production with different soil texture and organic matter content in Minnesota and North Dakota in 2015 and 2016. Research objectives for field experiments were to determine a preemergence S-metolachlor rate that provided adequate crop safety across different environments, and to investigate the contribution of organic matter content and precipitation on S-metolachlor sugarbeet crop safety.

2.1. Materials and Methods

Experiments were conducted at six locations in 2015 and five locations in 2016. All locations had low weed pressure as the focus of the research was on crop safety rather than weed control. Planting date across soil series and years ranged from April 16 to May 19 (Table 1).

In 2015, experiments were conducted near Ada, MN, Belgrade, MN, Crookston, MN, Foxhome, MN, Lake Lillian, MN, and Prosper, ND. Location soil series were Glyndon sandy-loam (Coarse-silty, mixed, superactive, frigid Aeric Calciaquolls), Osakis loam (Sandy, mixed, frigid Oxyaquic Hapludolls), Wheatville loam (Coarse-silty over clayer, mixed over smectitic, superactive, frigid Aeric Calciaquolls), Croke sandy-loam (Coarse-silty over clayey, mixed over smectitic, superactive, frigid Oxyaquic Hapludolls), Seaforth clay-loam (Fine-loamy, mixed, superactive, Mesi Aquic Calciudolls), and a homogenous mix of Bearden silt-loam (Fine-silty, mixed, superactive, frigid Aeric Calciaquolls) and Lindaas silt-loam (Fine, smectitic, frigid Typic Argiaquolls), respectfully (Soil Survey Staff 2017).

In 2016, experiments were conducted near Ada, MN, Crookston, MN, Foxhome, MN, Murdock, MN, and Prosper, ND. Location soil series were Glyndon sandy-loam, Wheatville loam, Croke sandy-loam, a homogenous mix of Bearden silty-clay-loam and Quam silty-clay-loam (Fine-silty, mixed, superactive, frigid Cumulic Endoaquolls), and a homogenous mix of Bearden silt-loam and Lindaas silt-loam, respectfully (Soil Survey staff 2017). The Glyndon and Wheatville soil experiments were abandoned in 2016 due to exceptionally dry conditions which resulted in significant sugarbeet emergence variability. Soil samples were collected to a depth of 0-15 cm and analyzed to measure percent organic matter, NO_3-N, phosphorous, potassium, and pH (Table 2). Mechanical analysis was performed to determine soil texture of each soil series evaluated (Table 3).

Field experiments were a randomized complete block design with four, six, or twelve replications for one, five, and three soil series, respectfully. Differences in experiment number of replications were due to field constraints at one location in 2015, and to added replication from six to twelve from 2015 to 2016, respectfully. Each experimental unit was a six-row plot 3.3 meters wide by 9 meters in length. Experimental areas were fertilized to soil test and prepared for planting with field cultivation. Seed treatments limit the effect of insects and pathogens. Crystal '981RR' (ACH Seeds, Inc., 574 Prairie Center Drive #135, PMB 305, Eden Prairie, MN 55344) sugarbeet seed was treated with hymexazol (Tachigaren 70 WP, Mitsui Chemicals Agro, Inc., 1-5-2 Higashi-Shimbashi, Minato-ku, Tokyo 105-7117, Japan) and penthiopyrad (Kabina ST, Mitsui Chemicals Agro, Inc., 1-5-2 Higashi-Shimbashi, Minato-ku, Tokyo 105-7117, Japan) fungicide at 45 and 12 grams ai, respectively, per 100,000 seeds. Seed was also treated with insecticide (Poncho Beta, Bayer Crop Science, LP., P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709) that included active ingredients clothianidin and beta-cyfluthrin at 150 ml of product per 100,000 seeds. Crystal '981RR' seed was planted 2.5 cm deep with 56 cm row spacing throughout each experimental area.

S-metolachlor was applied preemergence to sugarbeet at 0, 0.54, 1.08 and 2.15 kg ai ha^{-1}. Herbicide treatments were applied at 159 L ha^{-1} spray solution through 8002XR nozzles (XR TeeJet Flat Fan Spray Tips, TeeJet Technologies, 200 W. North Ave, Glendale Heights, IL 60139) using a bicycle wheel plot sprayer with a shielded boom to reduce particle drift and pressurized with CO_2 at 207 kPa to the center four rows of the experimental unit. Cercospora leaf spot (*Cercospora beticola*) and rhizoctonia root rot (*Rhizoctonia solani*) broadcasted foliar applications were applied as required to reduce overall effects of disease. Glyphosate (Roundup PowerMAX, Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO 63167) was broadcasted to reduce the impact of weed competition on the experiment. Maintenance sprays eliminated effects that may otherwise have confounded sugarbeet crop safety.

Evaluations include crop stand collected from the middle two rows of the experimental unit at the two-leaf sugarbeet growth stage. Plot harvest date across soil series and years ranged from September 13 to October 18 (Table 1). The center two rows of each plot were mechanically harvested, and approximately 11 kg samples were collected and analyzed for quality at American Crystal Sugar quality lab in East Grand Forks, Minnesota. Sugarbeet percent sugar, percent purity, root yield (kg ha^{-1}), and sucrose content (kg sucrose ha^{-1}) were recorded. Standard root yield [1] and sucrose content [2] calculations were used.

$$Root\ yield\ in\ kg\ per\ hectare = \frac{weight\ of\ harvested\ plot\ (kg)}{\%\ of\ hectare\ harvested} \qquad [1]$$

$$Extractable\ sucrose\ in\ kg\ per\ hectare = \left(\frac{[(\%purity\ x\ 100)x\ \%\ sugar]}{100}\right) x\ root\ yield \qquad [2]$$

Table 1. Field experiment plant and harvest dates across field soil type and years.

Year	Soil series	Location	Plant date	Harvest date
2015	Bearden/Lindass	Prosper, ND	April 16	September 17
2015	Croke	Foxhome, MN	May 11	September 15
2015	Glyndon	Ada, MN	April 28	September 22
2015	Osakis	Belgrade, MN	April 23	September 16
2015	Seaforth	Lake Lillian, MN	April 28	September 26
2015	Wheatville	Crookston, MN	May 4	September 24
2016	Bearden/Lindass	Prosper, ND	May 2	September 13
2016	Bearden/Quam	Murdock, MN	May 9	October 18
2016	Croke	Foxhome, MN	May 19	September 22
2016	Glyndon	Ada, MN	April 29	Not harvested
2016	Wheatville	Crookston, MN	April 21	Not harvested

Soil texture was recorded across years and soil series. S-metolachlor's environmental fate, biological activity, and persistence in the soil is greatly influenced by the herbicides adsorption to soil, clay complexes, and organic matter (Pusino et al. 1992). Soil texture varied across the different soil series within and across years. The 2015 Glyndon and Croke, and 2016 Croke, soils were sandy-loam textured. The 2015 Osakis and Wheatville, and 2016 Bearden/Lindass soils were loam textured. The 2015 Seaforth and Bearden/Lindass soils were clay-loam textured while the 2016 Bearden/Quam was a silty-clay-loam texture (Table 2). S-metolachlor was moderately adsorbed to soil, more readily adsorbed to high clay soils than to soils with low clay content, and more readily adsorbed to organic matter than to clay complexes (Shaner 2014).

Organic matter was recorded across years and soil series. Organic matter content may be the most important factor that regulates S-metolachlor adsorption to soil, and the extent of adsorption was highly correlated (R^2=0.98) to increased organic matter (Pusino et al. 1992; Shaner et al. 2006). Organic matter content in this experiment ranged from 2.2% to 7.2% across soils and years. The 2015 Glyndon and Wheatville, and 2016 Bearden/Lindass soils had low organic matter of 2.2, 2.6, and 2.7%, respectively. The 2015 Osakis and Croke, and 2016 Croke soils had moderate organic matter of 3.2, 3.3, and 3.6%, respectively. The 2015 Bearden/Lindass and Seaforth, and 2016 Bearden/Quam soils had high organic matters of 4.1, 7.2, and 6.7%, respectively (Table 3).

Table 2. Soil nutrients, organic matter, and pH for 2015 and 2016 field soil series for the 0-30 cm depth.

Year	Soil series	NO_3-N	P	K	OM[b]	pH
		--------------------kg ha^{-1}--------------------			%	
2015	Bearden/Lindass	15	107	825	4.1	8.0
2015	Croke	13	28	177	3.3	7.8
2015	Glyndon	12	47	248	2.2	8.7
2015	Osakis	80	26	170	3.2	6.6
2015	Seaforth	138	75	264	7.2	7.8
2015	Wheatville	25	29	165	2.6	8.5
2016	Bearden/Lindass	83	33	177	2.7	7.4
2016	Bearden/Quam	141	30	240	6.7	8.2
2016	Croke	18	25	177	3.6	8.4

Table 3. Soil texture for 2015 and 2016 field soil series.

Year	Soil series	Mechanical analysis			Soil texture
		Sand	Silt	Clay	
		------------------------g kg^{-1}------------------------			
2015	Bearden/Lindass	231	465	304	Clay loam
2015	Croke	644	192	164	Sandy loam
2015	Glyndon	765	102	133	Sandy loam
2015	Osakis	438	397	165	Loam
2015	Seaforth	270	450	280	Clay loam
2015	Wheatville	492	318	190	Loam
2016	Bearden/Lindass	359	425	216	Loam
2016	Bearden/Quam	127	564	309	Silty clay loam
2016	Croke	644	192	164	Sandy loam

Data for sugarbeet stand and percent sugar were homogenous across years and soil series, and combined using the GLM procedure in SAS (Statistical Analysis Software 2016, version 9.4, SAS Institute, Inc., 100 SAS Campus Drive, Cary, NC 27513). Soil series within and across years were analyzed as random variables due to differentiating soil texture, organic matter, and precipitation. The combined analysis for sugarbeet stand and percent sugar provides a basis for general recommendation across years and soil series regardless of location, climate, or soil properties. The interaction of soil series and S-metolachlor rate for sugarbeet stand was not significant at the $P \leq 0.05$ level ($P \leq 0.088$) and may have been significant at the $P \leq 0.05$ level with increased replication and the associated precision. Previous research indicates S-metolachlor readily adsorbs to organic matter (Pusino et al. 1992; Shaner et al. 2006). Thus, sugarbeet stand data were further separated into three groups (low, moderate, and high) based on organic matter content organic. Each group included three soil series experiments and each sub-group was analyzed across years and soil series using the GLM procedure in SAS. Data for sugarbeet percent purity, root yield, and extractable sucrose were not homogenous across years and soil series; thus, were analyzed independently based on soil series using the GLM procedure in SAS.

2.2. Results and Discussion

S-metolachlor rate did not affect sugarbeet percent sugar content averaged across years and soil series. Data for sugarbeet stand and percent sugar as influenced by S-metolachlor rate across years and soil series are in the appendix (Table A1). S-metolachlor rates greater than 0.54 kg ai ha^{-1} reduced sugarbeet stand averaged across years and soil series as compared to the untreated control (Figure 1). However, S-metolachlor rates of 1.08 and 2.15 kg ai ha^{-1} only reduced sugarbeet stand by 3.9 and 6.5%, respectfully, compared to the untreated control. Degree of sugarbeet injury from these greater rates of S-metolachlor averaged across environments evaluated was similar to, or less than, injury observed when the micro-rate program for weed control was used in sugarbeet.

The micro-rate program was first implemented in 1992 by Dexter et al. (1993) to reduce sugarbeet injury and increase broadleaf weed control. According to Dexter and Luecke (2001)

94% of growers utilized the program in 1999. A majority of growers continued to use the micro-rate program until the introduction of glyphosate-resistant sugarbeet in 2008 when 54% of growers used the Roundup Ready sugarbeet system (Carlson et al. 2007; Carlson et al. 2009). Micro-rate program visual sugarbeet injury ranged from 8 and 38%, and averaged 20% in a study done by Dexter et al. (2007) across seven locations in 2006. A micro-rate program used by Bollman and Sprague (2007) resulted in an average of 6% visual sugarbeet injury. Thus, the 6.5% sugarbeet stand reduction at 2.15 kg ai ha^{-1} was likely not greater than sugarbeet injury observed in micro-rate programs.

A 6.5% sugarbeet stand reduction does not affect yield or quality of sugarbeet. Khan and Hakk (2016) suggest an initial quality stand of sugarbeet could withstand 25 to 50% stand reductions and continue to produce acceptable tonnage and recoverable sucrose. Results of the S-metolachlor sugarbeet safety field experiments indicate stand loss occurs from preemergence application of S-metolachlor, but literature review suggests the stand loss does not result in reductions in yield or extractable sucrose. According to this experiment, S-metolachlor at rates of 2.15 kg ai ha^{-1} was safe across environments evaluated. However, literature review suggests organic matter content was a substantial factor in adsorption of S-metolachlor to soil (Pusino et al. 1992; Shaner et al. 2006). The Dual Magnum label recommends S-metolachlor use rates based on soil texture and organic matter. Thus, soil series were divided into three groups based on soil organic matter content to; 1) determine the effect of organic matter on sugarbeet stand; and 2) determine whether differences in environment had an effect within each organic matter grouping.

