IMPACT AND MANAGEMENT OF GLYPHOSATE-RESISTANT VOLUNTEER CORN IN GLYPHOSATE-RESISTANT SUGARBEET

By

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ABSTRACT

IMPACT AND MANAGEMENT OF GLYPHOSATE-RESISTANT VOLUNTEER CORN IN GLYPHOSATE-RESISTANT SUGARBEET

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Glyphosate-resistant (GR) volunteer corn is one of the most common weed problems found in GR sugarbeet grown in Michigan. Field trials were conducted in 2012 and 2013 at two locations in Michigan. The objectives were to: 1) quantify the impact of GR volunteer corn on GR sugarbeet yield and quality in wide and narrow rows, and 2) identify the optimal time and herbicide for control of GR volunteer corn. A greenhouse trial was also conducted to determine if early-season competition for nitrogen may be contributing to the sugarbeet yield losses associated with volunteer corn. Volunteer corn biomass was 64%, 19%, and 31% lower in narrow rows than in wide rows when combined over volunteer corn densities at Richville 2012, East Lansing 2013, and Richville 2013, respectively. When data were combined over row width, sugarbeet yield was reduced by an average of 19% and 22.5% when GR volunteer corn competed season-long at a density of 1.72 plants m^{-2} and 3.44 plants m^{-2}, respectively.

Volunteer corn emerging simultaneously with sugarbeet required the earliest control to avoid yield loss. When volunteer corn was not controlled prior to the V4 growth stage, sugarbeet yield was reduced by 10%. Greenhouse research indicated that early-season competition for nitrogen is not likely the primary factor contributing to the suppression of sugarbeet growth and yield by volunteer corn. Clethodim and quizalofop were equally effective at controlling volunteer corn in sugarbeet. Implementing timely volunteer corn control strategies and planting sugarbeet in narrow rows can help alleviate the impact that volunteer corn has on sugarbeet yield and quality.

Dedicated to Mary G. Harden
April 27, 1923 – December 30, 2012

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CHAPTER 1

LITERATURE REVIEW

Introduction

Sugarbeet (*Beta vulgaris* L.) is a biennial species grown as an annual crop in temperate regions of the world for the production of sugar. In 2013, 175 million T of centrifugal sugar were produced worldwide (FAS et al. 2013). The United States contributed 8.1 million T, of which 52% came from sugarbeet (NASS 2014a). Minnesota, North Dakota, Idaho, and Michigan are the top sugarbeet producing states. Michigan represented 13% of the total sugarbeet acreage harvested in the United States in 2013 (NASS 2014a). The climate and soils of Michigan are uniquely conducive to dryland production of sugarbeet.

Certain regions of Michigan provide nearly optimal conditions for production of sugarbeet. Sugarbeet grows best with long day lengths and temperatures ranging from 16-27 C in the daytime and 4-10 C at night (Cattanach et al. 1991). Soils with a high water holding capacity and season-long precipitation totals exceeding 50 cm are optimal (Cattanach et al. 1991). In Michigan, plant hardiness zones 5 and 6 provide ideal climatic conditions (ARS 2012). Within these zones, sugarbeet are produced between the 42^{nd} and 45^{th} parallels where the soil is a wet loam, clay, or wet clay (SCS 1981). The predominant soils in this area are wet loams of the Capac-Parkhill and Shebeon-Kilmanagh associations. These soils are deep, have a high available water capacity, and permeability is moderate to moderately slow (SCS 1981). The overlap of these climatic and environmental growing conditions spans approximately twenty counties in Michigan. In 2013, 62,000 hectares of sugarbeet were harvested in Michigan, and the production value for the state was 215 million dollars (NASS 2014b).

Sugarbeet is a specialty crop in Michigan. Technology released in 2008 offered growers an opportunity to increase their net profit, while also easing labor requirements (Kniss et al. 2004). Glyphosate-resistant (GR) sugarbeet was preceded by GR cotton (1995) (*Gossypium herbaceum* L.), canola (1996) (*Brassica napus* L.), soybean (1996) (*Glycine max* L. Merr.), corn (1998 *Zea mays* L.), and alfalfa (2005) (*Medicago sativa* L.) (Green 2009). In 2008, GR sugarbeet was planted on 60% of U.S. hectarage and increased to 95% by 2009 (ERS 2012). Sugarbeet grown in Michigan was 100% GR in 2014 (G. Clark, Agronomist, Michigan Sugar Company, Bay City, MI, personal communication). The quick adoption of GR sugarbeet by growers can be attributed partially to familiarity with the technology in other crops, but more so to the flexibility, ease, and effectiveness of the weed control system.

Weed control in conventional sugarbeet was costly, management intensive, variable, and injurious to the crop. Micro-rate weed management systems were developed in 1998 to reduce crop injury without sacrificing control (Dale and Renner 2005). Weed control was consistent at the two-leaf weed stage, but was variable thereafter which made multiple applications necessary to prevent competition from newly emerging weeds. Three to five micro-rate applications provided effective weed control and reduced the cost of weed control per hectare. The availability of GR sugarbeet added flexibility and convenience to weed management systems. Glyphosate was a widely-used herbicide since its introduction in 1974, but became the primary agrochemical worldwide with the introduction of GR crops (Shaw et al. 2011). Glyphosate is an inexpensive herbicide, controls a broad spectrum of weed species, and is easily broken down in the soil. GR sugarbeet are not susceptible to glyphosate because the CP4 5-enol-pyruvylshikimate-3-phosphate synthase (EPSPS) gene was incorporated into the genome to confer resistance (Heck et al. 2005; Mannerlöf et al. 1997). The CP4 EPSPS gene ensures aromatic amino acid biosynthetic pathways are not disrupted. Micro-rates were quickly phased out of sugarbeet weed management systems once GR sugarbeet was commercialized.

Weed density effects in sugarbeet

Sugarbeet is disadvantaged by early-season competition with weeds because of its slow growth rate. Energy is primarily allocated to canopy development following establishment and growth of four to six true leaves (Wilson 2001). Energy will transfer primarily to root growth and sugar accumulation about halfway through the season. Until canopy closure occurs, light and space are readily available to weeds. Once the sugarbeet canopy closes, weed emergence and growth can be suppressed.

The impact of weed interference in sugarbeet is species- and density- specific. Understanding critical densities can determine when weed control is of economic value. Research conducted in Colorado investigated season-long interference of common sunflower (*Helianthus annuus* L.), kochia (*Kochia scoparia* L.), common lambsquarters (*Cbenopodium album* L.), velvetleaf (*Abutilon theophrasti* Medik.), and Powell amaranth (*Amaranthus powellii* S. Wats.) planted within 5 cm of sugarbeet rows (Schweizer 1973; 1981; 1983; Schweizer and Bridge 1982; Schweizer and Lauridson 1985). Common sunflower had the lowest critical density at 1 plant per 9 m of crop row. Kochia and common lambsquarters resulted in yield reductions if densities were $\geq$ 5 plants per 9 m of row. Sugarbeet was affected least by velvetleaf and Powell amaranth which caused yield loss at 10 plants per 9 m of row. The competitiveness of common sunflower was attributed to rapid early-season growth and looming architecture. Common sunflower has minor branching tendencies and can grow to 3.5 m in height. Kochia and common lambsquarters are also tall annual weeds, and can each grow up to 2 m tall (Bryson and

DeFelice 2010). Kochia and common lambsquarters are moderately branched. Sugarbeet, which grow slowly outward and upward, experience the most interference from weed species with fast and upright early-season growth characteristics.

Sugarbeet sugar concentration is not consistently affected by weed density. In equal mixtures of kochia, common lambsquarters, and redroot pigweed (*Amaranthus retroflexus* L.), densities ranging from 0 to 24 plants m^{-1} had no significant impact on sugarbeet sugar content (Schweizer 1981). Varied densities of velvetleaf, Powell amaranth, wild oat (*Avena fatua* L.), and wild mustard (*Sinapis arvensis* L.) in sugarbeet have also been reported as having no significant effect on sugar content (Schweizer and Bridge 1982; Schweizer and Lauridson 1985; Mesbah et al. 1995). Sugar content of sugarbeet was reduced by common sunflower in one of two years, but no differences in purity occurred (Schweizer and Bridge 1982). Schweizer and Bridge (1982) cited light as the most limiting resource for sugarbeet competing with weeds. Sugarbeet root yields have been positively correlated with the amount of light interception by sugarbeet (Scott et al. 1985). Reduction of photosynthates, however, does not typically alter sugar concentrations (Milford and Thorne 1973; Watson et al. 1972). According to Milford (1973), sugar content is altered by, “factors such as genotype, soil conditions, additional nitrogen, and population.”

Weeds are more effectively suppressed in narrower rows because the canopy is able to close more quickly, therefore limiting light supply and space for weed growth (Johnson and Hoverstad 1991). Higher sugar and root yields have been reported when sugarbeet are grown in 51-cm rows compared with 76-cm rows (Cattanach and Shroeder 1979). Michigan sugarbeet have traditionally been grown in 76-cm row widths, but 51-cm rows have also become common in recent years. In 2010, research was conducted in Michigan to evaluate the effect of row width

(38-, 51-, and 76-cm) on weed control and sugarbeet yield and quality (Armstrong and Sprague 2010). Sugar and root yield were significantly greater in 38- and 51-cm rows (which were statistically similar) than in 76-cm rows. End-of-season weed densities and biomass were similar between 38- and 51-cm rows, but were significantly less than the weed densities and biomass in 76-cm rows.

Impact of weed pressure on sugarbeet nitrogen uptake

Rapid early-season acquisition of nitrogen is important for sugarbeet growth and development. The primary role of soil-available nitrogen for sugarbeet is to increase the growth rate of above-ground tissue, and therefore increase canopy closure and total light interception (Armstrong et al. 1983; Milford et al. 1985; Scott and Jaggard 1993). The sugarbeet shoot accumulates 80-90% of nitrogen acquired early in the season (Armstrong et al. 1986). At plant maturity, a slight decrease in above-ground biomass occurs as nitrogen from leaf proteins is remobilized to the root (Cariolle and Duvall 2006). Nitrogen-poor soils can result in sugarbeet yield reductions, while overabundance can result in quality reductions (Cariolle and Duvall 2006). In research conducted by Lauer (1995) in northern Wyoming, sugarbeet root yield increased by an average of 24%, 10%, and 1% (over three years) when the nitrogen application rate was increased from 0 to 112, 112 to 168, and 168 to 224 kg N ha^{-1}, respectively. This pattern was also observed by Draycott and Webb (1971), with the yield plateau beginning at 134 kg N ha^{-1}. Fertilizer management is a critical component of sugarbeet production practices, but also alters weed competitiveness (Blackshaw and Brandt 2008).