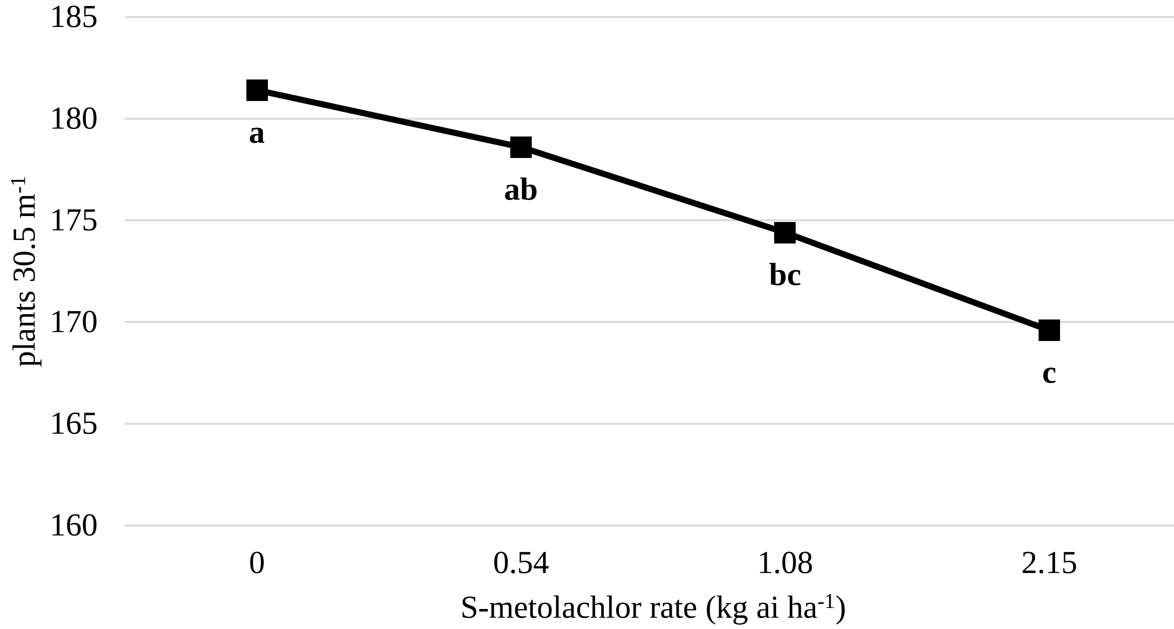

Figure 1. Sugarbeet stand loss from S-metolachlor rate averaged across years and soil series.

Each organic matter grouping was analyzed independent and contains three different soil series with similar organic matter as compared to other soil series evaluated. Each soil series was at a different location, and each location provided a different environment. Differences in environments include, but are not limited to, planting date, harvest date, precipitation, and elevation within the field. Environments, averaged across all S-metolachlor rates, within each grouping were significantly different. However, environments were random and unpredictable, so these differences were not discussed (Table 4).

Sugarbeet stand, as influenced by S-metolachlor rate and averaged across environments, within each grouping was not significant (Table 4). Thus, S-metolachlor rate had no effect on sugarbeet stand across organic matter groupings. However, sugarbeet stand tended to be less within each organic matter grouping at the 2.15 kg ai ha^{-1} S-metolachlor rate (Table 5). Sugarbeet stand loss from S-metolachlor at 2.15 kg ai ha^{-1} was reduced by 8.4, 6.0, and 1.1% in the low, moderate, and high organic matter groupings, respectfully, compared to S-metolachlor at 0.54 kg ai ha^{-1}. Although sugarbeet stand reductions tended to be greater in soils with less organic matter content, as compared to soils with more organic matter content, the stand reductions likely were not enough to affect yield or extractable sucrose (Khan and Hakk 2016).

Table 4. Sugarbeet stand sources of variation, degrees of freedom, and F-test results for organic matter groups.

Source of variation	df	Low OM	Moderate OM	High OM
Environment	2	**[a]	**	**
S-metolachlor rate	3	NS	NS	NS
Environment*S-metolachlor rate	6	*	NS	NS

[a]*, ** indicate significance at $P \leq 0.05$ or $P \leq 0.01$, respectfully

Table 5. Sugarbeet stand, averaged across environments, as influenced by S-metolachlor rate and organic matter content by soil series.

S-metolachlor	Low OM	Moderate OM	High OM
kg ai ha^{-1}	---------------plants 30.5 m^{-1}---------------		
0	181	172	191
0.54	179	167	190
1.08	173	162	188
2.15	164	157	188
LSD (0.05)	NS	NS	NS

The interaction of environment by S-metolachlor rate within each organic matter grouping was significant in the low organic matter grouping, but was not significant in the moderate or high organic matter groupings (Table 6). Thus, the moderate and high organic matter grouping data can be found in the appendix (Table A2 and Table A3). The significant interaction in the low organic matter grouping suggests S-metolachlor at greater rates interacted with one or more components of the environment to decrease sugarbeet stand (Table 6). Maximum, minimum, and average air temperatures, along with average soil temperature and dew point were similar between 2015 and 2016 cropping seasons (Table 7). Thus, temperature was likely not a factor. However, precipitation is required to activate S-metolachlor and differed between environments in the low organic matter grouping.

Precipitation was recorded across environments for the low organic matter grouping. Precipitation that occurs within 7 d following S-metolachlor application preemergence increased sugarbeet injury (Bollman and Sprague 2008). Bollman and Sprague defined sufficient precipitation to increase sugarbeet crop injury from S-metolachlor as 4 cm within 7 d of application. However, these data suggest precipitation totaling 4 cm within 14 d of S-metolachlor application preemergence caused a reduction in sugarbeet safety. The 14 DAA interval limits S-metolachlor degradation on the soil surface from photodegredation. The 14 DAA period was also consistent with S-metolachlor half-life (Cao et al. 2008). Although the 4 cm of precipitation within 14 DAA period was determined by evaluation of all nine soil series and climates, no interaction of S-metolachlor by environment occurred in the moderate and high organic matter groupings; thus, only the low organic matter grouping was discussed.

The soil series in the low organic matter grouping were Glyndon, Wheatville, and Bearden/Lindass in 2015, 2015, and 2016, respectfully. The Glyndon soil series and Bearden/Lindass series soils in 2015 and 2016, respectfully, received 1.8 cm and 0.1 cm precipitation within 14 DAA while the Wheatville series soil in 2015 received 8.4 cm precipitation within 14 DAA (Table 8). S-metolachlor rates within the Bearden/Lindass soil were not statistically different, therefore, results were not discussed (Table 6). The Glyndon soil gave the greatest stand reduction compared to the untreated control following S-metolachlor preemergence application at the 2.15 kg ai ha^{-1} rate as compared to the other soils evaluated. The reduction may be more attributed to low clay content (13.3%), rather than to precipitation. However, the interaction of low clay content and moderate precipitation at Glyndon may have reduced sugarbeet stand.

Greater precipitation in the Wheatville soil, as compared to Glyndon and Bearden/Lindass soils, increased soil available water and decreased sugarbeet stand following S-metolachlor preemergence application by 13.6% as compared to the control treatment. Although S-metolachlor caused significant stand loss in both Glyndon and Wheatville soils, the magnitude of stand loss between the 0.54 kg ai ha^{-1} and the 2.15 kg ai ha^{-1} rates was greater in the Wheatville soil (14.5%) as compared to the Glyndon soil (8.2%). The greater precipitation in the Wheatville soil appeared to amplify the degree of stand loss between S-metolachlor rates as compared to the Glyndon soil which suffered a more significant initial stand loss between the untreated control and 0.54 kg ai ha^{-1} S-metolachlor rate. Differences may be attribute to different clay content within each soil.

The Wheatville soil had 19.0% clay content, which was greater than the 13.3% clay content of the Glyndon soil. The greater clay content of the Wheatville soil may have initially buffered the effect of the 0.54 kg ai ha^{-1} S-metolachlor rate. However, as soil available water and herbicide rate increased, the clay content was insufficient to buffer S-metolachlor from the soil solution. Increased soil available water results in more water molecules within the soil solution which results in more S-metolachlor being desorbed from clay complexes and organic matter. As more S-metolachlor was desorbed, the concentration of S-metolachlor in the soil solution increased and was made more available for uptake by sugarbeet which resulted in increased sugarbeet injury.

Table 6. Sugarbeet stand, and percent of stand compared to the untreated control within each environment, as influenced by the interaction of S-metolachlor rate by soil series, low organic matter content grouping.

Environment				
Year	Soil series	S-metolachlor rate	Stand	Control
		kg ai ha^{-1}	plants 30.5 m^{-1}	% of
2015	Glyndon	0	213	100.0
2015	Glyndon	0.54	196	92.0
2015	Glyndon	1.08	194	91.1
2015	Glyndon	2.15	180	84.5
2015	Wheatville	0	177	100.0
2015	Wheatville	0.54	179	101.1
2015	Wheatville	1.08	168	94.9
2015	Wheatville	2.15	153	86.4
2016	Bearden/Lindass	0	154	100.0
2016	Bearden/Lindass	0.54	162	105.2
2016	Bearden/Lindass	1.08	157	101.9
2016	Bearden/Lindass	2.15	157	101.9
LSD (0.05)			18	

Table 7. Maximum, minimum, and average air temperature, average soil temperature, and dew point for April, May, and June 2015 and 2016, Fargo, ND.

	2015			2016		
	April	May	June	April	May	June
Max. air temperature[b]	16	19	26	11	22	26
Min. air temperature	1	7	14	1	9	16
Avg. air temperature	8	13	19	6	16	20
Avg. soil temperature	8	14	20	7	16	22
Dew point	-4	6	13	-1	4	13

[a]Data acquired from North Dakota Agricultural Weather Network.
[b]Max.=maximum; Min.=minimum; Avg.=average.
[c]All temperatures recorded in degrees Celsius.

Table 8. Precipitation by month across soil series for low organic matter content grouping in 2015 and 2016.

Year	Soil series	April	May	June	14 DAA[b]
		-------------------------------cm-------------------------------			
2015	Glyndon	2.0	11.9	10.0	1.8
2015	Wheatville	1.2	9.4	6.0	8.4
2016	Bearden/Lindass	4.3	8.2	10.6	0.1

[a]Data acquired from North Dakota Agricultural Weather Network.
[b]DAA=Days after preemergence application.

Differences in sugarbeet percent purity as S-metolachlor rate varied were significant in three of nine soils (Table 9). However, the differences in sugarbeet percent purity were not associated with increasing S-metolachlor rate and were attributed to random error. Thus, results were not discussed.

Differences in sugarbeet root yield as S-metolachlor rate varied were significant in six of nine soils and sugarbeet extractable sucrose was significant in four of nine soils (Table 10 and Table 11). However, reductions in sugarbeet root yield and extractable sucrose were only associated with increasing S-metolachlor rate in the Wheatville series soil. Significant differences in the other soils were attributed to random error. Thus, only differences in sugarbeet root yield and extractable sucrose in the Wheatville series soil were discussed. Root yield is one factor used to calculate extractable sucrose, so both evaluated variables are discussed simultaneously.

The Wheatville soil had sugarbeet stand loss from S-metolachlor preemergence application. The Wheatville soil environment received 23.1 cm precipitation April through June (Table 8). The quantity of early season precipitation may have caused additional sugarbeet stand loss from S-metolachlor after initial stand counts were taken at two-leaf sugarbeet. Sugarbeet stand loss greater than 25% may cause decreases root yield and extractable sucrose (Khan and Hakk 2016).

Table 9. Sugarbeet percent purity as influenced by S-metolachlor rate and soil series.

	2015						2016		
S-metolachlor	B/L[a]	Croke	Glyn	Osak	Sea	Wht	B/L	B/Q	Croke
kg ai ha^{-1}	---------------------------------------%---------------------------------------								
0	91.6	88.1	91.6	85.5	86.1	90.9	92.1	89.2	88.5
0.54	92.3	88.3	92.9	85.7	85.9	91.5	91.8	89.1	88.2
1.08	91.3	88.4	92.7	85.9	86.4	91.5	91.3	89.1	88.8
1.61	-	-	-	-	-	-	91.7	89.5	88.4
2.15	91.3	87.2	92.9	85.6	86.6	91.3	92.2	89.2	87.7
4.30	-	-	-	-	-	-	91.7	89.2	87.9
LSD (0.05)	0.4	NS	NS	NS	NS	NS	0.3	0.3	NS

[a]Soil series: B/L=Bearden/Lindass; Glyn=Glyndon; Osak=Osakis; Sea=Seaforth; Wht=Wheatville; B/Q=Bearden/Quam

Table 10. Sugarbeet root yield as influenced by S-metolachlor rate and soil series in 2015 and 2016.

	2015						2016		
S-metolachlor	B/L[a]	Croke	Glyn	Osak	Sea	Wht	B/L	B/Q	Croke
kg ai ha^{-1}	------------------------------------1000 kg ha^{-1}------------------------------------								
0	76.1	43.6	79.6	55.4	74.3	57.8	70.8	74.1	57.4
0.54	76.4	41.6	79.6	48.6	85.0	58.1	69.5	74.0	56.7
1.08	79.4	43.8	77.4	54.2	97.0	54.8	71.0	74.6	57.8
1.61	-	-	-	-	-	-	68.7	69.7	58.0
2.15	82.2	37.6	77.6	52.2	95.7	52.7	72.4	72.2	56.6
4.30	-	-	-	-	-	-	69.1	74.3	57.4
LSD (0.05)	1.5	NS	NS	NS	4.7	2.2	1.2	1.2	1.1

[a]Soil series: B/L=Bearden/Lindass; Glyn=Glyndon; Osak=Osakis; Sea=Seaforth; Wht=Wheatville; B/Q=Bearden/Quam

Table 11. Sugarbeet extractable sucrose as influenced by S-metolachlor rate and soil series in 2015 and 2016.

	2015						2016		
S-metolachlor	B/L[a]	Croke	Glyn	Osak	Sea	Wht	B/L	B/Q	Croke
kg ai ha^{-1}	--kg ha^{-1}--								
0	12805	6405	12578	8705	11814	9319	11905	10815	8375
0.54	13002	6100	12923	7900	13682	9367	11578	10947	8241
1.08	13206	6288	12432	8683	15618	8890	11601	11015	8525
1.61	-	-	-	-	-	-	11374	10426	8657
2.15	13674	5527	12523	8175	15571	8569	12155	10562	8374
4.30	-	-	-	-	-	-	11457	11002	8374
LSD (0.05)	NS	NS	NS	NS	782	292	211	173	NS

[a]Soil series: B/L=Bearden/Lindass; Glyn=Glyndon; Osak=Osakis; Sea=Seaforth; Wht=Wheatville; B/Q=Bearden/Quam

2.3. Summary

Sugarbeet stand loss is the greatest concern when using S-metolachlor preemergence. Sugarbeet stand loss from S-metolachlor at 0.54 kg ai ha^{-1} was similar to the untreated control across soil series evaluated in 2015 and 2016. S-metolachlor at 1.08 and 2.15 kg ai ha^{-1} reduced sugarbeet stand, however, the stand loss was not sufficient to reduce sugarbeet root yield, quality, or extractable sucrose across years and soil series evaluated. Thus, S-metolachlor may be recommend up to 2.15 kg ai ha^{-1} and, although growers may experience sugarbeet stand loss, growers should not experience loss in sugarbeet yield, quality, or extractable sucrose. However, not all environments or soils were evaluated in this experiment and growers with low clay and organic matter content soils should proceed with caution at rates greater than 0.54 kg ai ha^{-1}. Low clay and organic matter content soils, in combination with above average precipitation, may be at risk for yield losses.

CHAPTER 3. S-METOLACHLOR SUGARBEET SAFETY AS INFLUENCED BY ENVIRONMENT

Sugarbeet crop safety from S-metolachlor was greatest in soils with greater clay and organic matter content. Environmental variables, such as precipitation and temperature, may also impact sugarbeet crop safety from S-metolachlor. Dexter and Luecke (2004) hypothesized that excessive precipitation and prolonged cold air temperatures in 2003 following S-metolachlor application may have reduced sugarbeet crop safety, particularly sugarbeet stand. The objectives of this experiment were to investigate the effect of soil temperature and soil moisture on sugarbeet safety from S-metolachlor and to determine the biological effects of S-metolachlor on sugarbeet emergence and growth across soils with different textures, organic matter, temperatures, and moistures. Growth chambers provide controlled micro-environments that reduce variation of temperature, water evaporation, and daylight fluctuation. Herbicide rates were based on field experiments; soil field capacities and temperatures were based on a review of literature and preliminary experiments.

3.1. Materials and Methods

Growth chambers were used to conduct experiments at temperatures of 7, 14, and 21 C. The experimental design was a complete randomized design with a split-plot factorial arrangement and six replications. Replication was the experiment conducted over time. Temperature was the whole-plot treatment while sub-plot treatments included S-metolachlor rate, soil series, and soil water content. The experiment evaluated the interaction of temperature, soil water, and soil series at five S-metolachlor rates, 0, 0.54, 1.08, 1.61, and 2.15 kg ai ha^{-1}, applied preemergence in sugarbeet. Variable temperatures evaluated were 14 C and 21 C, and soil water contents were 75 and 100% of field capacity. Soil series evaluated were Glyndon, Fargo (Fine, smectitic, frigid Typic Epiaquerts), and a homogenous mix of Bearden/Lindass. Soils represented the sugarbeet growing area and were collected at a depth of 0-15 cm from Ada, Minnesota; Fargo, North Dakota; and Prosper, North Dakota, respectfully. Gravimetric water contents for the Glyndon, Fargo, and Bearden/Lindass soils at field capacity were 30, 44, and 53%, respectfully. Soil was evaluated at a depth of 0-15 cm for percent organic matter, NO_3-N, phosphorous, potassium, and pH (Table 12). Mechanical analysis was performed to determine soil texture of each soil series evaluated (Table 13). The Glyndon series soil was a sandy-loam texture with an organic matter content of 2.6% (Table 12 and Table 13). The Bearden/Lindass soil had a silt-loam texture with an organic matter content of 4.7%. The Fargo series soil was a silty-clay texture with an organic matter content of 7.7%.

Table 12. Soil nutrients, organic matter, and pH for the controlled environment experiment.

Soil series	NO_3-N	P	K	OM[b]	pH
	--------------------kg ha^{-1}[a]-------------------			%	
Bearden/Lindass	64	56	368	4.7	6.0
Fargo	121	33	513	7.7	7.2
Glyndon	61	37	256	2.6	8.1

Table 13. Soil texture for the controlled environment experiment.

Soil series	Mechanical analysis			Soil texture
	Sand	Silt	Clay	
	------------------------g kg^{-1}[a]------------------------			
Bearden/Lindass	230	504	266	Silt loam
Fargo	41	419	540	Silty clay
Glyndon	767	138	95	Sandy loam

Four hundred grams of soil was weighed and transferred into each pot (10 cm by 10 cm by 10 cm). Pot base and sides were externally wrapped in aluminum foil to prevent water loss from leaching. Sugarbeet was seeded using a standardized procedure, developed during preliminary experiments, for an accurate seeding depth of 2.5 cm as described by Bollman and Sprague (2008). Soil water content was represented as field capacities of 75 and 100%. Field capacities were calculated based on gravimetric water content at 100% field capacity. Soils were brought to respective field capacities prior to herbicide application. Pots contained five equally spaced sugarbeet seeds of one experimental variety and were watered to designated field capacities prior to herbicide application.

S-metolachlor was applied using a DeVries Generation III spray booth (Generation III, DeVries, Mfg., 86956 MN-251, Hollandale, MN 56045) that delivered 100 L ha^{-1} spray solution through TeeJet 8001XR nozzles (XR TeeJet Flat Fan Spray Tips, TeeJet Technologies, 200 W. North Ave, Glendale Heights, IL 60139) at 276 kPa and 4.8 km h^{-1}. Pots were transferred into a growth chamber set at 7 C and 15-h photoperiod after application to deliver a light intensity of 700 mE $m^{-2}s^{-1}$ (GR36L, Percival Scientific, Inc., 505 Research Drive, Perry, IA 50220) for 7 d. After 7 d, pots were transferred into growth chambers set at either 14 C (PT-80, Percival Scientific, Inc., 505 Research Drive, Perry, IA 50220) or 21 C (G-15, Environmental Growth Chambers, P.O. Box 390, 510 Washington Street, Chagrin Falls, OH 44022) and 15-h photoperiod that delivered a light intensity of 700 mE $m^{-2}s^{-1}$ for an additional 14 d. Tap water was added daily to maintain required field capacities.

Sugarbeet growth was measured and recorded for each pot as total fresh weight and average plant fresh weight after each 21-day replication cycle. Sugarbeet average plant fresh weight was calculated as total fresh weight divided by total sugarbeet emergence for each pot. Sugarbeet emergence was recorded daily and after each 21-day replication cycle. Average number of days to sugarbeet emergence was recorded for each sugarbeet singly, and the additive total of all sugarbeets within each pot was divided by the total number of emerged sugarbeet per pot.

Growth chamber data was analyzed using the GLM procedure in SAS. The controlled environment experiment was tested for significance of main effects and interactions. Data was tested at alpha $P \leq 0.05$.

3.2. Results and Discussion

Sources of variation include four main effects, six two-way interactions, four three-way interactions, and one four-way interaction (Table 14). The main effect of soil series was significant across all evaluated variables. Each main effect was significant for one or more dependent variables. Data tables for all non-significant interactions are in the appendix (Tables A4-A11).

Total fresh weight was significantly affected by the main effects of soil water, soil series, S-metolachlor rate, and the interaction of soil water by soil series (Table 14). Average fresh weight was significantly affected by the main effects of soil water, soil series, and S-metolachlor rate, and by the interaction of S-metolachlor rate by temperature. Pot emergence was significantly affected by the main effects of soil water and soil series, and by the interactions of soil series by temperature, soil water by temperature, soil water by soil series, and soil water by soil series by temperature. Average days to emergence was significantly affected by the main effects of soil water, soil series, and temperature, and by the interactions of soil water by soil series, soil water by temperature, and soil water by soil series by temperature.

Table 14. Sources of variation, degrees of freedom, and F-test results for the growth chamber controlled environment experiment. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence was evaluated.

Source of variation	df	Average fresh weight	Fresh weight	Days to emergence	Emergence
Capacity[a]	1	**[b]	NS	*	**
Rate	4	**	**	NS	NS
Soil	2	**	**	**	**
Temp	1	NS	NS	**	NS
Capacity*Rate	4	NS	NS	NS	NS
Capacity*Soil	2	NS	**	**	**
Capacity*Temp	1	NS	NS	*	**
Rate*Soil	8	NS	NS	NS	NS
Rate*Temp	4	*	NS	NS	NS
Soil*Temp	2	NS	NS	NS	**
Capacity*Rate*Soil	8	NS	NS	NS	NS
Capacity*Soil*Temp	2	NS	NS	**	**
Capacity*Rate*Temp	4	NS	NS	NS	NS
Rate*Soil*Temp	8	NS	NS	NS	NS
Capacity*Rate*Soil*Temp	8	NS	NS	NS	NS

[a]Capacity, rate, soil, and temp=field capacity, S-metolachlor rate, soil series, and temperature.
[b]*, ** indicates significant at $P \leq 0.05$ or 0.01 levels, respectively.

Soil series, averaged across all other factors, affected sugarbeet fresh weight, average fresh weight, emergence, and rate of emergence. Soil series varied in soil texture, clay content, and organic matter content. Bearden/Lindass, Fargo, and Glyndon soil series differed in texture, silt-loam, silty-clay, and sandy-loam, respectfully; clay content, 26.6, 54.0, and 9.5%, respectfully; and organic matter content, 4.7, 7.7, and 2.6%, respectfully.

Sugarbeet fresh weight, average fresh weight, and rate of emergence was greater for the Fargo soil, and tended to give greater emergence compared to the other soils evaluated. Emergence in the Bearden/Lindass soil was similar to the Fargo soil (Table 15). Emergence in the Bearden/Lindass soil was similar to the Fargo soil. Sugarbeet fresh weight, average fresh weight, emergence, and rate of emergence for the Glyndon soil was less than the other soils evaluated. Differences were most likely attributed to soil available water. Fargo and

Bearden/Lindass soils contained greater clay and organic matter content compared to the Glyndon soil, and as a result, the Fargo and Bearden/Lindass soils had greater soil available water (Saxton and Willey 2007). Differences in NO_3-N, across soils evaluated, did not affect sugarbeet germination and emergence; thus, NO_3-N was not normalized across soils. Sugarbeet uptake of nitrogen is greatest mid-season at growth stages beyond the cotyledon to 2-leaf sugarbeet stage attained in this experiment (Carter et al. 1974; Carter and Traveller 1981).

Table 15. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series.