Weeds can remove significant quantities of nitrogen from the soil. Nitrogen fertilizer affects the competitiveness of weeds on a species-specific basis (Blackshaw and Brandt 2008).

In wheat (*Triticum aestivum* L.), varied nitrogen rates did not affect the competitiveness of Persian darnel (*Lolium persicum* Boiss. & Hohen. ex Boiss) or Russian thistle (*Kali tragus* L. Scop.) (Blackshaw and Brandt 2008). Increased nitrogen rates would be expected to correlate with increased weed competitiveness for species such as wild oat and redroot pigweed which are highly responsive to nitrogen. This was true for redroot pigweed in wheat, however, wild oat competitiveness remained consistent (Blackshaw and Brandt 2008). Common chickweed (*Stellaria media* L. Vill.) competitiveness was reduced by high nitrogen rates in potato (*Solanum tuberosum* L.), but not reduced in wheat (Van Delden et al. 2002). Additions of nitrogen have consistently favored corn in competition with specific weeds and also weed communities (Abouziema et al. 2007; Cathart and Swanton 2004; Evans et al. 2003, Lindsey et al. 2013). Research indicates that the effect of nitrogen fertilizer on weed competitiveness is not only species-dependent, but crop-dependent as well.

In Michigan, nitrogen assimilation by weeds in sugarbeet has been linearly correlated with increased weed growth at nitrogen rates of 0, 67, 100, and 134 kg N ha^{-1} (Spangler et al. 2014). In this research, weeds were removed at heights of 2, 8, 15, and 30 cm. The weed communities were diversely comprised of common lambsquarters, Pennsylvania smartweed (*Polygonum pensylvanicum* L.), Powell amaranth, giant foxtail (*Setaia faberi* R. Herm.), velvetleaf, common purslane (*Portulaca oleracea* L.), common ragweed (*Ambrosia artemisiifolia* L.), and wild mustard. When weeds were controlled at 8 cm, sugarbeet yield and recoverable white sucrose ha^{-1} were reduced by 15% and 8-16%, respectively. When data were combined over removal times, nitrogen assimilation by weeds was three times greater than sugarbeet at each nitrogen rate. However, in greenhouse trials sugarbeet outcompeted common lambsquarters and Powell amaranth for relative nitrogen and relative biomass at 0, 67, and 134 kg N ha^{-1} (Spangler and Sprague 2013). Results display consistent and adequate nitrogen acquisition by sugarbeet in a range of different environments.

Effects of weed control timing in sugarbeet

With the greater flexibility of weed control in GR sugarbeet, growers are not confined to strict schedules for herbicide applications. In micro-rate herbicide systems, weeds beyond 2.5 cm tall were at risk of escaping control (Dale and Renner 2005). Weeds competing with GR sugarbeet season-long reduced yield by 66% compared with weed control implemented when weeds were 2.5 cm tall (Kemp et al. 2009). Glyphosate is able to control larger weeds so it important to understand the critical timing of weed removal. Research conducted in GR sugarbeet grown in Michigan found the critical time of weed removal to be 8 weeks after planting (WAP) in 1998 and prior to 15 WAP at lower weed densities in 1999 (Kemp et al. 2009). Uncontrolled weeds beyond these times resulted in 10% yield reductions. The primary weed species in this research were pigweed spp. and common lambsquarters. The recommendation of Armstrong and Sprague (2010) was to control weeds before they reached 10 cm in height. Sugarbeet yield loss occurred when glyphosate was applied to weeds 15 cm tall. In research conducted by Spangler et al. (2014), sugarbeet yield was highest when weeds were controlled before the 2 cm height compared with weed control implemented at 8-, 15-, and 30-cm weed heights. A nitrogen component of the research mandated an early weed removal time. Common lambsquarters, redroot pigweed, and annual mercury (*Mercurialis annua* L.) reduced sugarbeet yield by 87% in the Czech Republic when weeds were uncontrolled season-long compared with the weed-free control (Jursík et al. 2008). Yield was not significantly reduced when plots were kept weed-free until the 8-10 leaf stage of sugarbeet, but was reduced by 38%

when weeds were allowed to compete with sugarbeet beyond the four-leaf stage. If weed control is implemented before or at the sugarbeet two-leaf stage, there is a risk of weed emergence occurring afterwards and additional weed control will be needed (Wilson 1998). More urgent weed control times, such as 1.6 weeks after sugarbeet emergence, have been proposed for weeds in irrigated sugarbeet systems (Mesbah et al. 1995).

Glyphosate-resistant volunteer corn

Glyphosate-resistant technology simplifies weed management for sugarbeet producers, but also introduces a novel weed problem. GR plants remaining in the field after harvest are capable of emerging as weeds the following spring. By design, these weeds will be insensitive to applications of glyphosate and will compete with the crop for light, water, nutrients, and space. In Michigan crop rotations, 34% of sugarbeet follow corn, 19% follow wheat, and 17% follow soybean (G. Clark, Agronomist, Michigan Sugar Company, Bay City, MI, personal communication). GR volunteer corn continues to be a problem for Michigan sugarbeet growers, but research on management remains limited.

Interference of volunteer GR corn in GR sugarbeet was evaluated at Lingle, Wyoming, and Scottsbluff, Nebraska, in 2009 and 2010 (Kniss et al. 2012). Sugarbeet was planted at populations of 173,000 (76-cm rows) and 128,000 seeds ha^{-1} (56-cm rows) at Lingle and Scottsbluff, respectively. To evaluate the impact of density on sugarbeet yield and quality, GR corn was planted at densities of 0, 0.3, 0.6, 0.9, 1.2, and 1.7 plants m^{-2} between sugarbeet rows. Linear regression indicated that sugarbeet yield was reduced by 19% for each corn plant m^{-2} when sugarbeet emergence occurred prior to or at the time of corn emergence. A killing frost at one location resulted in replanting of sugarbeet and corn. Not all of the corn was affected by the killing frost, and consequently, corn emerged before, during, and after sugarbeet emergence. In this situation, yield was reduced by 45% for each corn plant m^{-2}.

Lipid synthesis inhibiting herbicides provide excellent control of GR volunteer corn. These herbicides prevent fatty acid biosynthesis by binding to carboxyl-transferase and thereby inhibit the catalyst acetyl coA carboxylase (ACCase) (Kaundun et al. 2012). This inhibition prevents the formation of malonyl coA, which is required for structure and stability of cell membranes and cuticle layers (NSF, 2014). Lipid synthesis inhibitors control grass species effectively, but do not harm broadleaf plants. Grasses have only one form of the ACCase enzyme while most other plants have two forms. The second form of ACCase can compensate for inhibition by offering an alternative route. Therefore, this mode of action is ideal for postemergence grass control in non-grass crops.

Lipid synthesis inhibiting herbicides have been evaluated as control options for GR volunteer corn in GR sugarbeet. Quizalofop (1.20 kg ha^{-1}), sethoxydim (0.30 kg ha^{-1}), and clethodim (0.86 kg ha^{-1}) provided 100%, 94%, and 100% control of GR volunteer corn (1.2 plants m^{-2}) when applied at the sugarbeet two-leaf stage, and 100%, 74%, and 85% control when applied at the sugarbeet eight-leaf stage, respectively (Kniss et al. 2012). Each herbicide was applied with glyphosate (0.84 kg ae ha^{-1}), ammonium sulfate (AMS) (20 g L^{-1}), and an adjuvant. Yield was reduced by 5% if volunteer corn (1.2 plants m^{-2}) remained in the field longer than 3.5 WAE. Alternatively, hand-weeded corn could remain in the field almost 6 WAE because shading diminished immediately. As a result of a killing frost, weed control at the two-leaf stage was less effective than weed-control at the eight-leaf stage because corn continued to emerge after control was implemented. The results of Kniss et al. (2012) were largely influenced by location and resulting corn emergence times.

While control options are available for GR volunteer corn, many growers in Michigan do not implement these strategies because the impact on sugarbeet is not widely understood. The influence of corn on sugarbeet nitrogen acquisition may be a primary factor of yield and quality reductions. Identifying a critical density of GR volunteer corn in narrow and wide row widths, evaluating the effectiveness of lipid synthesis inhibiting herbicides, and determining the optimal time of volunteer corn control will help provide a complete management system to maximize sugarbeet yield and quality in Michigan.

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CHAPTER 2

EFFECT OF GLYPHOSATE-RESISTANT VOLUNTEER CORN DENSITY AND ROW WIDTH ON GLYPHOSATE-RESISTANT SUGARBEET YIELD AND QUALITY

Abstract

Glyphosate-resistant (GR) volunteer corn is a consistent problem in GR sugarbeet grown in Michigan. There are effective options for removal of volunteer corn, but many growers do not implement these strategies because the impact on sugarbeet yield and quality is not widely understood. Field experiments were conducted in 2012 and 2013 at the Michigan State University Agronomy Farm in East Lansing and at the Saginaw Valley Research and Extension Center near Richville, Michigan. The objectives of this research were to: 1) quantify the effects of GR volunteer corn on GR sugarbeet yield and sugar quality, and 2) determine the effects of row width on volunteer corn interference in sugarbeet. GR sugarbeet 'HM 9173 RR' was planted at 124,000 plants ha^{-1} in 38- and 76-cm rows. At the time of planting, 'F_2' GR corn seed was planted approximately 13-cm off the sugarbeet row in an alternating pattern at populations of 0, 0.22, 0.43, 0.86, 1.72, and 3.44 plants m^{-2}. Sugarbeet canopy closure in the 38- and 76-cm row widths was measured throughout the season. Volunteer corn biomass was harvested and weighed prior to sugarbeet harvest. Sugarbeet was harvested for yield and quality. The sugarbeet canopy developed quicker in 38- than in 76-cm rows, with closure 13%, 17%, and 12% greater 10 weeks after planting at Richville 2012, East Lansing 2013, and Richville 2013, respectively. Sugarbeet planted in narrow rows yielded 13% higher at both East Lansing 2012 and Richville 2013. When data were combined over row width, sugarbeet root yield was reduced by 19% and 22.5% when GR volunteer corn competed season-long at a density of 1.72

plants m^{-2} and 3.44 plants m^{-2}, respectively. Neither sugar content nor recoverable white sucrose concentration were significantly impacted by interference of volunteer GR corn. Planting GR sugarbeet in narrow rows reduced competition from GR volunteer corn. Volunteer corn needs to be controlled if populations are greater than approximately 0.86 plants m^{-2} in order to maximize sugarbeet yield and quality.

Nomenclature: Corn, *Zea mays* L.; Sugarbeet, *Beta vulgaris* L.

Introduction

Glyphosate-resistant (GR) sugarbeet was commercially available in 2008, and was rapidly adopted by growers. By 2009, 95% of sugarbeet hectarage in the United States was planted with GR sugarbeet (ERS 2012). Weed control in conventional sugarbeet was costly, management intensive, variable, and injurious to the crop (Kemp et al. 2009). The use of glyphosate in GR sugarbeet offered growers an inexpensive alternative to conventional weed management systems and controlled a broader spectrum of weeds over a greater period of time. In 2014, 100% of sugarbeet grown in Michigan were GR (G. Clark, Agronomist, Michigan Sugar Company, Bay City, MI, personal communication). While the GR technology simplified weed management for sugarbeet producers, a novel weed problem was also introduced. Harvest loss of seeds of other GR crops planted previous to sugarbeet emerged as weeds the following spring. By design, these weeds cannot be controlled by applications of glyphosate and will compete with the crop for light, water, nutrients, and space.

Sugarbeet is a poor early-season competitor because of its slow growth rate. When the sugarbeet canopy closes, weeds are more effectively suppressed. Planting sugarbeet in narrower rows helps the canopy close more quickly and limits light and space for weed growth (Johnson and Hoverstad 1991). Sugarbeet in Michigan have traditionally been grown in 76-cm row widths, but 51-cm rows have also become common in recent years. In 2010, research was conducted in Michigan to evaluate the effect of row width (38-, 51-, and 76-cm) on weed control and sugarbeet yield and quality (Armstrong and Sprague 2010). Sugar and root yield were significantly greater in 38- and 51-cm rows (which were statistically similar) than in 76-cm rows. End-of-season weed density and biomass were similar between 38- and 51-cm rows, but were significantly less than the weed density and biomass in 76-cm rows.

Weeds with fast and upright early-season growth characteristics are highly competitive with sugarbeet. Common sunflower (*Helianthus annuus* L.) competing season-long with sugarbeet reduced yield by 40% with 0.2 plants m^{-1} of crop row (Schweizer and Bridge 1982). In addition to early-season growth habits of common sunflower, competitiveness was also attributed to prolonged light interception. Kochia (*Kochia scoparia* L.) and common lambsquarters (*Chenopodium album* L.) are shorter in stature and more branched than common sunflower, and 0.2 plants m^{-2} reduced sugarbeet yield by 16% and 13%, respectively (Schweizer 1973; Schweizer 1983).

Glyphosate-resistant volunteer corn is a common problem for GR sugarbeet growers. Research conducted in the Western sugarbeet growing region of the U.S. (Wyoming and Nebraska) found that when volunteer corn emerged simultaneously with sugarbeet, root yield was reduced by 19% for each volunteer corn plant m^{-2} (Kniss et al. 2012). However, when volunteer corn emerged prior to sugarbeet, sugarbeet yield was reduced by 45% for each corn plant m^{-2}. The impact of volunteer corn on sugar concentrations of sugarbeet was not discussed.

Reductions in sugar quality are rarely associated with weed competition and are more often a result of factors such as variety, planting population, or soil characteristics (Milford 1973). Armstrong and Sprague (2010) reported higher recoverable white sucrose Megagram^{-1} (RWSMg) for sugarbeet grown in 38- and 51-cm rows compared with 76-cm rows, and attributed results to reduced intraspecific competition. The effects of GR volunteer corn interference in GR sugarbeet have not been investigated in the Eastern sugarbeet growing region of the U.S. As a result, many growers do not implement control strategies necessary to maximize sugarbeet yield and quality. The objectives of this research were to: 1) quantify the impact of GR volunteer corn on GR sugarbeet yield and quality, and 2) evaluate the impact of sugarbeet row width on volunteer corn interference in sugarbeet.

Materials and Methods

Field research was conducted at the Michigan State University Agronomy Farm at East Lansing, Michigan (42°42’ N, 84°28’ W), and the Saginaw Valley Research and Extension Center near Richville, Michigan (43°24’ N, 83°41’ W), in 2012 and 2013. The soil at East Lansing was a Capac loam (fine-loamy, mixed, active, mesic Aquic Glossudalfs) with a pH of 6.6 and an organic matter content of 2.8%. The soil at Richville was a Tappan-Londo loam (fine-loamy, mixed, active, calcareous, mesic Typic Epiaquolls and fine-loamy, mixed, semiactive, mesic Aeric Glossaqualfs) with a pH of 7.8 and an organic matter content of 2.2%. Prior to planting, fields were fall chisel plowed and soil finished in the spring. Nitrogen fertilizer was applied as urea and incorporated prior to planting at recommended rates for each location.

The experimental design was set up as a split-plot randomized complete block design with 4 replications. Plots were 3 m by 9 m in size. The whole- and sub-plot factors were sugarbeet row width and GR volunteer corn density, respectively. ‘Hilleshög 173RR’ (Syngenta Seeds Inc., 1020 Sugarmill Rd., Longmont, CO 80501) GR sugarbeet was planted in 38- and 76-cm row widths at a population of 124,000 seeds ha^{-1}. Sugarbeet planted in narrow rows were approximately 20 cm apart while sugarbeet planted in wide rows were approximately 10 cm apart. This population was based on research conducted by Armstrong and Sprague (2010) which concluded that sugarbeet planted at 124,000 seeds ha^{-1} had faster canopy closure at both row widths than sugarbeet planted at lower populations. Sugarbeet was planted on April 12, 2012 and May 3, 2013 at East Lansing and on April 4, 2012 and May 2, 2013 at Richville. Immediately following sugarbeet planting, ‘F_2’ seed from a ‘DeKalb 46-61’ (Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO 63167) GR field corn harvested the previous fall was hand-planted approximately five cm deep at densities of 0, 0.22, 0.43, 0.86, 1.72, and 3.44 plants m^{-2}. Corn was staggered 13 cm off the two sugarbeet harvest rows and spaced equidistantly along the row. Multiple seeds were planted in each space to ensure establishment and were subsequently thinned to one plant. Fatal germination of volunteer corn occurred at East Lansing in 2013 as a result of shallow planting. Volunteer corn was then re-planted, and was uniformly established by the sugarbeet 2-leaf stage. Any corn from the first planting was removed by hand. Plots were kept free of other weeds throughout the season with applications of glyphosate + ammonium sulfate (0.84 kg ae ha^{-1} + 2% w w^{-1}) at the 2- and 6-leaf stages of sugarbeet.

Light interception was measured weekly through mid-season and bi-weekly thereafter in narrow and wide row sugarbeet using a 1 m by 13 mm wand (SunScan Canopy Analysis System, Dynamax Inc., 10808 Fallstone Road #350, Houston, TX 77099) and a hand-held computer for data collection (Recon, Trimble Navigation Limited, 935 Stewart Drive, Sunnyvale, CA 94085). Three measurements were taken above the sugarbeet canopy (90 cm above ground level) and at the corresponding locations below the canopy (5 cm above ground level). Canopy closure was calculated using equation one.

$$\text{Canopy closure (\%)} = [(\text{above canopy measurement} - \text{below canopy measurement}) / (\text{above canopy measurement})]*100 \quad [1]$$

Prior to sugarbeet harvest, volunteer corn was hand-harvested from each plot. In 2012, volunteer corn was harvested by plot, dried, and weighed. In 2013, volunteer corn was harvested and fresh weights were recorded in the field. The fresh weights of four subsamples of volunteer corn were also recorded. These samples were dried and weighed to be used as a conversion factor for dry biomass of the fresh weights plot^{-1} recorded in the field. Two center rows of sugarbeet was mechanically harvested and weighed. Sub-samples, 10 sugarbeet roots plot^{-1}, were sent to the Michigan Sugar Company laboratory (Michigan Sugar Company, 2600 S. Euclid Avenue, Bay City, MI 48706) to determine sugar concentrations. In 2012, sugarbeet was harvested on October 17 and September 11 at East Lansing and Richville, respectively. Sugarbeet was harvested on October 15, 2013 at East Lansing and September 25, 2013 at Richville.

Precipitation and temperature data for each location were obtained from the Michigan State University Enviro-weather Automated Weather Station Network (http://www.agweather.geo.msu.edu/mawn/), which maintains stations less than a mile from both field locations (Tables 2.1 and 2.2).