Soil series	Average fresh weight	Fresh weight	Days to emergence	Emergence
	g $plant^{-1}$	g pot^{-1}	days	plant pot^{-1}
Bearden/Lindass	0.12	0.52	13.5	4.4
Fargo	0.18	0.78	12.9	4.4
Glyndon	0.04	0.17	14.9	3.2
LSD (0.05)	0.01	0.05	0.3	0.2

Soil water content, averaged across all other factors, affected sugarbeet average fresh weight, emergence, and rate of emergence (Table 16). However, soil water content did not affect sugarbeet fresh weight. The 100% soil field capacity caused greater sugarbeet average fresh weight, emergence, and rate of emergence, and, although not significant, was associated with greater fresh weight compared to the 75% field capacity. Soil water content had a greater impact on sugarbeet emergence than on sugarbeet growth. Differences may be attributed to less plant available water at 75% field capacity which may have led to drought stress and reductions in sugarbeet growth and emergence. Plant available water is the difference between field capacity and wilting point (Cassel and Nielsen 1986). At wilting point, plant growth no longer occurs, but the plant remains alive.

Table 16. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil field capacity.

Field capacity	Average fresh weight	Fresh weight	Days to emergence	Emergence
%	g plant^{-1}	g pot^{-1}	days	plant pot^{-1}
75	0.10	0.47	13.9	3.8
100	0.12	0.50	13.6	4.2
LSD (0.05)	0.01	NS	0.2	0.2

Soil water by soil series, averaged across all other factors, affected sugarbeet fresh weight, emergence, and rate of emergence (Table 17). However, the interaction of soil water by soil series did not affect sugarbeet average fresh weight. Soil series tended to have a greater impact on sugarbeet average fresh weight, days to emergence, and emergence than soil field capacity.

Sugarbeet fresh weight was greatest in the Fargo soil, moderate in the Bearden/Lindass soil, and least in the Glyndon soil. Differences were most likely attributed to soil available water. Fargo and Bearden/Lindass soils had greater clay and organic matter contents compared to the Glyndon soil, as a result, the Fargo and Bearden/Lindass soils had greater soil available water (Saxton and Willey 2007).

Sugarbeet emergence and rate of emergence was greatest in the Fargo and Bearden/Lindass soils at 75% soil field capacity and in the Glyndon soil at 100% field capacity, moderate in the Fargo and Bearden/Lindass soils at 100% soil field capacity, and least in the Glyndon soil at 75% soil field capacity (Table 17). Fargo and Bearden/Lindass soils contained greater clay and organic matter compared to the Glyndon soil, and as a result, the Fargo and Bearden/Lindass soils had greater soil available water (Saxton and Willey 2007). The greater soil available water of the Fargo and Bearden/Lindass soils, as compared to the Glyndon soil, may have attributed to differences in sugarbeet emergence and rate of emergence between soil field capacities. The decreased sugarbeet emergence at 100% soil field capacity in the Fargo and Bearden/Lindass soils may be a result of seedling-death due to consistently greater soil water compared to 75% soil field capacity. Seedlings germinating under high soil water conditions, or anaerobic conditions, may experience seedling-death. Anaerobic conditions lack the presence of oxygen and affect plant growth. Under anaerobic conditions, barnyard grass (*Echinochloa crus-galli*) primary leaves did not emerge and no root growth occurred (Kennedy et al. 1980). The lower soil available water of the Glyndon soil may have resulted in decreased water retention through losses of evaporation or percolation; thus, sugarbeet emergence was increased at 100% soil field capacity as the 75% soil field capacity may have resulted in drought stress. Soil crusting was likely not a factor that affected emergence as pots were watered daily which limited the possibility of soil crusting.

Table 17. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series and field capacity.

Treatment					
Soil series	Field capacity	Average fresh weight	Fresh weight	Days to emergence	Emergence
	%	g plant^{-1}	g pot^{-1}	days	plant pot^{-1}
Bearden/Lindass	75	0.11	0.54	13.6	4.8
Bearden/Lindass	100	0.13	0.49	13.5	4.0
Fargo	75	0.16	0.76	12.7	4.7
Fargo	100	0.20	0.79	13.2	4.0
Glyndon	75	0.04	0.10	15.9	1.8
Glyndon	100	0.05	0.22	14.2	4.6
LSD (0.05)		NS	0.07	0.4	0.3

S-metolachlor rate, averaged across all other factors, affected sugarbeet fresh weight and average fresh weight (Table 18). However, S-metolachlor rate did not affect sugarbeet emergence or rate of emergence. Reductions in sugarbeet fresh weight and average fresh weight were directly related to increased S-metolachlor rate. Sugarbeet fresh weight and average fresh weight decreased at S-metolachlor rates greater than 1.08 kg ai ha^{-1} (Table 18).

Reductions in sugarbeet growth were expected based on previously reported research. S-metolachlor is absorbed by sugarbeet shoots and roots and is metabolized and detoxified in by cleavage of the methyl-ether followed by conjugation with glucose or by conjugation of the chloroacetyl group with glutathione (Shaner 2014), a process which requires resources and energy. Differences in sugarbeet growth between the S-metolachlor rates may be attributed to a trade-off by the sugarbeet to metabolize S-metolachlor rather than continue active growth. S-metolachlor sugarbeet injury consisted of stunting and reduced plant growth (Bollman et al. 2008). S-metolachlor metabolism results in plant stress and may affect the plants ability to tolerate secondary abiotic or biotic stresses and may result in greater sugarbeet stand loss under unfavorable growing conditions, such as, abnormally cold temperature, abnormally high precipitation, or the presence of a pathogen.

Table 18. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by S-metolachlor rate.

Rate	Average fresh weight	Fresh weight	Days to emergence	Emergence
kg ai ha^{-1}	g plant^{-1}	g pot^{-1}	days	plant pot^{-1}
0.00	0.13	0.55	13.6	4.0
0.54	0.13	0.54	13.8	4.0
1.08	0.12	0.49	13.8	3.9
1.61	0.11	0.46	13.7	4.0
2.15	0.09	0.40	14.0	4.1
LSD (0.05)	0.01	0.06	NS	NS

Temperature, averaged across all other factors, affected sugarbeet rate of emergence (Table 19). However, temperature did not affect sugarbeet fresh weight, average fresh weight, or total emergence. The 21 C temperature resulted in a more rapid emergence compared to the 14 C temperature. Differences were expected based on previously reported research. The rate of most biological processes are affected by temperature (Russelle et al. 1984). Russelle et al. (1984) also stated that growth and development of organisms demonstrated a temperature response on many individual physiological processes. The relationship between temperature and crop development led to the development of additional methods to calculate and predict plant growth. One method developed was growing degree days (GDD) which are calculated as the average daily temperature divided by two followed by the subtraction of the base temperature (McMaster and Wilhelm 1997). The base temperature is crop specific and is related to the lowest temperature at which the crop actively grows.

The main effect of temperature was so important that the remaining three significant two-way interactions and one three-way interaction were temperature inclusive. The two-way interactions of temperature by soil water, temperature by soil series, and temperature by S-metolachlor rate were more affected by temperature than by the other factor. As a result, the two-way interactions were not discussed and data are in the appendix (Tables A12-A14).

Table 19. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by temperature.

Temperature	Average fresh weight	Fresh weight	Days to emergence	Emergence
C	g plant^{-1}	g pot^{-1}	days	plant pot^{-1}
14	0.12	0.51	14.3	4.0
21	0.11	0.46	13.2	3.9
LSD (0.05)	NS	NS	0.21	NS

The three-way interaction of soil water by soil series by temperature, averaged across S-metolachlor rates affected sugarbeet emergence and rate of emergence (Table 20). However, soil water by soil series by temperature did not affect sugarbeet fresh weight or average fresh weight. Three-way interactions are complex; thus, only trends can be discussed.

Differences in sugarbeet emergence tended to be more affected by the interaction of soil series and soil water, for reasons discussed prior, than by the effect of temperature. Sugarbeet rate of emergence tended to be more related to temperature, for reasons discussed prior, than by soil series or soil water. However, trends suggest soil series may have had a lesser, secondary effect.

The interaction of soil water by soil series by temperature represents the whole effect of environmental factors evaluated. The interaction was significant because soil water, soil series, and temperature are random variables in field production of sugarbeet, while S-metolachlor rate can be controlled the grower. Results indicated that sugarbeet emergence and rate of emergence were more affected by random variables, such as location and weather events, in commercial fields rather than by S-metolachlor rate.

Table 20. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series, field capacity, and temperature.

Treatment			Average fresh weight	Fresh weight	Days to emergence	Emergence
Soil series	F.C.[a]	Temperature				
	%	C	g $plant^{-1}$	g pot^{-1}	days	plant pot^{-1}
Bearden/Lindass	75	14	0.13	0.59	14.1	4.8
Bearden/Lindass	75	21	0.10	0.49	13.0	4.8
Bearden/Lindass	100	14	0.13	0.47	14.1	3.7
Bearden/Lindass	100	21	0.12	0.50	12.8	4.2
Fargo	75	14	0.17	0.79	13.2	4.6
Fargo	75	21	0.15	0.73	12.2	4.8
Fargo	100	14	0.21	0.82	13.6	3.8
Fargo	100	21	0.18	0.76	12.8	4.2
Glyndon	75	14	0.03	0.11	16.4	2.7
Glyndon	75	21	0.04	0.10	14.5	1.0
Glyndon	100	14	0.06	0.29	14.4	4.6
Glyndon	100	21	0.04	0.19	14.0	4.6
LSD (0.05)			NS	NS	0.5	0.5

[a]F.C.=Field capacity.

3.3. Summary

Soil series, soil water, and the interaction of soil series by soil water had the greatest effect on sugarbeet emergence and growth. S-metolachlor at rates greater than 1.08 kg ai ha^{-1} resulted in sugarbeet growth reductions. The main effect of temperature on sugarbeet rate of emergence was so important that the remaining three significant two-way interactions and one three-way interaction were temperature inclusive. The three-way interaction of soil water by soil series by temperature was significant because soil water, soil series, and temperature are random variables in field production of sugarbeet, while S-metolachlor rate can be controlled by the grower. As S-metolachlor rate increased, sugarbeet growth decreased, but S-metolachor did not affect sugarbeet emergence. Sugarbeet emergence was more dependent on soil series, soil water, and temperature than on S-metolachlor rate.

CHAPTER 4. S-METOLACHLOR SUGARBEET SAFETY VARIETY SCREEN

The controlled environment experiment examined the effects of S-metolachlor on sugarbeet emergence and growth. Results of the controlled environment experiment concluded that S-metolachlor caused reductions in sugarbeet growth, but did not affect emergence. Reductions in sugarbeet growth indicated other factors may interact with S-metolachlor and should be considered. Bollman et al. (2008) found genetic differences among sugarbeet varieties in response to S-metolachlor rates. The objective for this experiment was to determine how sugarbeet varieties responded to S-metolachlor applied preemergence.

4.1. Materials and Methods

The experiment was a complete randomized design with a factorial arrangement and eight replications. Replication was the experiment conducted over time. S-metolachlor was applied at 0 and 2.15 kg ai ha^{-1} to 36 sugarbeet varieties from five seed companies: Betaseed, Crystal, Hilleshog, Maribo (Maribo Seed International, Hojbygardvej 31, 4960 Holeby, Denmark), and SesVanderhave (SesVanderhave N.V., Industriepark, Soldatenplein Zone 2 Nr 15, 3300 Tienen Belgium). Wheatville loam series soil was collected at a depth of 0-15 cm from Crookston, MN, and analyzed for percent organic matter, NO_3-N, phosphorous, potassium, and pH (Table 21). Mechanical analysis was performed to determine soil texture of the soil series evaluated (Table 22). Gravimetric water content at field capacity was 41 percent.

Table 21. Soil nutrients, organic matter, and pH for the variety screen experiment.

Soil series	NO_3-N	P	K	OM	pH
	------------kg ha^{-1}------------			%	
Wheatville	18	15	93	3.3	8.6

Table 22. Soil texture for the variety screen experiment.

Soil series	Mechanical analysis			Soil texture
	Sand	Silt	Clay	
	----------------------	$g\ kg^{-1}$	----------------------	
Wheatville	493	312	195	Loam

Four hundred grams of soil was weighed and transferred into each pot (10 cm by 10 cm by 10 cm). Pot base and sides were externally wrapped in aluminum foil to prevent water loss from leaching. Sugarbeet was seeded using a standardized procedure, developed during preliminary experiments, for an accurate seeding depth of 2.5 cm as described by Bollman and Sprague (2008). Field capacity of 100% was calculated from measured gravimetric water content and maintained throughout the experiment based on calculated pot weight and daily surface irrigation. Pots contained five equally spaced sugarbeet seeds of one variety and were watered to 100% field capacity prior to herbicide application. S-metolachlor was applied using a DeVries Generation III spray booth that delivered 100 L ha^{-1} spray solution through TeeJet 8001XR nozzles at 276 kPa and 4.83 km h^{-1}. Pots were transferred into a growth chamber set at 14 C and 15-h photoperiod after application to deliver a light intensity of 700 mE $m^{-2}s^{-1}$ (PT-80, Percival Scientific, Inc., 505 Research Drive, Perry, IA 50220). Sugarbeet growth for each pot was measured and recorded as total fresh weight and average plant fresh weight after 14 days. Sugarbeet average plant fresh weight was calculated as total fresh weight divided by total emergence for each pot. Sugarbeet emergence for each pot was recorded at the conclusion of the experiment.