Statistical analysis was conducted using SAS 9.3 (SAS Institute Inc, Cary NC). Assumptions of normality and homogeneity of variances were confirmed with a stem-and-leaf plot and Levene's test ($p \leq 0.05$), respectively. Analysis of variance was conducted using PROC MIXED to test the effects of row width and corn density on sugarbeet yield, recoverable white sucrose ha^{-1} (RWSH), percent sugar, recoverable white sucrose Mg^{-1} (RWSMg), corn biomass, and canopy closure. Means were separated with Fisher's Protected LSD ($p \leq 0.05$). Data from each year and each location were analyzed separately due to significant year by location interactions. Main effects are presented for sugarbeet row width and volunteer corn density, since interactions regarding sugarbeet quality and yield were not significant. Main effects of row width and volunteer corn density on volunteer corn biomass remaining at harvest are presented for East Lansing in 2012 and 2013 due to insignificant interactions. Interactions between row width and volunteer corn density on biomass remaining at harvest were significant at Richville in 2012 and 2013. Linear regression was used to relate volunteer corn biomass (kg ha^{-1}) to sugarbeet yield expressed as a percentage for each site-year using SigmaPlot version 11.0 (Systat Software Inc., San Jose, CA). Data for East Lansing and Richville in 2012, and East Lansing in 2013 did not fit the linear model and therefore, are not presented. SigmaPlot was also used for non-linear regression analysis of volunteer corn density (plants ha^{-1}) and sugarbeet yield (Mg ha^{-1}). For non-linear regression, sugarbeet yield was normalized by comparison with the control treatment (no volunteer corn) for each replicate, and converted into percentages. Data were then transformed so the largest percentage per site-year was equal to 100% (Kemp et al. 2009). Data were fit to the logistic equation (Equation 2; Kemp et al. 2009; Knezevic et al. 2002):

$$Y = [(1/\exp(c \cdot (T-d))+f)]+[(f-1)/f] \cdot 100, \qquad [2]$$

where *Y* is sugarbeet yield expressed as a percentage, *T* is density expressed as plants ha^{-1}, *d* is the point of inflection, and *c* and *f* are constants. Results of regression analysis are not presented due to poor fit and low r^2 values.

Results and Discussion

Growing conditions. In 2012, drought conditions in Michigan were severe. East Lansing and Richville received 4 cm and 3 cm of rainfall, respectively, in the first month after planting, whereas a typical rainfall in April is nearly 8 cm (Table 2.1). Sugarbeet growth was stunted by drought conditions, but emerged evenly. In addition to drought stress, volunteer corn emergence was inhibited by cool early-season temperatures resulting in volunteer corn emergence when sugarbeet was at the two-leaf stage (Table 2.2). Soil temperatures need to be > 10 C in order for corn to germinate.

In 2013, precipitation at East Lansing and Richville totaled 8 cm and 9 cm, respectively, in the first 30 d after planting (Table 2.1). Abundant rainfall continued through June at East Lansing and promoted rapid growth of sugarbeet and corn. Soil temperatures were ideal for germination of corn and sugarbeet (Table 2.2). Sugarbeet and corn emerged at the same time at Richville in 2013. However, due to shallow planting volunteer corn was replanted and emerged at the sugarbeet two-leaf stage at East Lansing. Weather conditions in previous research have caused variations in corn emergence time, and have altered the magnitude of interference with sugarbeet (Kniss et al. 2012).

Volunteer corn biomass and sugarbeet canopy closure. Significant interactions occurred between years and locations with respect to corn biomass remaining at harvest, therefore data were separated accordingly. Volunteer corn biomass was variable among years and locations (Figure 2.1). Overall volunteer corn biomass was greatest at Richville 2013 followed by East Lansing 2012. The main effects of row width and volunteer corn density are presented for East Lansing 2012 and 2013. The highest density of corn (3.44 plants m^{-2}) weighed 3600 and 2200 kg ha^{-1} at East Lansing in 2012 and 2013, respectively, when combined over row width (Table 2.3). The interaction between row width and volunteer corn density was significant for Richville 2012 and 2013. Volunteer corn growing at a density of 3.44 plants m^{-2} in narrow and wide rows weighed 800 kg ha^{-1} and 2500 kg ha^{-1}, respectively, at Richville 2012. At Richville 2013, volunteer corn weighed 5000 kg ha^{-1} and 5300 kg ha^{-1} in narrow and wide rows, respectively (Table 2.4).

Sugarbeet planted in narrow rows suppressed volunteer corn growth at East Lansing 2013 (Table 2.3). Volunteer corn growth was suppressed 19% when sugarbeet was planted in narrow rows compared with wide rows at East Lansing 2013, averaged across volunteer corn densities. Volunteer corn biomass between narrow and wide rows was similar at East Lansing in 2012. Early-season growing conditions and the relative time of volunteer corn emergence may have impacted the competitive potential of volunteer corn in sugarbeet. Reductions of volunteer corn biomass for sugarbeet planted in narrow rows was consistent with conclusions of Armstrong and Sprague (2010) who found end-of-season weed biomass to be similar between 38- and 51-cm (narrow) rows, but significantly less than the weed biomass in 76-cm (wide) rows. Significant quantities of volunteer corn biomass (dry weight) were measured when 0.43 plants m^{-2} were competing at East Lansing in 2012 and 2013.

At Richville 2012 and 2013, sugarbeet in narrow rows suppressed volunteer corn growth more effectively than sugarbeet in wide rows when 1.72 volunteer corn plants m^{-2} were allowed to compete with sugarbeet (Table 2.4). Sugarbeet in narrow rows suppressed volunteer corn growth more effectively when 3.44 volunteer corn plants m^{-2} were competed with sugarbeet at Richville 2012, but not at Richville 2013. Volunteer corn biomass increased as the density of volunteer corn increased at Richville 2012, whereas the greatest biomass at Richville 2013 occurred at 1.72 plants m^{-2} (7900 kg ha^{-1}) as opposed to 3.44 plants m^{-2} (5300 kg ha^{-1}) Volunteer corn biomass may have been lower as a result of intraspecific competition when volunteer corn at 3.44 plant m^{-2} competed with sugarbeet at Richville 2013.

Sugarbeet canopy closure was poor at East Lansing in 2012 (Figure 2.2). Season-long drought conditions severely stunted sugarbeet growth and emergence (Table 2.1). Precipitation totals of May, June, and July were 6.2 cm, 2.7 cm, and 3.7 cm, respectively, which were well below the 30-year average (Table 2.1). Peak canopy closure was less than 60% for sugarbeet planted in narrow and wide rows. Canopy closure of narrow rows was > 70% at the remaining site-years, and was significantly greater than the canopy closure of sugarbeet planted in wide rows (Figure 2.2; Figure 2.3). Drought conditions affected early-season growth of sugarbeet at Richville in 2012, however, sufficient rainfall occurred in May (9.9 cm) which promoted canopy development by sugarbeet (Table 2.1). Adequate rainfall in 2013 resulted in more typical canopy development. The sugarbeet canopy in narrow rows at East Lansing in 2013 reached peak closure (80%) approximately 10 weeks after planting, and at Richville in 2013 reached 78% closure approximately 11 weeks after planting (Figure 2.2; Figure 2.3). Well-developed sugarbeet canopies are more effective at inhibiting the growth of volunteer corn than poorly-developed sugarbeet canopies. The sugarbeet canopy can limit the amount of light and space available to volunteer corn.

Sugarbeet quality and yield. Sugarbeet quality and yield data are presented separately by years and locations due to significant interactions. Interactions between row width and volunteer corn density did not occur when evaluating sugar concentration or recoverable white sucrose Mg^{-1} (RWSMg). As a result, main effects are presented. Percent sugar and RWSMg were similar for sugarbeet planted in narrow and wide rows at East Lansing and Richville in 2013 (Table 2.5). However, percent sugar and RWSMg at East Lansing and Richville in 2012 were higher for sugarbeet planted in narrow rows. Sugar concentrations of sugarbeet grown in narrow rows at East Lansing and Richville in 2012, were 20.2% and 17.2%, respectively, while sugar concentrations of sugarbeet grown in wide rows were 19.5% and 16.5%. Armstrong and Sprague (2010) also reported higher RWSMg for sugarbeet grown in 38- and 51-cm (narrow) rows compared with 76-cm (wide) rows, with a consistent harvest population of 77,000 seeds ha^{-1}. Results were attributed to reduced intraspecific competition. Harsh drought conditions at East Lansing and Richville in 2012 would have amplified intraspecific competition of sugarbeet planted in wide rows. The planting population was 124,000 seeds ha^{-1} for each row width so there was twice as much distance between sugarbeet in narrow rows than in wide rows. Volunteer corn density (0 to 3.44 plants m^{-2}) did not affect sugarbeet sugar concentrations or RWSMg at any site-year (Table 2.5) which is consistent with the literature (Schweizer 1981;

Schweizer and Bridge 1982; Schweizer and Lauridson 1985; Mesbah et al. 1995). Weeds limit the amount of water and light available to sugarbeet. These reductions, however, do not typically alter sugar concentrations (Schweizer and Bridge 1982; Milford and Thorne 1973; Watson et al. 1972). According to Milford (1973), sugar content is altered by, “factors such as genotype, soil conditions, additional nitrogen, and crop density.”

Sugarbeet yield and RWSH were variable among site-years, so data are presented separately due to significant interactions. Mean yields of the control treatment (no volunteer corn) were 52, 65, 71, and 38 Mg ha^{-1} at East Lansing 2012, Richville 2012, East Lansing 2013, and Richville 2013, respectively (Table 2.6). Mean RWSH of sugarbeet with no volunteer corn interference was 7300, 7800, 9200, and 5700 kg ha^{-1} at East Lansing 2012, Richville 2012, East Lansing 2013, and Richville 2013, respectively (Table 2.6).

Interactions between row width and volunteer corn density were not significant for yield or RWSH, so main effects were evaluated. Sugarbeet yield in narrow rows was 13% and 11% greater than sugarbeet yield in wide rows at East Lansing 2012 and Richville 2013, respectively (Table 2.6). Row width did not have a significant impact on sugarbeet yield at Richville 2012 or East Lansing 2013. However, RWSH was greater in sugarbeet planted narrow rows than wide rows in three of four site-years; East Lansing 2012, Richville 2012, and Richville 2013 (Table 2.6). Increased RWSH ranged from 7 to 17% in sugarbeet planted narrow rows compared with sugarbeet planted in wide rows. East Lansing 2012 and Richville 2013 had the highest volunteer corn biomass quantities of the four site-years, and therefore experienced greater interference (Table 2.3). Sugarbeet growing in narrow rows suppressed corn growth and experienced less competitive pressure. RWSH differences observed at Richville in 2012 were a result of increased percent sugar from sugarbeet planted in narrow rows. Armstrong and Sprague (2010) also reported higher RWSH in sugarbeet planted in narrow (38- and 51-cm) rows compared with wide rows (76-cm).

Sugarbeet yield loss occurred when volunteer corn was growing at a density greater than 0.86 plants m^{-2} in all site-years (Table 2.6). Yield was reduced by 15%, 19%, 16%, and 27% when 1.72 corn plants per m^{-2} were allowed to compete with sugarbeet compared with the control treatment (no volunteer corn), at East Lansing 2012, Richville 2012, East Lansing 2013, and Richville 2013, respectively. At a higher density, 3.44 plants m^{-2}, yield was reduced by 27%, 14%, 16%, and 33%. Site-years with more volunteer corn biomass at harvest experienced the most severe yield reductions. The biomass of 3.44 plants m^{-2} at East Lansing in 2012, Richville in 2012, East Lansing in 2013, and Richville in 2013 were approximately 3600, 1700, 2200, and 5800 kg ha^{-1}, respectively (Table 2.3). At Richville in 2013, sugarbeet yield decreased as volunteer corn biomass increased (Figure 2.4). Sugarbeet yield was reduced by 15% when the dry weight of volunteer corn at harvest was 200 kg ha^{-1}. Yield and biomass data from East Lansing and Richville in 2012, and East Lansing in 2013 correlated poorly and are not presented due to low r^2 values.

Volunteer corn density also significantly impacted RWSH at each site-year. At Richville in 2012, East Lansing in 2013, and Richville in 2013, reductions in RWSH occurred when 1.72 corn plants m^{-2} were competing with sugarbeet (Table 2.6). RWSH was reduced by 18% (Richville 2012), 15% (East Lansing 2013), and 33% (Richville 2013). RWSH was reduced by

24% at East Lansing in 2012 when corn was competing at a density of 3.44 plants m^{-2}. Sugarbeet was able to compete effectively with volunteer corn when densities were $\leq$ 0.86 plants m^{-2}.

Conclusions. Volunteer corn has been an effective competitor for yield with other crops. Volunteer corn competing with soybean reduced yield by 25% at a density of 0.5 plants m^{-2} (Beckett and Stoller 1988). In another study, 0.4 corn plants m^{-2} reduced soybean yield by an average of 31%, but ranged extensively by site-year as a result of drought conditions and one location with sandy soil (Andersen et al. 1982). In sugarbeet, Kniss et al. (2012) also observed differences based on site-year in research conducted in Nebraska and Wyoming. Sugarbeet yield was reduced by 19% per plant up to 1.7 plants m^{-2} when three sites were combined. However, when a killing frost affected sugarbeet and corn emergence times in Wyoming, sugarbeet yield was reduced by 45% per plant up to 1.7 plants m^{-2} when volunteer corn emerged before sugarbeet. In Michigan, a commonality of improved sugarbeet competitiveness was the delayed emergence of volunteer corn. The sugarbeet canopy has more time to develop and becomes capable of limiting volunteer corn growth. When sugarbeet and volunteer corn emerge simultaneously, volunteer corn can quickly surpass the sugarbeet canopy.

Our study demonstrated that planting sugarbeet in narrow rows can be a valuable volunteer corn management strategy for Michigan growers. Canopy closure of sugarbeet planted in narrow rows was quicker than in wide rows and suppressed volunteer corn growth. In drought conditions, sugar concentrations and RWSMg were higher when sugarbeet was grown in narrow rows. Yield of sugarbeet was also higher in narrow rows at two of four site-years, where volunteer corn biomass was greatest. Simultaneous emergence of sugarbeet and volunteer corn may have contributed to reduced competitiveness of sugarbeet at Richville 2013. Sugarbeet may be more competitive when volunteer corn emergence is delayed by conditions such as cool early-season temperatures, inadequate soil moisture, or seed depth. Volunteer corn emergence in the field is rarely uniform in time or space, and grower tillage practices can contribute to variable seed depths. Therefore, emergence can be ongoing. Volunteer corn also can also emerge in the field in clumps as opposed to individually. Despite variable growing conditions observed between years and locations of this research, results consistently implicate 0.86 corn plants m^{-2} as the critical density for removal of volunteer corn to maximize sugarbeet yield and quality.

APPENDICES

APPENDIX A

CHAPTER 2 TABLES AND FIGURES

Table 2.1. Monthly precipitation at East Lansing, MI and Richville, MI in 2012 and 2013 and a 30-yr average.[a]

	2012		2013		
Month	East Lansing	Richville	East Lansing	Richville	30-yr avg.[c]
	cm		cm		cm
April	(3.9)[b]	(3.0)	--	--	7.7
May	6.2	9.9	(8.4)	(8.7)	8.5
June	2.7	2.8	11.5	4.4	8.8
July	3.7	9.2	5.6	5.2	7.2
August	5.3	10.2	11.0	4.7	8.2
September	5.5	4.1	1.8	1.5	8.9
October	9.2	--	11.8	--	6.4

[a] Enviro-weather Automated Weather Network. Michigan State University (2014) http://enviroweather.msu.edu Accessed December 22, 2014.

[b] Precipitation data in parenthesis is from the time of planting.

[c] The 30-yr average precipitation is from Lansing, Michigan (1981-2010).

Table 2.2. Average air and soil temperatures 1-3 weeks after planting (WAP) at East Lansing and Richville, MI in 2012 and 2013.[a]

	2012		2013	
Weeks after planting[b]	East Lansing	Richville	East Lansing	Richville
Air temperature	C		C	
Week 1	18	13	24	25
Week 2	15	17	19	18
Week 3	15	13	25	26
Soil temperature[c]				
Week 1	10	8	16	17
Week 2	10	11	14	12
Week 3	10	9	18	18

[a] Enviro-weather Automated Weather Network. Michigan State University (2014) http://enviroweather.msu.edu Accessed December 22, 2014, February 15, 2015.

[b] Sugarbeet was planted on April 12, 2012 and May 3, 2013 at East Lansing and on April 4, 2012 and May 2, 2013 at Richville.

[c] Temperature of the soil at a depth of 5 cm.

Table 2.3. Main effects of volunteer corn density and row width on volunteer corn biomass at East Lansing, MI in 2012 and 2013.[a]

Main effects	2012	2013
Row width[b]	kg ha^{-1}	
Narrow	1269 a	846 a
Wide	1497 a	1042 b
V. corn density[c]		
0 plants m^{-2}	0 a	0 a
0.22 plants m^{-2}	521 ab	260 ab
0.43 plants m^{-2}	684 b	488 b
0.86 plants m^{-2}	1074 b	911 c
1.72 plants m^{-2}	2279 c	1758 d
3.44 plants m^{-2}	3613 d	2213 e
ANOVA	*p* value	
Row width	0.1738	0.0106
V. corn density	< 0.0001	< 0.0001
Row width x density	0.9273	0.0902

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Sugarbeet was planted in narrow (38 cm) and wide (76 cm) rows.

[c] F_2 volunteer glyphosate-resistant corn was hand-planted 13 cm off of the sugarbeet row directly following sugarbeet planting.

Table 2.4. Effect of volunteer corn density and row width on volunteer corn biomass at Richville, MI in 2012 and 2013.[a]

	2012		2013	
	Narrow[b]	Wide	Narrow	Wide
V. corn density[c]	kg ha^{-1}		kg ha^{-1}	
0 plants m^{-2}	0 a	0 a	0 ab	0 a
0.22 plants m^{-2}	33 a	146 a	423 ab	765 ab
0.43 plants m^{-2}	142 a	195 ab	1099 abc	1383 bc
0.86 plants m^{-2}	301 ab	513 bc	2417 cd	2995 d
1.72 plants m^{-2}	524 bc	1544 d	3735 de	7852 g
3.44 plants m^{-2}	822 c	2543 e	4988 ef	5346 f
ANOVA	*p* value		*p* value	
Row width	< 0.0001		0.0017	
V. corn density	< 0.0001		< 0.0001	
Row width x density	< 0.0001		0.0010	

[a] Means followed by the same letter within years are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Sugarbeet was planted in narrow (38 cm) and wide (76 cm) rows.

[c] F_2 volunteer glyphosate-resistant corn was hand-planted 13 cm off of the sugarbeet row directly following sugarbeet planting.

Table 2.5. Main effects of volunteer corn density and sugarbeet row width on percent sugar and recoverable white sucrose Mg^{-1} of root (RWSMg).[a]

	Sugar				RWSMg			
	2012		2013		2012		2013	
Main effects	East Lansing	Richville	East Lansing	Richville	East Lansing	Richville	East Lansing	Richville
Row width[b]	%				kg Mg^{-1}			
Narrow	20.2 a	17.2 a	17.6 a	20.1 a	148 a	128 a	130 a	152 a
Wide	19.5 b	16.5 b	17.5 a	19.7 a	142 b	121 b	130 a	149 a
V. corn density[c]								
0 plants m^{-2}	19.5 a	16.5 a	17.4 a	19.8 a	141 a	121 a	127 a	149 a
0.22 plants m^{-2}	19.7 a	17.1 a	17.7 a	19.7 a	145 a	126 a	131 a	148 a
0.43 plants m^{-2}	20.0 a	16.7 a	17.6 a	20.2 a	146 a	123 a	130 a	153 a
0.86 plants m^{-2}	19.9 a	17.3 a	17.3 a	20.1 a	145 a	128 a	127 a	152 a
1.72 plants m^{-2}	19.8 a	16.7 a	17.8 a	19.9 a	145 a	123 a	132 a	150 a
3.44 plants m^{-2}	20.1 a	17.0 a	17.8 a	19.9 a	148 a	125 a	132 a	150 a
ANOVA	*p* value				*p* value			
Row width	< 0.0001	< 0.0001	0.2126	0.0468	< 0.0001	< 0.0001	0.9083	0.0620
V. corn density	0.2767	0.1139	0.3643	0.8826	0.1243	0.0730	0.1850	0.7023
Row x density	0.1895	0.6663	0.2191	0.9720	0.1857	0.6646	0.3324	0.9287

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Sugarbeet was planted in narrow (38 cm) and wide (76 cm) rows.

[c] F_2 volunteer glyphosate-resistant corn was hand-planted 13 cm off of the sugarbeet row directly following sugarbeet planting.