Data were analyzed using the ANOVA procedure in SAS. The data were analyzed for significance of main effects and the interaction. Data were tested at alpha $P \leq 0.05$.

4.2. Results and Discussion

S-metolachlor significantly affected sugarbeet fresh weight and average plant fresh weight, but did not affect emergence (Table 23). Differences among sugarbeet varieties were observed for sugarbeet average fresh weight, total fresh weight, and emergence. The S-metolachlor rate and sugarbeet variety interaction was not significant; thus, sugarbeet response to S-metolachlor was similar across varieties and varieties could not be categorized as tolerant or susceptible. Data from the S-metolachlor by sugarbeet variety interaction appear in the appendix (Table A15 and Table A16).

Table 23. Sources of variation, degrees of freedom, and F-test results for the variety screen experiment. Sugarbeet average fresh weight, fresh weight, and emergence were evaluated.

Source of variation	df	Average fresh weight	Fresh weight	Emergence
Rate	1	**[a]	**	NS
Variety	35	**	**	**
Rate*Variety	35	NS	NS	NS

[a]** indicates significant at $P \leq 0.01$.

S-metolachlor affected sugarbeet average fresh weight and fresh weight (Table 24). The untreated control pots had greater sugarbeet average fresh weight and fresh weight compared to the S-metoachlor treated pots. As expected, sugarbeet growth reduction and stunting from S-metolachlor applied preemergence occurred (Bollman and Sprague 2008; Bollman et al. 2008; Bollman and Sprague 2009; Dexter and Luecke 2004).

Table 24. Sugarbeet average fresh weight, fresh weight, and emergence as influenced by S-metolachlor.

Rate	Average fresh weight	Fresh weight	Emergence
kg ai ha^{-1}	g $plant^{-1}$	g pot^{-1}	plant pot^{-1}
0.00	0.06	0.25	4.4
2.15	0.04	0.19	4.3
LSD (0.05)	0.01	0.01	NS

Sugarbeet varieties differed in sugarbeet average fresh weight, total fresh weight, and emergence (Table 25). Differences in sugarbeet emergence or fresh weight were not specific to a seed source and are attributed to diverse genetics. The data indicated some varieties had less growth reduction or emergence compared to other varieties evaluated.

Results from this experiment are similar to results of a greenhouse experiment done by Bollman and Sprague (2008) considering growth reduction across 12 sugarbeet varieties. Although sugarbeet growth reduction from preemergence S-metolachlor occurred, Bollman and Sprague (2008) concluded that the sugarbeet varieties evaluated could not be separated into distinct tolerant and susceptible groups. However, Bollman and Sprague (2008) suggested that two sugarbeet varieties appeared to be less affected by S-metolachlor as compared to the other 10 varieties evaluated.

In a hydroponics metabolism study by Bollman et al. (2008), four sugarbeet varieties were evaluated for differences in tolerance to S-metolachlor using ^{14}C. Bollman et al. (2008) concluded there was a difference in sugarbeet variety tolerance. More tolerant sugarbeet varieties metabolized S-metolachlor at a greater rate compared to the less tolerant varieties (Bollman et al. 2008). A similar study in corn confirmed Bollman et al. (2008) results and also attributed the differences to a greater rate of metolachlor metabolism in the more tolerant corn variety (Rowe et al. 1990). However, neither of these studies, which reported varietal differences in sugarbeet and corn from S-metolachlor were grown in a field soil medium. A field soil medium would have most likely buffered sugarbeet, or corn, from uptake of greater concentrations of S-metolachlor because of the herbicides high affinity to adsorb to organic matter and clay content. In a soil medium, as was used in this variety screen experiment, varietal tolerance most likely would not have been distinguishable (Bollman and Sprague 2008).

Table 25. Sugarbeet average fresh weight, fresh weight, and emergence as influenced by sugarbeet variety.

Variety	Average fresh weight	Fresh weight	Emergence
	g plant^{-1}	g pot^{-1}	plant pot^{-1}
BTS 80RR52	0.061	0.28	4.50
BTS 82RR28	0.052	0.25	4.69
BTS 82RR33RP	0.057	0.27	4.69
BTS 83CNRP	0.043	0.21	4.81
BTS 8337RP	0.059	0.27	4.56
BTS 8363RP	0.057	0.27	4.56
CR 093RR	0.061	0.23	3.88
CR 101RR	0.060	0.27	4.50
CR 246RR	0.063	0.39	4.56
CR 247RR	0.060	0.28	4.63
CR 355RR	0.060	0.26	4.38
CR 981RR	0.053	0.25	4.44
CR 986RR	0.052	0.23	4.25
HM 4094RR	0.041	0.18	4.25
HM 4302RR	0.039	0.17	4.19
HM 4448RR	0.045	0.22	4.81
HM 9173RR	0.058	0.28	4.75
HM 9221RR	0.067	0.31	4.56
HM 9295RR	0.069	0.32	4.75
HM 9334RR	0.040	0.17	4.06
HM 9528RR	0.058	0.27	4.56
MA 102RR	0.045	0.21	4.56
MA 305RR	0.039	0.18	4.63
NT 9442RR	0.032	0.14	4.31
PM 9172RR	0.046	0.21	4.44
SV B14670013	0.043	0.20	4.63
SV 36175RR	0.026	0.08	2.81
SV 5115	0.055	0.22	4.13
SV 5120	0.060	0.27	4.56
SV 5215	0.047	0.22	4.63
SV 5234	0.047	0.21	4.50
SV 5237	0.036	0.15	4.13
SV 5307	0.041	0.18	4.19
SV 5310	0.034	0.12	3.56
SV 6296	0.048	0.18	3.63
SV 6427	0.037	0.16	4.25
LSD (0.05)	0.010	0.05	0.53

4.3. Summary

The variety screen experiment confirmed S-metolachlor causes sugarbeet growth reduction, but does not affect sugarbeet emergence. Genetic diversity affected sugarbeet growth and emergence. S-metolachlor response was the same across evaluated sugarbeet varieties; thus, a S-metolachlor tolerant variety was not identified.

CHAPTER 5. S-METOLACHLOR APPLICATION TIMING ON SUGARBEET SAFETY

Preemergence application is defined as the time interval between seeding and sugarbeet emergence. Early-postemergence application is defined as the time interval between emergence and sugarbeet at the four-leaf stage of development. Bollman et al. (2008) reiterated the primary site of S-metolachlor absorption was through the roots of sugarbeet seedlings. However, some S-metolachlor absorption occurs through the sugarbeet hypocotyl. Thus, sugarbeet safety from S-metolachlor should be greater early-postemergence compared to preemergence application. The objective of this experiment was to determine the effect of S-metolachlor application timing on sugarbeet crop safety when applied to two field soil mediums with different soil properties than the field soil describe by Bollman and Sprague (2008).

5.1. Materials and Methods

The experiment was a complete randomized design with a factorial arrangement and four replications. S-metolachlor was applied at 4.30 kg ai ha^{-1} at six different application time points and sugarbeet growth stages over two different soils. Application timings and growth stages were the day of planting; 3, 5, and 7 days after planting (DAP); cotelydon growth stage; and two-leaf growth stage of sugarbeet. Wheatville loam and Bearden silty-clay (Fine-silty, mixed, superactive, frigid Aeric Calciaquolls) series soils were acquired from Crookston, MN, and Moorhead, MN, respectfully (Soil Survey Staff 2017). Soils were analyzed for percent organic matter, NO_3-N, phosphorous, potassium, and pH (Table 26). Mechanical analysis was performed to determine soil texture of each soil series evaluated (Table 27). Gravimetric water content at field capacity for Wheatville and Bearden soils was 41 and 55%, respectively. Wheatville and Bearden series soils had clay and organic matter contents of 19.5 and 43.9%, and

3.3 and 5.0%, respectfully. The Wheatville series soil was the same source used in the S-metolachlor variety screen experiment.

Table 26. Soil nutrients, organic matter, and pH for the application timing experiment.

Soil series	NO_3-N	P	K	OM	pH
	------------kg ha^{-1}------------			%	
Bearden	61	46	492	5.0	8.2
Wheatville	18	15	93	3.3	8.6

Table 27. Soil texture for the application timing experiment.

	Mechanical analysis			
Soil series	Sand	Silt	Clay	Soil texture
	----------------------g kg^{-1}----------------------			
Bearden	43	518	439	Silty clay
Wheatville	493	312	195	Loam

Four hundred grams of soil were weighed and transferred into pots (10 cm by 10 cm by 10 cm). Pot base and sides were externally wrapped in aluminum foil to prevent water loss from leaching. Sugarbeet was seeded using a standardized procedure, developed as a result of preliminary experiments, for an accurate seeding depth of 2.5 cm as described by Bollman and Sprague (2008). A field capacity of 100% was calculated from the measured gravimetric water content. Pots contained five equally spaced sugarbeet seeds of an experimental variety and were watered prior to herbicide application. S-metolachlor was applied at 4.30 kg ai ha^{-1} using a DeVries Generation III spray booth that delivered a 100 L ha^{-1} spray solution through TeeJet 8001XR nozzles at 276 kPa and 4.83 km h^{-1}. Pots were transferred into a growth chamber set at 14 C and 15-h photoperiod after application to deliver a light intensity of 700 mE $m^{-2}s^{-1}$ (G-15, Environmental Growth Chambers, P.O. Box 390, 510 Washington Street, Chagrin Falls, OH 44022) for 21 days. Sugarbeet growth was measured and recorded for each pot as total fresh weight and average plant fresh weight after 21 days. Sugarbeet average plant fresh weight was calculated as total fresh weight divided by total sugarbeet emergence for each pot. Sugarbeet emergence for each pot was recorded at the conclusion of the experiment for each pot.

Data were analyzed using the ANOVA procedure in SAS. The data were analyzed for significance of main effects and the interaction. Data were tested at alpha $P \leq 0.05$.

5.2. Results and Discussion

Soil series, S-metolachlor application timing, and the interaction of soil series by S-metolachlor application timing were evaluated. Soil series significantly affected sugarbeet fresh weight, but did not affect average fresh weight or emergence (Table 28). S-metolachlor application timing significantly affected sugarbeet average fresh weight, fresh weight, and emergence. Soil series by S-metolachlor application timing interaction did not affect sugarbeet average fresh weight, fresh weight, or emergence and this data can be found in the appendix (Table A17).

Table 28. Sources of variation, degrees of freedom, and F-test results for the combined soils application timing experiment. Sugarbeet average fresh weight, fresh weight, and emergence were evaluated.

Source of variation	df	Average fresh weight	Fresh weight	Emergence
Soil	1	NS	**[a]	NS
Timing	6	**	**	**
Soil*Timing	6	NS	NS	NS

[a]** indicates significant at $P \leq 0.01$.

Soil series, averaged across S-metolachlor application timing, affected sugarbeet fresh weight, but did not affect average fresh weight or emergence (Table 29). Sugarbeet fresh weight was greater in the Bearden series soil than in the Wheatville series soil. Differences in sugarbeet fresh weight between soil series may be attributed to the greater clay and organic matter content of the Bearden soil. S-metolachlor stunts and reduces sugarbeet growth. S-metolachlor's environmental fate, biological activity, and persistence in the soil was greatly influenced by the herbicides adsorption to soil, clay complexes, and organic matter (Pusino et al. 1992; Shaner 2014; Shaner et al. 2006).

Table 29. Sugarbeet average fresh weight, fresh weight, and emergence as influenced by soil series.

Soil series	Average fresh weight	Fresh weight	Emergence
	g plant^{-1}	g pot^{-1}	number of plants
Bearden	0.08	0.31 a	4.04
Wheatville	0.07	0.24 b	3.57
LSD (0.01)	NS[b]	0.05	NS

S-metolachlor application timing, average across all soils, impacted sugarbeet fresh weight, average fresh weight, and emergence (Figure 2, Figure 3, and Figure 4). The data table can be found in the appendix (Table A18). Sugarbeet fresh weight was greatest following S-metolachlor application at the two-leaf growth stage, was moderate following S-metolachlor application at the 0, 3, and 7 DAP and cotyledon stage timings, and was least following S-metolachlor application at the 5 DAP timing (Figure 2). However, the 0, 3, and 7 DAP timings were not significantly different from the 5 DAP timing. Sugarbeet fresh weight at the two-leaf growth stage was similar to the untreated control. Sugarbeet average fresh weight was greatest at the two-leaf growth stage, moderate at the 0 DAP and cotyledon stage timings, and least at the 3, 5, and 7 DAP timings (Figure 3). However, the 0 DAP and cotyledon stage timings were not significantly different from the 3, 5, and 7 DAP timings. Sugarbeet average fresh weight at the two-leaf growth stage was similar to the untreated control.