Table 2.6. Main effects of volunteer corn density and sugarbeet row width on sugarbeet root yield and recoverable white sucrose per hectare (RWSH).[a]

	Yield				RWSH			
	2012		2013		2012		2013	
Main effects	East Lansing	Richville	East Lansing	Richville	East Lansing	Richville	East Lansing	Richville
Row width[b]	——— $Mg\ ha^{-1}$ ———				——— $kg\ ha^{-1}$ ———			
Narrow	50.6 a	62.7 a	67.9 a	35.1 a	7459 a	8054 a	8926 a	5354 a
Wide	43.8 b	62.0 a	68.0 a	31.4 b	6191 b	7483 b	8808 a	4681 b
V. corn density[c]								
0 plants m^{-2}	51.6 a	64.9 a	70.6 a	38.1 a	7280 ab	7849 a	9203 a	5695 a
0.22 plants m^{-2}	52.1 a	67.1 a	73.0 a	40.4 a	7532 a	8450 a	9574 a	5964 a
0.43 plants m^{-2}	45.4 ab	67.9 a	74.3 a	38.1 a	6627 ab	8344 a	9738 a	5827 a
0.86 plants m^{-2}	52.3 a	65.6 a	71.4 a	34.0 ab	7575 a	8489 a	9066 ab	5179 a
1.72 plants m^{-2}	44.0 bc	52.5 b	59.6 b	28.0 bc	6375 bc	6445 b	7850 bc	3829 b
3.44 plants m^{-2}	37.6 c	56.1 b	59.0 b	25.6 c	5564 c	7034 b	7771 c	3826 b
ANOVA	——— *p* value ———				——— *p* value ———			
Row width	0.0008	0.7302	0.2768	0.0092	< 0.0001	0.0372	0.8702	0.0391
V. corn density	0.0014	0.0020	0.0009	< 0.0001	0.0080	0.0030	0.0011	0.0001
Row x density	0.6871	0.8394	0.1128	0.5570	0.8556	0.7769	0.6859	0.5415

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Sugarbeet was planted in narrow (36 cm) and wide (78 cm) rows.

[c] F_2 volunteer glyphosate-resistant corn was hand-planted 13 cm off of the sugarbeet row directly following sugarbeet planting.

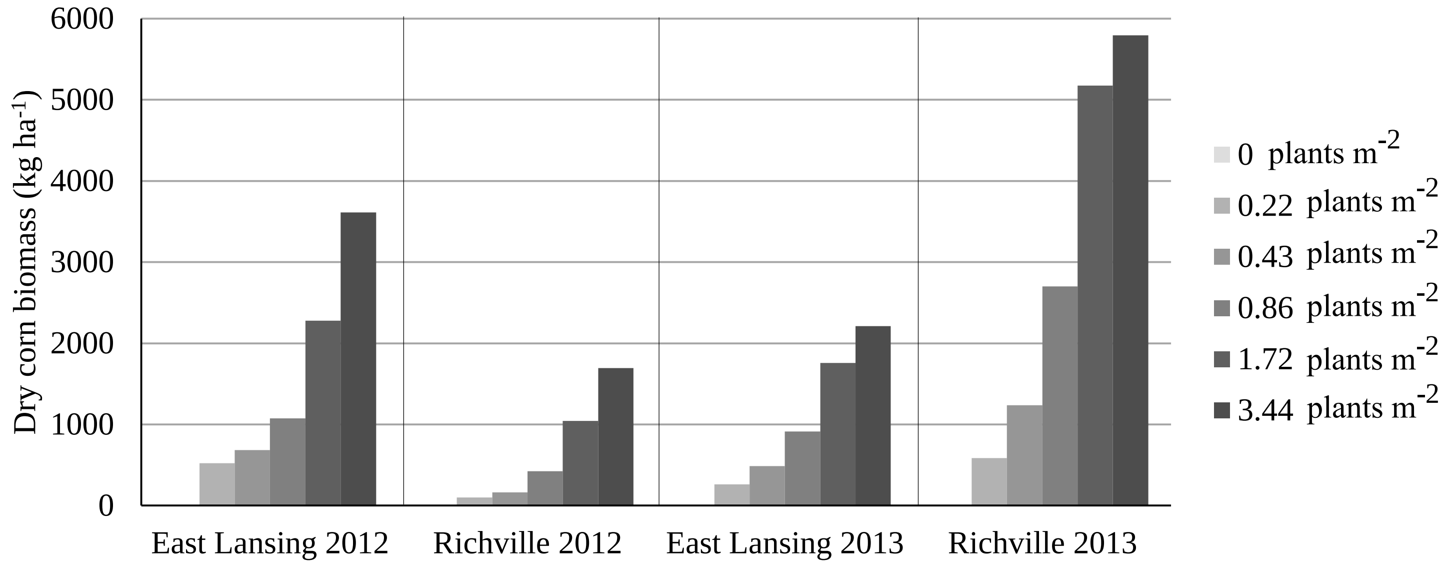

Figure 2.1. End-of-season corn biomass at East Lansing 2012, Richville 2012, East Lansing 2013, and Richville 2013 at 0, 0.22, 0.43, 0.86, 1.72, and 3.44 volunteer corn plants m^{-2} averaged over narrow and wide row sugarbeet.

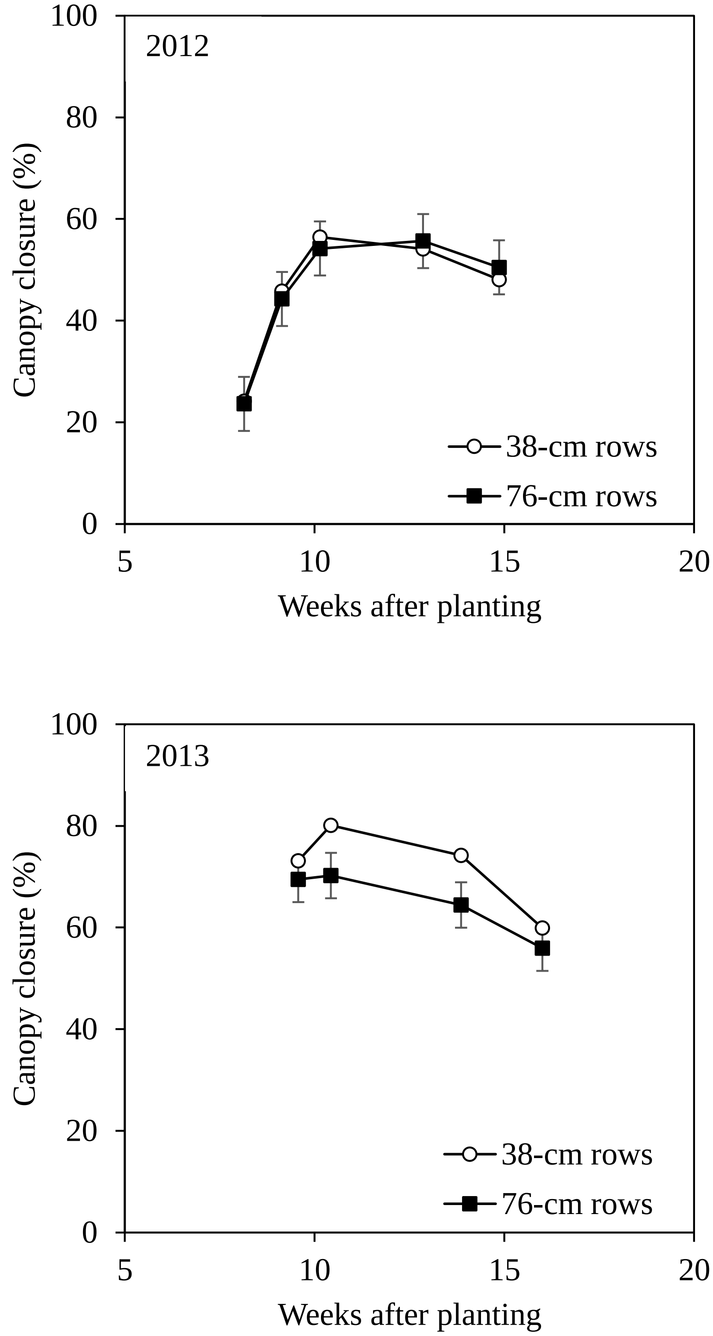

Figure 2.2. Main effects of row width on sugarbeet canopy closure at East Lansing, MI in 2012 and 2013. In 2012, canopy closure of narrow and wide row widths was not significantly different. Vertical bars represent Fisher's protected LSD ($\alpha \leq 0.05$).

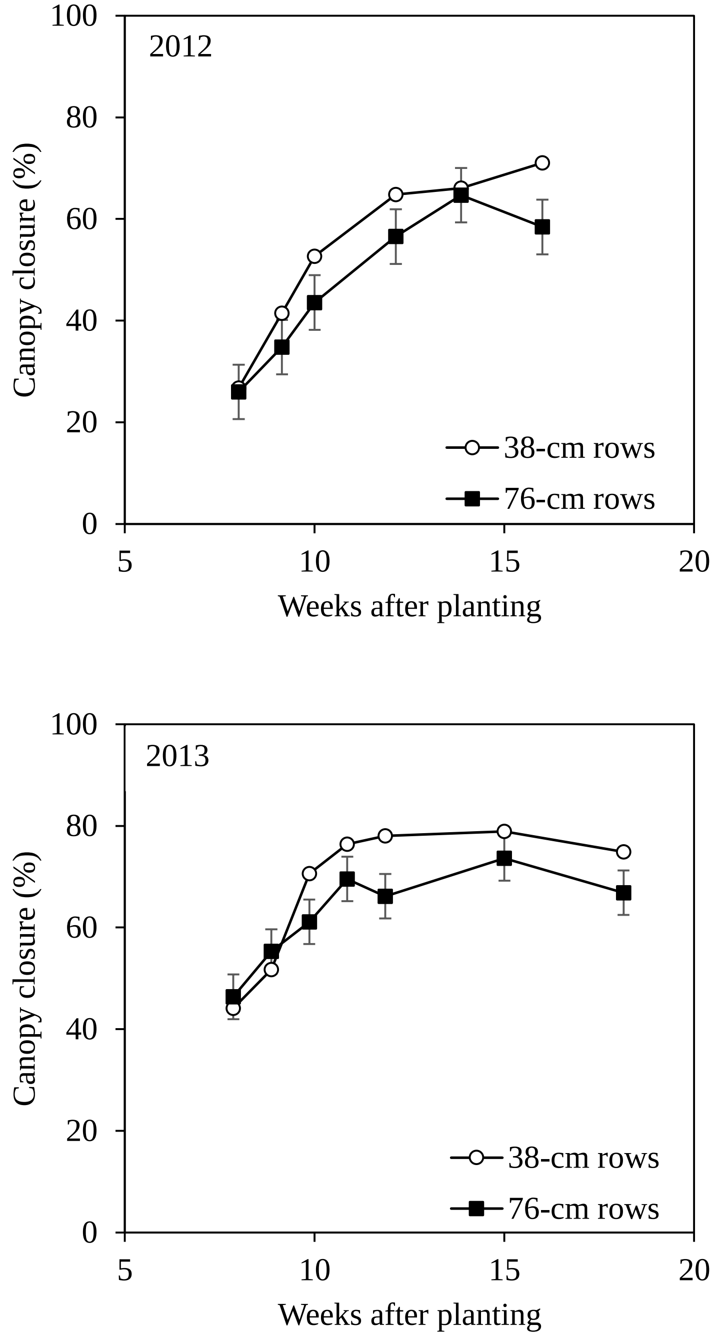

Figure 2.3. Main effects of row width on sugarbeet canopy closure at Richville, MI in 2012 and 2013. Vertical bars represent Fisher's protected LSD ($\alpha \leq 0.05$).

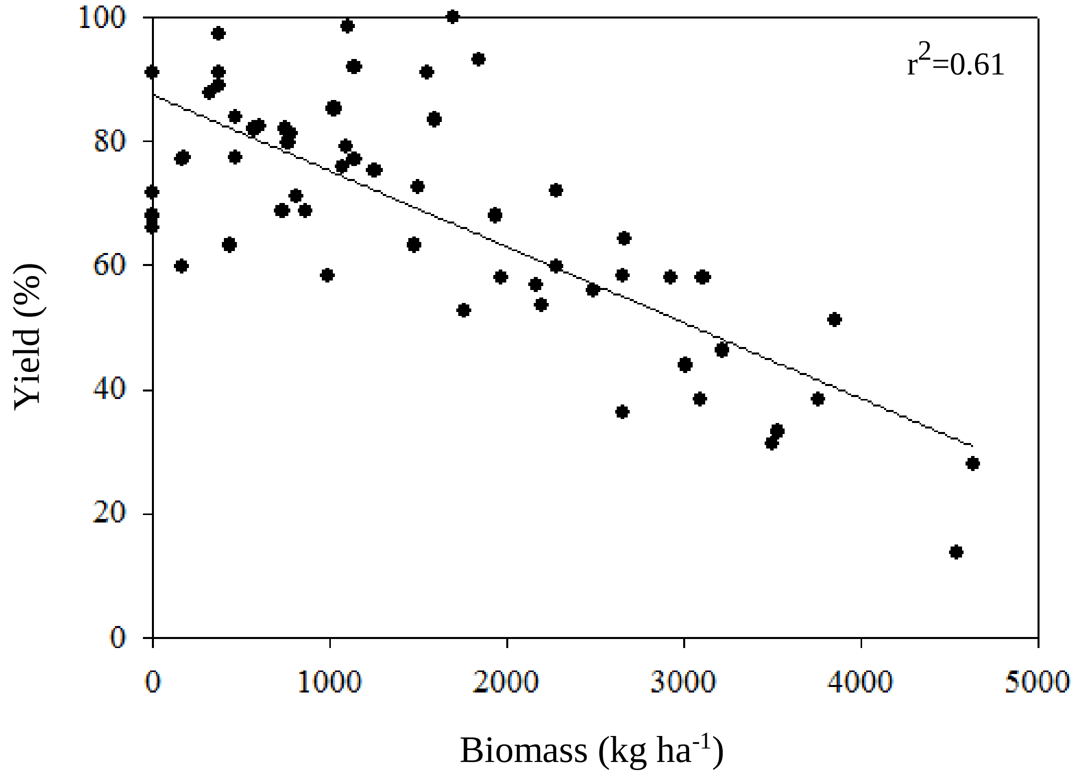

Figure 2.4. Sugarbeet yield reduction in response to volunteer corn biomass at Richville in 2013. The linear regression equation is: $y = 87.5 – 0.0122x$. Intercept and slope were significant ($p \leq 0.0001$). Yield loss was not observed at Richville 2012 or East Lansing 2013, and data did not fit to linear models. The model was also a poor fit for East Lansing 2012.

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CHAPTER 3

GLYPHOSATE-RESISTANT VOLUNTEER CORN DOES NOT OUTCOMPETE GLYPHOSATE-RESISTANT SUGARBEET FOR NITROGEN

Abstract

Glyphosate-resistant (GR) volunteer corn in GR sugarbeet is a common problem for Michigan sugarbeet growers. Michigan research has shown that volunteer corn populations of 1.7 plants m^{-2} significantly reduced sugarbeet yield and recoverable white sucrose per hectare. To determine if competition for nitrogen may be contributing to the sugarbeet yield losses associated with volunteer corn, a greenhouse study was conducted in East Lansing, Michigan in 2014. GR sugarbeet 'HM 173 RR' and GR (F_2) volunteer corn were grown in a replacement series design with four replications at proportions of 100:0, 75:25, 50:50, 25:75, and 0:100 with 8 plants pot^{-1}. Nitrogen fertilizer was applied at rates of 0, 67, 101, 134, and 168 kg N ha^{-1}. At the sugarbeet four-leaf stage (~5.5 WAP), sugarbeet and volunteer corn were harvested for biomass and nitrogen concentration measurements. Relative biomass and relative nitrogen assimilation were calculated by comparing sugarbeet and volunteer corn grown in mixture with respective monocultures. The nitrogen concentration of sugarbeet grown in monoculture was 43% higher than the nitrogen concentration of volunteer corn grown in monoculture when data were combined over nitrogen rates. In each mixture, total nitrogen concentration, relative biomass, and relative nitrogen assimilation was greater in sugarbeet than in volunteer corn. Sugarbeet competed more effectively for nitrogen than volunteer corn at each nitrogen rate, but was most aggressive at the highest rate of 168 kg ha^{-1}. These results indicate that early-season

competition for nitrogen is probably not a primary factor contributing to the suppression of sugarbeet growth and yield by volunteer corn.

Nomenclature: Corn, *Zea mays* L.; Sugarbeet, *Beta vulgaris* L.

Key words: Glyphosate-resistant, recoverable white sucrose, nitrogen, replacement series, relative biomass, relative nitrogen assimilation.

Introduction

Rapid early-season acquisition of nitrogen is important for sugarbeet growth and development. The primary role of soil-available nitrogen for sugarbeet is to increase the growth rate of above-ground tissue, and therefore increase canopy closure and total light interception (Armstrong et al. 1983; Milford et al. 1985; Scott and Jaggard 1993). Nitrogen-poor soils can result in sugarbeet yield reductions, while overabundance can result in quality reductions (Cariolle and Duvall 2006). In research conducted by Lauer (1995) in northern Wyoming, sugarbeet root yield increased by an average of 24%, 10%, and 1% (over three years) when the nitrogen application rate was increased from 0 to 112, 112 to 168, and 168 to 224 kg N ha^{-1}, respectively. Nitrogen was applied as ammonium nitrate and was broadcast and incorporated prior to planting. Preplant broadcast of nitrogen fertilizer is common for Michigan sugarbeet growers (Michigan Sugar Company, 2014). If additional nitrogen is required, application should take place soon after sugarbeet emergence. Sugarbeet require the most nitrogen early in the growing season, and respond poorly to excessive rates. The plateau of sugarbeet yield in response to nitrogen observed by Lauer (1995) was also observed by Draycott and Webb (1971), with the yield plateau beginning at 134 kg N ha^{-1}. Fertilizer management is a critical component of sugarbeet production practices, but also alters weed competitiveness (Blackshaw and Brandt 2008).

Weeds can interfere with sugarbeet growth by removing significant quantities of nitrogen from the soil. The response of weeds to nitrogen availability depends on the species. Blackshaw and Brandt (2008) hypothesized that weeds highly responsive to nitrogen would become more competitive as nitrogen fertilizer rates increased, and competitiveness of minimally responsive weeds would remain consistent. Nitrogen was applied using aqueous solutions of ammonium nitrate in a controlled environment. Blackshaw and Brandt (2008) selected Persian darnel (*Lolium persicum* Boiss. & Hohen. ex Boiss) and Russian thistle (*Kali tragus* L. Scop.) as low nitrogen responsive weeds to compete with wheat (*Triticum aestivum* L.). As predicted, variable nitrogen rates did not affect competitiveness of the two weed species. Redroot pigweed (*Amaranthus retroflexus* L.) and wild oat (*Avena fatua* L.) are highly nitrogen-responsive weed species. The hypothesis of the authors was only partially fulfilled. Redroot pigweed competitiveness with wheat increased as nitrogen rate increased, but wild oat competitiveness did not fluctuate. Results display species-specific responses to nitrogen availability.

In addition to species-specific responses, weed competitiveness for nitrogen has also been shown to vary among crops. In field conditions, common chickweed (*Stellaria media* L. Vill.) competitiveness was reduced by high nitrogen rates in potato (*Solanum tuberosum* L.), but not in wheat (Van Delden et al. 2002). Among various weed communities, nitrogen applications are often more beneficial to corn which can quickly shade out weeds (Abouziema et al. 2007; Cathcart and Swanton 2003; Evans et al. 2003; Lindsey et al. 2013). Preplant broadcast of ammonium nitrate is a common practice used to promote corn growth.