Previous research indicates sugarbeet safety from S-metolachlor was greater at the cotyledon or two-leaf growth stages compared to preemergence (Bollman et al. 2008; Dexter and Luecke 2004). In a similar experiment, Bollman and Sprague (2008) concluded S-metolachlor applied preemergence and early-postemergence at two-leaf sugarbeet caused sugarbeet leaf crinkling and reduced growth compared to S-metolachlor applied to four-leaf sugarbeets. S-metolachlor applied preemergence reduced sugarbeet growth compared to S-metolachlor application at two-leaf sugarbeet, which was in agreement with results from this experiment. However, fresh weight following S-metolachlor application at two-leaf sugarbeet was not significantly different from the untreated control in this experiment, even though the S-metolachlor rate was 4.30 kg ai ha^{-1} compared to the 1.40 kg ai ha^{-1} rate used by Bollman and Sprague (2008). The difference between the results were most likely attributed to soil organic matter. The Bollman and Sprague (2008) study utilized Spinks loamy sand (sand, mixed mesic Psammentic Hapludalf) that contained 2.4% organic matter as compared to soil series evaluated in this experiment which had greater clay and organic matter content. Greater organic matter increases adsorption of S-metolachlor and decreases herbicide concentration in the soil solution which reduces availability of uptake in sugarbeet. A sandy textured soil with less organic matter, compared to soils evaluated in this experiment, may have resulted in growth reduction at the two-leaf sugarbeet application timing.

S-metolachlor preemergence application timing was 0, 3, 5, and 7 DAP with sugarbeet growth reduction being numerically greatest at the 5 and 7 DAP timing. A possible explanation for differences in S-metolachlor preemergence application timing may be related to the concentration of herbicide contacted by the sugarbeet. S-metolachlor applied preemergence to sugarbeet was broadcast onto the soil surface. Thus, the greatest concentration of S-metolachlor was located on the soil surface. Pots were watered daily through surface irrigation. Each irrigation event moved S-metolachlor deeper into the soil profile. S-metolachlor was diluted and adsorbed to more clay and organic matter content as the herbicide continued to percolate from the soil surface. S-metolachlor applied at 0 and 3 DAP would have contacted the recently seeded sugarbeet deeper in the soil profile at a lower concentration. However, S-metolachlor applied at

5 and 7 DAP would have contacted already germinated and emerging sugarbeet seedlings shallower in the soil profile at greater herbicide concentrations. Sugarbeet can metabolize lower concentrations of S-metolachlor more easily than higher concentrations; thus, the earlier preemergence application timings resulted in less growth reduction.

Sugarbeet emergence was greatest following S-metolachlor application 0 and 3 DAP, cotyledon stage, and two-leaf stage timings and least at the 5 and 7 DAP (Figure 4). However, S-metolachlor application 0 and 3 DAP were not significantly different from application 5 and 7 DAP. These results were not consistent with other growth chamber experiments that indicated S-metolachlor did not affect sugarbeet emergence. However, S-metolachlor rate may partially explain these differences between experiments. S-metolachlor was applied at 4.30 kg ai ha^{-1} in this experiment compared to 2.15 kg ai ha^{-1} for previous growth chamber experiments.

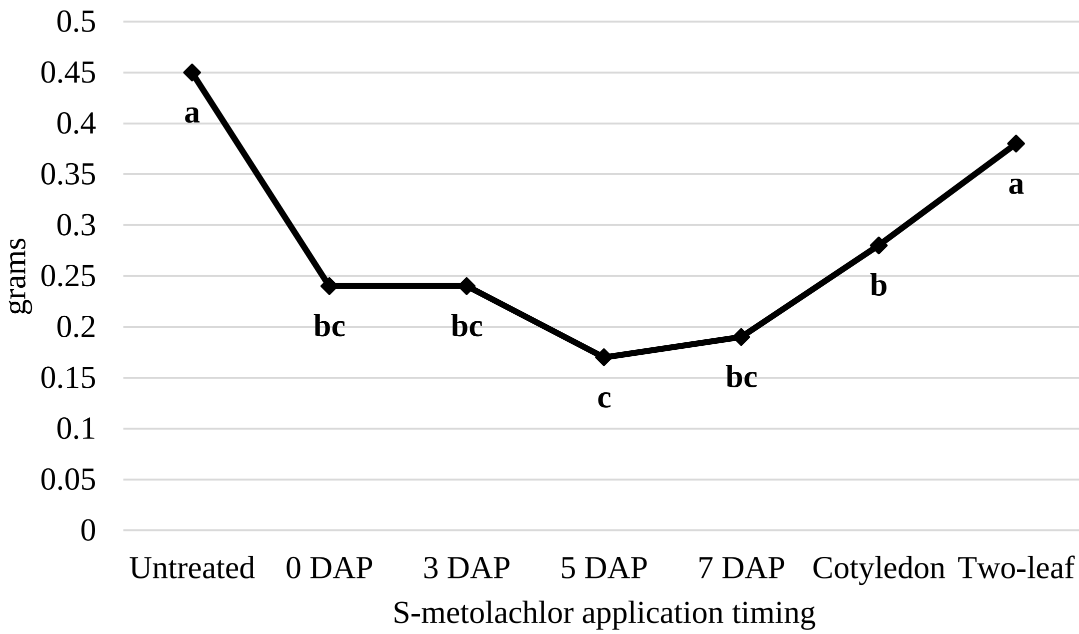

Figure 2. Sugarbeet fresh weight as influenced by S-metolachlor application timing averaged across soil series.

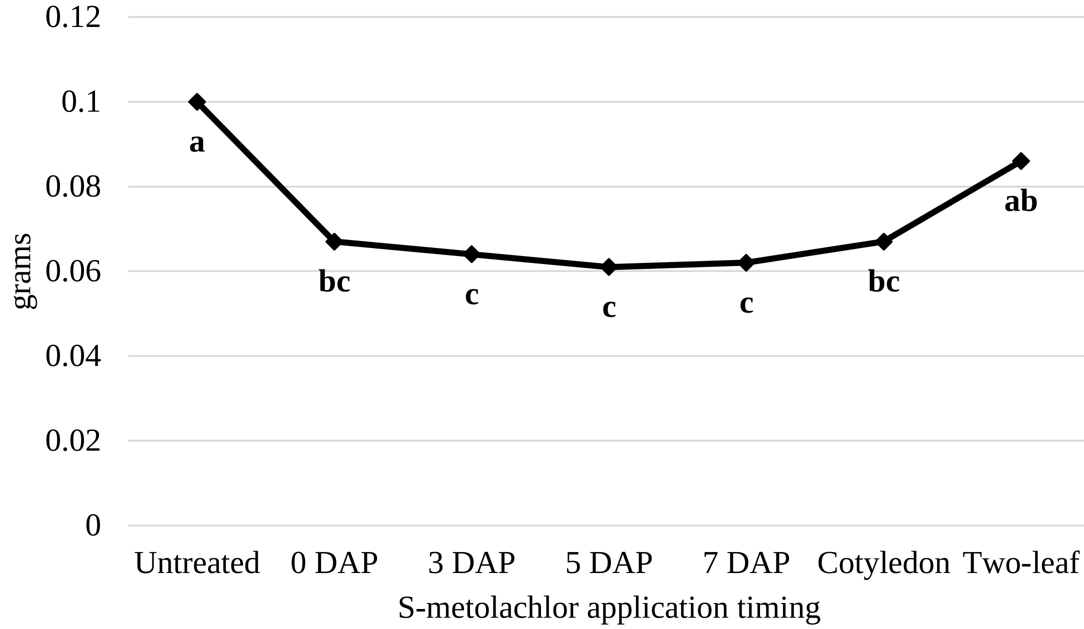

Figure 3. Sugarbeet average fresh weight as influenced by S-metolachlor application timing averaged across soil series.

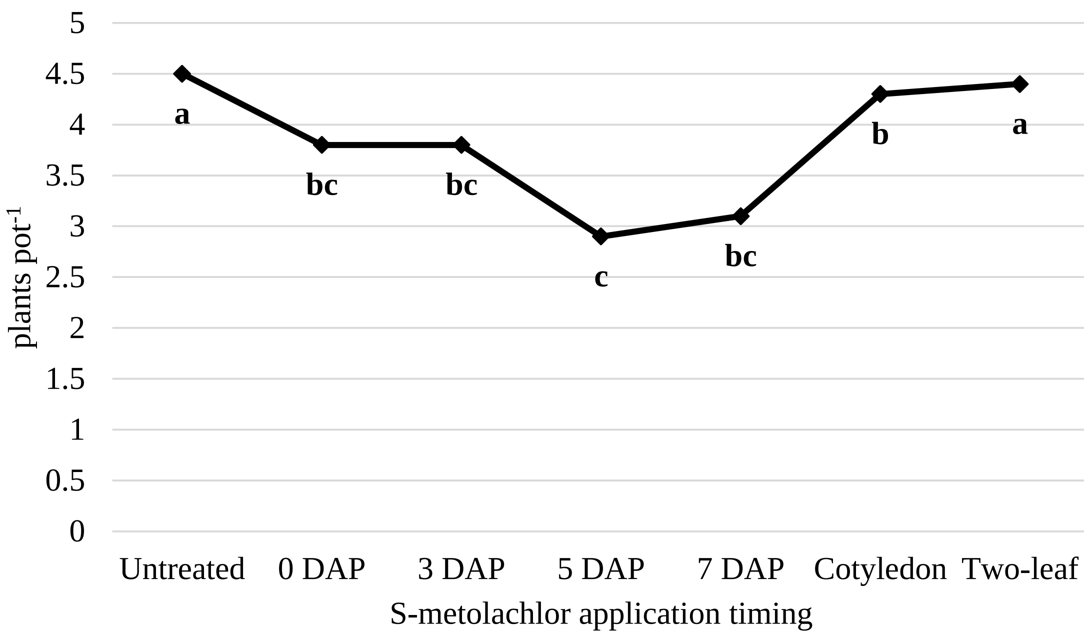

Figure 4. Sugarbeet emergence as influenced by S-metolachlor application timing averaged across soil series.

5.3. Summary

S-metolachlor was applied at a 4X use rate to measure sugarbeet response to application timing. S-metolachlor growth and emergence were impacted by S-metolachlor application timing in this experiment. Sugarbeet crop safety from S-metolachlor was greatest at two-leaf sugarbeet, moderate immediately after planting and at cotyledon sugarbeet, and least at preemergence application 3, 5, and 7 DAP. Sugarbeet growers should time S-metolachlor preemergence applications close to planting to minimize negative effect on sugarbeet crop safety.

CHAPTER 6. SUMMARY

Sugarbeet stand loss is the greatest concern when using S-metolachlor as a preemergence application. No sugarbeet stand loss occurred from S-metolachlor applied preemergence at 0.54 kg ai ha^{-1}. S-metolachlor at 1.08 and 2.15 kg ai ha^{-1} reduced sugarbeet stand, however, the stand loss was not sufficent to reduce sugarbeet root yield, quality, or extractable sucrose across all years and soil series evaluated. Thus, S-metolachlor may be recommend up to 2.15 kg ai ha^{-1} and, although growers may experience sugarbeet stand loss, growers may not experience loss in sugarbeet yield, quality, or extractable sucrose. However, not all environments or soils were evaluated in this experiment and growers with low clay and organic matter content soils should proceed with caution at rates greater than 0.54 kg ai ha^{-1}. Low clay and organic matter content soils in combination with above average precipitation may be at risk for yield losses.

Soil series, soil water, and the interaction of soil series by soil water had the greatest effect on sugarbeet emergence and growth. The three-way interaction of soil series by soil water by temperature was significant because soil series, soil water, and temperature are random variables in field production of sugarbeet, while S-metolachlor rate can be controlled the grower. S-metolachor stunted sugarbeet growth, but did not affect sugarbeet emergence. Sugarbeet emergence was most dependent on soil series, soil water, and temperature.

S-metolachlor affects sugarbeet varieties similarly, however, sugarbeet growth and emergence were impacted by S-metolachlor application timing. Sugarbeet crop safety from S-metolachlor was greatest at two-leaf stage sugarbeet, moderate immediately after planting and at the cotyledon growth stage, and least following preemergence application 3, 5, and 7 DAP. Sugarbeet growers should time S-metolachlor preemergence applications close to planting to minimize negative effect on sugarbeet crop safety.

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APPENDIX. TABLES

Table A1. Sugarbeet stand and percent sugar as influenced by S-metolachlor rates averaged across years and soil series.

S-metolachlor rate	Stand	Sugar
kg ai ha^{-1}	30.5 m	---%---
0	181.4	15.7
0.54	179.6	15.9
1.08	174.4	15.7
2.15	169.6	15.8
LSD (0.01)	6.1	NS

Table A2. Sugarbeet stand as influenced by the interaction of S-metolachlor rate by soil series in the moderate organic matter content group.

Environment			
Year	Soil series	S-metolachlor rate	Stand
		kg ai ha^{-1}	plants 30.5 m^{-1}
2015	2015 Croke	0	119
2015	2015 Croke	0.54	106
2015	2015 Croke	1.08	94
2015	2015 Croke	2.15	86
2015	2015 Osakis	0	223
2015	2015 Osakis	0.54	220
2015	2015 Osakis	1.08	220
2015	2015 Osakis	2.15	211
2016	2016 Croke	0	174
2016	2016 Croke	0.54	174
2016	2016 Croke	1.08	171
2016	2016 Croke	2.15	173
LSD (0.05)			NS

Table A3. Sugarbeet stand as influenced by the interaction of S-metolachlor rate by soil series in the high organic matter content group.

Environment			
Year	Soil series	S-metolachlor	Stand
		kg ai ha^{-1}	plants 30.5 m^{-1}
2015	Bearden/Lindass	0	203
2015	Bearden/Lindass	0.54	194
2015	Bearden/Lindass	1.08	195
2015	Bearden/Lindass	2.15	197
2015	Seaforth	0	197
2015	Seaforth	0.54	197
2015	Seaforth	1.08	190
2015	Seaforth	2.15	195
2016	Bearden/Quam	0	173
2016	Bearden/Quam	0.54	179
2016	Bearden/Quam	1.08	180
2016	Bearden/Quam	2.15	174
LSD (0.05)			NS

Table A4. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series and S-metolachlor rate.

Treatment		Average fresh	Fresh	Days to	
Soil series	Rate	weight	weight	emergence	Emergence
	kg ha^{-1}	g plant^{-1}	g	days	plant #
Bear/Lind[a]	0.00	0.15	0.63	13.4	4.4
Bear/Lind	0.54	0.14	0.60	13.4	4.4
Bear/Lind	1.08	0.12	0.50	13.8	4.3
Bear/Lind	1.61	0.11	0.45	13.4	4.2
Bear/Lind	2.15	0.09	0.40	13.6	4.5
Fargo	0.00	0.20	0.83	12.8	4.2
Fargo	0.54	0.19	0.83	13.0	4.5
Fargo	1.08	0.19	0.80	13.0	4.3
Fargo	1.61	0.17	0.76	12.8	4.3
Fargo	2.15	0.15	0.65	13.1	4.5
Glyndon	0.00	0.05	0.19	14.7	3.3
Glyndon	0.54	0.05	0.19	15.0	3.0
Glyndon	1.08	0.04	0.18	14.6	3.1
Glyndon	1.61	0.04	0.16	14.8	3.5
Glyndon	2.15	0.03	0.14	15.2	3.3
LSD (0.05)		NS	NS	NS	NS

[a]Bear/Lind=Bearden/Lindass soil series.

Table A5. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by S-metolachlor rate and field capacity.

Treatment					
Rate	Field capacity	Average fresh weight	Fresh weight	Days to emergence	Emergence
kg ha^{-1}	%	g $plant^{-1}$	g	days	plant #
0.00	75	0.12	0.52	13.7	3.8
0.00	100	0.14	0.58	13.5	4.1
0.54	75	0.11	0.52	14.0	3.8
0.54	100	0.14	0.56	13.6	4.1
1.08	75	0.11	0.49	13.8	3.6
1.08	100	0.12	0.50	13.8	4.3
1.61	75	0.10	0.43	13.9	3.9
1.61	100	0.12	0.48	13.4	4.1
2.15	75	0.08	0.39	14.2	3.8
2.15	100	0.10	0.40	13.8	4.3
LSD (0.05)		NS	NS	NS	NS

Table A6. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series, S-metolachlor rate, and temperature.

Treatment			Average fresh weight	Fresh weight	Days to emergence	Emergence
Soil series	Rate	Temperature				
	kg ha^{-1}	C	g plant^{-1}	g	days	plant #
Bear/Lind[a]	0.00	14	0.14	0.60	14.2	4.3
Bear/Lind	0.00	21	0.15	0.66	12.5	4.4
Bear/Lind	0.54	14	0.15	0.62	14.0	4.3
Bear/Lind	0.54	21	0.13	0.58	12.9	4.5
Bear/Lind	1.08	14	0.12	0.50	14.5	4.1
Bear/Lind	1.08	21	0.11	0.50	13.1	4.5
Bear/Lind	1.61	14	0.12	0.48	14.0	4.0
Bear/Lind	1.61	21	0.10	0.41	12.8	4.3
Bear/Lind	2.15	14	0.10	0.45	14.0	4.4
Bear/Lind	2.15	21	0.07	0.34	13.2	4.7
Fargo	0.00	14	0.19	0.77	13.6	4.1
Fargo	0.00	21	0.21	0.89	12.0	4.3
Fargo	0.54	14	0.21	0.89	13.2	4.3
Fargo	0.54	21	0.17	0.78	12.8	4.7
Fargo	1.08	14	0.21	0.86	13.2	4.2
Fargo	1.08	21	0.17	0.74	12.8	4.4
Fargo	1.61	14	0.20	0.85	13.2	4.0
Fargo	1.61	21	0.15	0.67	12.4	4.6
Fargo	2.15	14	0.16	0.66	13.8	4.4
Fargo	2.15	21	0.14	0.65	12.4	4.5
Glyndon	0.00	14	0.05	0.19	15.1	3.6
Glyndon	0.00	21	0.05	0.19	14.2	3.0
Glyndon	0.54	14	0.05	0.17	15.8	3.0
Glyndon	0.54	21	0.05	0.21	14.1	2.9
Glyndon	1.08	14	0.05	0.22	15.3	3.6
Glyndon	1.08	21	0.04	0.14	13.9	2.7
Glyndon	1.61	14	0.05	0.23	15.2	4.3
Glyndon	1.61	21	0.03	0.08	14.8	2.8
Glyndon	2.15	14	0.05	0.19	15.7	3.8
Glyndon	2.15	21	0.02	0.08	14.8	2.8
LSD (0.05)			NS	NS	NS	NS

[a]Bear/Lind=Bearden/Lindass soil series.

Table A7. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series, S-metolachlor rate, and field capacity.

Treatment						
Soil series	Rate	F.C.[a]	Average fresh weight	Fresh weight	Days to emergence	Emergence
	$kg\ ha^{-1}$	%	$g\ plant^{-1}$	g	days	plant #
Bear/Lind[b]	0.00	75	0.13	0.64	13.3	4.8
Bear/Lind	0.00	100	0.16	0.62	13.4	3.9
Bear/Lind	0.54	75	0.13	0.63	13.5	4.9
Bear/Lind	0.54	100	0.15	0.57	13.3	3.9
Bear/Lind	1.08	75	0.12	0.56	13.6	4.6
Bear/Lind	1.08	100	0.11	0.44	13.9	4.0
Bear/Lind	1.61	75	0.10	0.48	13.6	4.8
Bear/Lind	1.61	100	0.12	0.42	13.1	3.6
Bear/Lind	2.15	75	0.09	0.42	13.7	4.8
Bear/Lind	2.15	100	0.09	0.38	13.5	4.3
Fargo	0.00	75	0.18	0.80	12.6	4.5
Fargo	0.00	100	0.22	0.86	13.0	3.9
Fargo	0.54	75	0.17	0.82	12.6	4.8
Fargo	0.54	100	0.20	0.85	13.5	4.2
Fargo	1.08	75	0.17	0.80	12.7	4.7
Fargo	1.08	100	0.21	0.80	13.4	3.9
Fargo	1.61	75	0.15	0.71	12.7	4.7
Fargo	1.61	100	0.19	0.81	12.9	3.9
Fargo	2.15	75	0.14	0.68	12.9	4.9
Fargo	2.15	100	0.16	0.62	13.3	4.0
Glyndon	0.00	75	0.04	0.13	15.3	2.2
Glyndon	0.00	100	0.06	0.25	14.0	4.4
Glyndon	0.54	75	0.04	0.11	15.8	1.6
Glyndon	0.54	100	0.06	0.27	14.1	4.3
Glyndon	1.08	75	0.04	0.11	15.0	1.4
Glyndon	1.08	100	0.05	0.25	14.2	4.8
Glyndon	1.61	75	0.04	0.10	15.3	2.2
Glyndon	1.61	100	0.04	0.21	14.3	4.8
Glyndon	2.15	75	0.02	0.07	16.0	1.8
Glyndon	2.15	100	0.04	0.21	14.5	4.7
LSD (0.05)			NS	NS	NS	NS

[a]F.C.=Field capacity.
[b]Bear/Lind=Bearden/Lindass soil series.

Table A8. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by S-metolachlor rate, field capacity, and temperature.

Treatment						
Rate	F.C.[a]	Temperature	Average fresh weight	Fresh weight	Days to emergence	Emergence
kg ha^{-1}	%	°C	g $plant^{-1}$	g	days	plant #
0.00	75	14	0.12	0.50	14.4	4.0
0.00	75	21	0.12	0.54	13.1	3.7
0.00	100	14	0.14	0.54	14.2	4.0
0.00	100	21	0.15	0.61	12.7	4.2
0.54	75	14	0.11	0.53	14.8	3.9
0.54	75	21	0.11	0.51	13.1	3.7
0.54	100	14	0.15	0.58	13.9	3.9
0.54	100	21	0.12	0.54	13.4	4.4
1.08	75	14	0.12	0.51	14.5	3.8
1.08	75	21	0.10	0.47	13.1	3.3
1.08	100	14	0.14	0.54	14.2	4.1
1.08	100	21	0.11	0.46	13.5	4.4
1.61	75	14	0.11	0.52	14.4	4.3
1.61	75	21	0.08	0.34	13.4	3.4
1.61	100	14	0.14	0.53	13.9	3.8
1.61	100	21	0.10	0.44	13.0	4.4
2.15	75	14	0.09	0.43	14.9	4.1
2.15	75	21	0.08	0.35	13.5	3.6
2.15	100	14	0.11	0.44	14.1	4.3
2.15	100	21	0.09	0.37	13.5	4.3
LSD (0.05)			NS	NS	NS	NS

[a]F.C.=Field capacity.

Table A9. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series, S-metolachlor, field capacity, and temperature in Bearden/Lindass soil.

Treatment				Average fresh weight	Fresh weight	Days to emergence	Emergence
Soil series	Rate	F.C.[a]	Temp[b]				
	kg ha^{-1}	%	C	g $plant^{-1}$	g	days	plant #
Bear/Lind[c]	0.00	75	14	0.13	0.62	14.0	4.8
Bear/Lind	0.00	75	21	0.14	0.66	12.6	4.8
Bear/Lind	0.00	100	14	0.16	0.59	14.4	3.8
Bear/Lind	0.00	100	21	0.17	0.66	12.5	4.0
Bear/Lind	0.54	75	14	0.14	0.66	14.1	4.8
Bear/Lind	0.54	75	21	0.12	0.59	13.0	5.0
Bear/Lind	0.54	100	14	0.15	0.57	13.9	3.8
Bear/Lind	0.54	100	21	0.14	0.57	12.7	4.0
Bear/Lind	1.08	75	14	0.13	0.60	14.2	4.7
Bear/Lind	1.08	75	21	0.12	0.53	13.1	4.5
Bear/Lind	1.08	100	14	0.11	0.41	14.7	3.5
Bear/Lind	1.08	100	21	0.11	0.47	13.2	4.5
Bear/Lind	1.61	75	14	0.12	0.59	14.2	4.8
Bear/Lind	1.61	75	21	0.08	0.36	13.1	4.7
Bear/Lind	1.61	100	14	0.12	0.37	13.8	3.2
Bear/Lind	1.61	100	21	0.12	0.46	12.5	4.0
Bear/Lind	2.15	75	14	0.11	0.50	14.2	4.7
Bear/Lind	2.15	75	21	0.07	0.33	13.2	4.8
Bear/Lind	2.15	100	14	0.10	0.41	13.8	4.2
Bear/Lind	2.15	100	21	0.08	0.35	13.3	4.5
LSD (0.05)				NS	NS	NS	NS

[a]F.C.=Field capacity.
[b]Temp=Temperature.
[c]Bear/Lind=Bearden/Lindass soil series.

Table A10. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence by soil series, S-metolachlor rate, field capacity, temperature interaction in Fargo soil.

Treatment				Average fresh weight	Fresh weight	Days to emergence	Emergence
Soil series	Rate	F.C.[a]	Temp[b]				
	kg ha^{-1}	%	C	g plant^{-1}	g	days	plant #
Fargo	0.00	75	14	0.18	0.79	13.2	4.3
Fargo	0.00	75	21	0.18	0.82	12.0	4.7
Fargo	0.00	100	14	0.19	0.76	14.0	3.8
Fargo	0.00	100	21	0.24	0.95	12.1	4.0
Fargo	0.54	75	14	0.18	0.87	13.0	4.8
Fargo	0.54	75	21	0.16	0.78	12.1	4.8
Fargo	0.54	100	14	0.23	0.91	13.5	3.8
Fargo	0.54	100	21	0.17	0.78	13.5	4.5
Fargo	1.08	75	14	0.18	0.83	13.1	4.5
Fargo	1.08	75	21	0.16	0.76	12.2	4.8
Fargo	1.08	100	14	0.23	0.88	13.4	3.8
Fargo	1.08	100	21	0.19	0.72	13.4	4.0
Fargo	1.61	75	14	0.17	0.78	13.2	4.5
Fargo	1.61	75	21	0.13	0.63	12.3	4.8
Fargo	1.61	100	14	0.22	0.91	13.3	3.5
Fargo	1.61	100	21	0.17	0.72	12.5	4.3
Fargo	2.15	75	14	0.14	0.68	13.6	4.8
Fargo	2.15	75	21	0.14	0.69	12.2	5.0
Fargo	2.15	100	14	0.17	0.63	13.9	4.0
Fargo	2.15	100	21	0.15	0.62	12.7	4.0
LSD (0.05)				NS	NS	NS	NS

[a]F.C.=Field capacity.
[b]Temp=Temperature.

Table A11. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series, S-metolachlor rate, field capacity, and temperature in Glyndon soil.

Treatment				Average			
Soil series	Rate	F.C.[a]	Temp[b]	Average fresh weight	Fresh weight	Days to emergence	Emergence
	kg ha^{-1}	%	C	g plant^{-1}	g	days	plant #
Glyndon	0.00	75	14	0.03	0.11	15.9	2.8
Glyndon	0.00	75	21	0.04	0.15	14.8	1.5
Glyndon	0.00	100	14	0.06	0.27	14.3	4.3
Glyndon	0.00	100	21	0.05	0.23	13.7	4.5
Glyndon	0.54	75	14	0.02	0.06	17.4	2.0
Glyndon	0.54	75	21	0.05	0.15	14.2	1.2
Glyndon	0.54	100	14	0.07	0.27	14.3	4.0
Glyndon	0.54	100	21	0.06	0.27	14.0	4.7
Glyndon	1.08	75	14	0.04	0.11	16.1	2.2
Glyndon	1.08	75	21	0.04	0.12	13.9	0.7
Glyndon	1.08	100	14	0.07	0.34	14.4	5.0
Glyndon	1.08	100	21	0.04	0.17	14.0	4.7
Glyndon	1.61	75	14	0.04	0.17	15.9	3.7
Glyndon	1.61	75	21	0.04	0.03	14.8	0.7
Glyndon	1.61	100	14	0.06	0.29	14.5	4.8
Glyndon	1.61	100	21	0.03	0.14	14.1	4.8
Glyndon	2.15	75	14	0.03	0.10	16.8	2.7
Glyndon	2.15	75	21	0.02	0.04	15.1	1.0
Glyndon	2.15	100	14	0.06	0.28	14.5	4.8
Glyndon	2.15	100	21	0.03	0.13	14.4	4.5
LSD (0.05)				NS	NS	NS	NS

[a]F.C.=Field capacity.
[b]Temp=Temperature.

Table A12. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by field capacity and temperature.

Treatment					
Field capacity	Temperature	Average fresh weight	Fresh weight	Days to emergence	Emergence
%	C	g plant^{-1}	g pot^{-1}	days	plant pot^{-1}
75	14	0.11	0.50	14.6	4.01
75	21	0.10	0.44	13.2	3.53
100	14	0.13	0.53	14.0	4.03
100	21	0.12	0.48	13.2	4.33
LSD (0.05)		NS	NS	0.3	0.27

Table A13. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by soil series and temperature.

Treatment		Average fresh	Fresh	Days to	
Soil series	Temperature	weight	weight	emergence	Emergence
	C	g plant^{-1}	g pot^{-1}	days	plant pot^{-1}
Bearden/Lindass	14	0.13	0.53	14.1	4.23
Bearden/Lindass	21	0.11	0.50	12.9	4.48
Fargo	14	0.19	0.81	13.4	4.20
Fargo	21	0.17	0.75	12.5	4.50
Glyndon	14	0.05	0.20	15.4	3.63
Glyndon	21	0.04	0.14	14.3	2.82
LSD (0.05)		NS	NS	NS	0.33

Table A14. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence as influenced by S-metolachlor rate and temperature.

Treatment		Average		Days to	
Rate	Temperature	fresh weight	Fresh weight	emergence	Emergence
kg ai ha^{-1}	C	g plant^{-1}	g pot^{-1}	days	plant pot^{-1}
0.00	14	0.13	0.52	14.3	4.0
0.00	21	0.14	0.58	12.9	3.9
0.54	14	0.13	0.56	14.3	3.9
0.54	21	0.12	0.52	13.3	4.0
1.08	14	0.13	0.53	14.3	3.9
1.08	21	0.11	0.46	13.3	3.9
1.61	14	0.12	0.52	14.1	4.1
1.61	21	0.09	0.39	13.2	3.9
2.15	14	0.10	0.43	14.5	4.2
2.15	21	0.08	0.36	13.5	4.0
LSD (0.05)		0.02	NS[a]	NS[a]	NS

[a]Not statistically significant, however, perhaps with added replication and associated precision this observation may, or may not, have been significant.

Table A15. Sugarbeet average fresh weight, fresh weight, and emergence as influenced by sugarbeet variety and S-metolachlor rate.

Treatment				
Variety	Rate	Average fresh weight	Fresh weight	Emergence
	kg ha^{-1}	g $plant^{-1}$	g	plant #
BTS 80RR52	0.00	0.07	0.30	4.6
BTS 82RR28	0.00	0.07	0.31	4.6
BTS 82RR33RP	0.00	0.05	0.23	4.6
BTS 83CNRP	0.00	0.06	0.28	4.9
BTS 8337RP	0.00	0.07	0.33	4.6
BTS 8363RP	0.00	0.07	0.31	4.5
CR 093RR	0.00	0.08	0.29	3.6
CR 101RR	0.00	0.07	0.29	4.3
CR 246RR	0.00	0.07	0.34	4.9
CR 247RR	0.00	0.06	0.30	4.8
CR 355RR	0.00	0.06	0.29	4.5
CR 981RR	0.00	0.06	0.30	4.6
CR 986RR	0.00	0.06	0.27	4.5
HM 4094RR	0.00	0.05	0.23	4.8
HM 4302RR	0.00	0.05	0.21	4.0
HM 4448RR	0.00	0.08	0.36	4.6
HM 9173RR	0.00	0.05	0.20	4.3
HM 9221RR	0.00	0.07	0.33	4.9
HM 9295RR	0.00	0.04	0.20	4.4
HM 9334RR	0.00	0.07	0.32	4.4
HM 9528RR	0.00	0.06	0.30	4.8
MA 102RR	0.00	0.05	0.21	4.5
MA 305RR	0.00	0.05	0.21	4.4
NT 9442RR	0.00	0.04	0.15	4.1
PM 9172RR	0.00	0.05	0.21	4.3
SV B14670013	0.00	0.04	0.13	3.4
SV 36175RR	0.00	0.05	0.25	4.8
SV 5115	0.00	0.04	0.18	4.1
SV 5120	0.00	0.05	0.24	4.6
SV 5215	0.00	0.04	0.18	4.4
SV 5234	0.00	0.05	0.24	4.9
SV 5237	0.00	0.05	0.23	4.6
SV 5307	0.00	0.06	0.21	3.6
SV 5310	0.00	0.03	0.10	2.8
SV 6296	0.00	0.06	0.24	4.1
SV 6427	0.00	0.07	0.31	4.6
LSD (0.05)		NS	NS	NS

Table A16. Sugarbeet average fresh weight, fresh weight, days to emergence, and emergence by sugarbeet variety and S-metolachlor rate interaction.

Treatment				
Variety	Rate	Average fresh weight	Fresh weight	Emergence
	kg ha^{-1}	g $plant^{-1}$	g	plant #
BTS 80RR52	2.15	0.05	0.23	4.6
BTS 82RR28	2.15	0.05	0.23	4.8
BTS 82RR33RP	2.15	0.04	0.19	4.8
BTS 83CNRP	2.15	0.04	0.21	4.8
BTS 8337RP	2.15	0.05	0.22	4.4
BTS 8363RP	2.15	0.05	0.23	4.5
CR 093RR	2.15	0.04	0.17	4.1
CR 101RR	2.15	0.05	0.26	4.8
CR 246RR	2.15	0.06	0.26	4.3
CR 247RR	2.15	0.06	0.26	4.5
CR 355RR	2.15	0.06	0.24	4.3
CR 981RR	2.15	0.04	0.19	4.3
CR 986RR	2.15	0.05	0.19	4.0
HM 4094RR	2.15	0.04	0.20	4.9
HM 4302RR	2.15	0.03	0.13	4.4
HM 4448RR	2.15	0.06	0.29	4.9
HM 9173RR	2.15	0.03	0.14	3.9
HM 9221RR	2.15	0.05	0.24	4.6
HM 9295RR	2.15	0.04	0.17	4.1
HM 9334RR	2.15	0.06	0.29	4.8
HM 9528RR	2.15	0.05	0.24	4.4
MA 102RR	2.15	0.04	0.20	4.6
MA 305RR	2.15	0.03	0.15	4.6
NT 9442RR	2.15	0.03	0.12	4.5
PM 9172RR	2.15	0.04	0.21	4.6
SV B14670013	2.15	0.03	0.11	3.8
SV 36175RR	2.15	0.04	0.19	4.5
SV 5115	2.15	0.03	0.13	4.4
SV 5120	2.15	0.03	0.11	3.8
SV 5215	2.15	0.03	0.13	3.9
SV 5234	2.15	0.05	0.19	4.1
SV 5237	2.15	0.04	0.16	4.6
SV 5307	2.15	0.04	0.14	3.6
SV 5310	2.15	0.02	0.05	2.9
SV 6296	2.15	0.05	0.21	4.1
SV 6427	2.15	0.05	0.23	4.5
LSD (0.05)		NS	NS	NS

Table A17. Sugarbeet average fresh weight, fresh weight, and emergence as influenced by soil series and S-metolachlor application timing.

Treatment				
Soil series	Timing	Average fresh weight	Fresh weight	Emergence
		g plant^{-1}	g	plant #
Bearden	Untreated	0.12	0.52	4.5
Bearden	0 DAP[a]	0.06	0.27	4.3
Bearden	3 DAP	0.07	0.29	4.5
Bearden	5 DAP	0.05	0.19	3.3
Bearden	7 DAP	0.07	0.23	3.3
Bearden	Cotelydon	0.07	0.28	4.0
Bearden	Two leaf	0.09	0.42	4.5
Wheatville	Untreated	0.08	0.38	4.5
Wheatville	0 DAP	0.07	0.21	3.3
Wheatville	3 DAP	0.06	0.18	3.0
Wheatville	5 DAP	0.07	0.15	2.5
Wheatville	7 DAP	0.06	0.16	3.0
Wheatville	Cotelydon	0.06	0.28	4.5
Wheatville	Two leaf	0.08	0.34	4.3
LSD (0.05)		NS	NS	NS

[a]DAP=Days after planting

Table A18. Sugarbeet average fresh weight, fresh weight, and emergence as influenced by S-metolachlor application timing.

Timing	Average fresh weight	Fresh weight	Emergence
	g plant^{-1}	g	plant #
Untreated	0.10 a[b]	0.45 a	4.5 a
0 DAP[a]	0.07 bc	0.24 bc	3.8 ab
3 DAP	0.06 c	0.24 bc	3.8 ab
5 DAP	0.06 c	0.17 c	2.9 b
7 DAP	0.06 c	0.19 bc	3.1 b
Cotelydon	0.07 bc	0.28 b	4.3 a
Two leaf	0.09 ab	0.38 a	4.4 a

[a]DAP=Days after planting
[b]Numbers followed by the same letter within each observation are not significantly different according to probability of difference ($P \leq 0.01$).