The competitiveness of volunteer corn in sugarbeet has not been evaluated in Michigan. With 100% of Michigan sugarbeet growers planting glyphosate-resistant (GR) sugarbeet, and 34% following corn, GR volunteer corn is a common problem (G. Clark, Agronomist, Michigan Sugar Company, Bay City, MI, personal communication). Results presented in Chapter 2 state that GR volunteer corn competing with GR sugarbeet at a density of 1.72 plants m^{-2} will reduce root yield by 15-27%. The demand for nitrogen by corn is high and is often the most limiting factor of its growth. Sugarbeet, however, have been found to acquire adequate nitrogen while experiencing weed competition from common lambsquarters (*Chenopodium album* L.) and Powell amaranth (*Amaranthus powellii* S. Wats.) at 0, 67, and 134 kg N ha^{-1} in greenhouse trials (Spangler and Sprague 2013). However, nitrogen assimilation by weeds correlated linearly with increasing weed growth in sugarbeet (0, 67, 100, and 134 kg N ha^{-1}) (Spangler et al. 2014). The fast early-season growth rate of corn compared with sugarbeet may result in severe nitrogen limitations and significantly contribute to sugarbeet yield-loss. Therefore, the objective of this research was to evaluate the effect of nitrogen on GR volunteer corn interference with GR sugarbeet using a replacement series experimental design.

Materials and Methods

Greenhouse trials were conducted in 2014 to determine if competition for nitrogen may be contributing to the sugarbeet yield losses associated with volunteer corn. This study was arranged as a two-factor randomized complete block design with four replications and was conducted twice. The two factors were: 1) GR sugarbeet competing with GR volunteer corn at five crop:weed ratios, and 2) five different nitrogen fertilizer rates. A Capac loam soil (fine-loamy, mixed, active, mesic Aquic Glossudalfs) and sand mixture (75:25) was used to fill 3.1 L pots (d=17.8 cm). The organic matter content was 2.1% and had a pH of 7.1. The soil was sampled at planting to evaluate nutrient levels. As a result, potassium and micronutrients were applied to reach adequate levels. Greenhouse temperatures were maintained at 25 $\pm$ 5 C and a 16 h d length was maintained with supplemental lighting.

Prior to nitrogen applications, each pot was watered to bring the soil water content to field capacity. Nitrogen was applied at five rates: 0, 67, 101, 134, and 168 kg N ha^{-1} using aqueous solutions of urea (46-0-0). Stock solutions (50 mL) of each nitrogen rate were evenly pipetted on to the soil surface and incorporated with approximately 200 mL of water. Pots were left to equilibrate for 5 d prior to planting. Sugarbeet and corn were planted in ratios of 100:0, 75:25, 50:50, 25:75, and 0:100, with 8 plants pot^{-1} in a replacement series experimental design (Figure 3.1). 'Hilleshög 173RR' (Syngenta Seeds Inc., 1020 Sugarmill Rd., Longmont, CO 80501) GR sugarbeet and volunteer GR corn 'F_2 - DeKalb 46-61' (Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO 63167) were planted at depths of 1.3- and 2.5-cm, respectively. To ensure establishment, sugarbeet was planted one week prior to volunteer corn. Pots were sub-irrigated throughout the experiment.

Plants were harvested when sugarbeet and volunteer corn was at the 4-leaf and V3 growth stages, respectively, approximately 5.5 weeks after sugarbeet planting. Excess soil was rinsed from the roots and blotted dry with paper towel. Each plant sample (roots and shoots) was oven-dried at 66 C for 5 d and weighed. Dried samples were subsequently ground to pass through a 2 mm sieve using a Wiley Mill (Arthur H. Thomas Wiley Cutting Mill, Thomas Scientific, 1654 High Hill Road, Swedesboro, NJ 08085). Nitrogen concentration was determined for each plant sample by the micro-Kjeldahl digestion method (Bremner 1996; Jung et al. 2003) and colorimetric analysis using a Lachat rapid flow injection unit (Hach Company, 5600 Lindbergh Drive, Loveland, CO 80538). Nitrogen assimilation for each species was calculated by multiplying plant biomass by the nitrogen concentration.

Data were analyzed using SAS 9.3 (SAS Institute Inc, Cary NC) statistical software. Assumptions of normality and equal variances were checked using a stem-and-leaf plot and Levene's Test ($p \leq 0.05$), respectively. Analysis of variance was conducted to compare treatment means using Fisher's Protected LSD at the $p \leq 0.05$ significance level and PROC MIXED. Data from both trials were combined due to an insignificant trial by treatment interaction. Main effects of species proportion and nitrogen rate were presented when interactions were not significant. Nitrogen assimilation and biomass measurements of sugarbeet and corn were converted to relative nitrogen assimilation (RN) and relative biomass (RB) using equation 1 (Blackshaw and Brandt 2008). RN and RB values were used to create replacement series diagrams to compare sugarbeet and corn competitiveness at five nitrogen rates in mixtures compared with monocultures.

RB or RN = Biomass or N assimilation in mixture /Biomass or N assimilation in monoculture [1]

Competitiveness of corn was also measured using the aggressivity index (AI) discussed by Blackshaw and Brandt (2008). AI values were calculated for nitrogen assimilation and biomass accumulation using equation 2.

AI = (RB or RN of volunteer corn) – (RB or RN of sugarbeet) [2]

Positive AI values indicate that volunteer corn was more competitive than sugarbeet. Negative AI values indicate that sugarbeet was more competitive than volunteer corn.

Results and Discussion

Relative nitrogen assimilation. The interaction between species and nitrogen rate was not significant for volunteer corn and sugarbeet nitrogen concentrations, therefore, main effects were evaluated. The nitrogen concentration of sugarbeet grown in monoculture was higher than the nitrogen concentration of volunteer corn grown in monoculture with 1.47% and 0.84%, respectively, combined over all nitrogen rates. Nitrogen rate significantly impacted relative nitrogen assimilation of sugarbeet and volunteer corn. In equal mixtures, sugarbeet was more competitive than volunteer corn in terms of relative nitrogen assimilation at all nitrogen rates (0, 67, 101, 134, and 168 kg N ha^{-1}) (Figure 3.2). Replacement series diagrams showed an increase in sugarbeet competitiveness as nitrogen rates increased. AI values indicate that sugarbeet was more competitive than volunteer corn from 0 kg N ha^{-1} to 134 kg N ha^{-1}, and was most competitive at 168 kg N ha^{-1} (Table 3.1). AI values for 0, 67, 101, 134, and 168 kg N ha^{-1} were -0.13, -0.14, -0.17, -0.23, and -0.40, respectively. Sugarbeet was also more competitive at each nitrogen rate in the 75:25 mixture. However, volunteer corn was more competitive for nitrogen than sugarbeet in the 25:75 (sugarbeet:volunteer corn) mixture when nitrogen was applied. However, when no nitrogen was applied, sugarbeet was able to outcompete corn (AI = -0.03).

Past research has shown an increase in the competitiveness of corn when nitrogen is applied (Abouziema et al. 2007; Cathcart and Swanton 2003; Evans et al. 2003; Lindsey et al. 2013). Corn competing with weeds season-long [primarily velvetleaf (*Abutilon theophrasti*

Medik.) and pigweed species (*Amaranthus* spp.] had higher grain yield when 120 kg ha^{-1} was applied compared with 0 kg N ha^{-1} (Abouziema et al. 2007). Yield reductions of corn by green foxtail (*Setaria viridis* L. P. Beauv.) were significantly greater when 0 kg N ha^{-1} was applied compared with 200 kg N ha^{-1}, with losses of 35-40% and 12-17%, respectively (Cathcart and Swanton 2003). When volunteer corn was the predominant species (25:75; sugarbeet:volunteer corn), nitrogen applications were required to outcompete sugarbeet (Table 3.1). This may help sugarbeet compete with corn clumps in the field because of the localized density and nitrogen demand.

Responsiveness of weeds to nitrogen is not a consistently reliable tool to predict competitiveness with a crop (Blackshaw and Brandt 2008; Spangler and Sprague 2013). Wild oat is considered highly responsive to nitrogen, but was not affected by nitrogen rate when competing with wheat (Blackshaw and Brandt 2008). Common lambsquarters and Powell amaranth are considered luxury consumers of nitrogen, but sugarbeet was more competitive than these species at 0, 67, and 134 kg N ha^{-1} (Spangler and Sprague 2013). Sugarbeet competitiveness with volunteer corn was similar to competitiveness with Powell amaranth. In equal mixture, sugarbeet was able to outcompete volunteer corn and Powell amaranth for nitrogen, and the competitiveness improved with greater additions of nitrogen (Table 3.1). Sugarbeet rapidly accumulates nitrogen early in the season. The responsiveness of interfering weeds, including volunteer corn, to nitrogen may not be a significant factor given the strength of acquisition by sugarbeet. Additionally, corn begins to acquire nitrogen at rapid rates after the V6 growth stage (Bender et al. 2013) which may further benefit sugarbeet competitiveness early in the growing season.

Relative biomass. Replacement series diagrams were constructed for each nitrogen rate because of significant nitrogen by crop:weed interactions. Similar to the replacement series diagrams of relative nitrogen sugarbeet appear to be more competitive than corn at each nitrogen rate in terms of relative biomass (Figure 3.3). However, sugarbeet competitiveness did not increase as nitrogen rate increased. AI values indicate that sugarbeet was more competitive with volunteer corn, and that the competitiveness was similar from 0 kg N $ha^{-1}$to 168 kg N ha^{-1} (Table 3.1). Sugarbeet was more competitive than corn in the 75:25 (sugarbeet:volunteer corn) mixture, and less competitive than corn in the 25:75 mixture at all nitrogen rates. Corn was significantly more competitive when nitrogen was applied than when no nitrogen was applied. AI values for 0, 67, 101, 134, and 168 kg N ha^{-1} were 0.18, 0.52, 0.40, 0.42, and 0.38, respectively.

Sugarbeet was more competitive with volunteer corn in terms of relative nitrogen compared with relative biomass. In the 50:50 mixture, sugarbeet relative biomass competitiveness did not significantly improve at the highest nitrogen rate (168 kg N ha^{-1}). In the 25:75 sugarbeet:corn mixture, sugarbeet was able to outcompete volunteer corn for relative nitrogen assimilation when no nitrogen was applied, but not for relative biomass. This suggests that interference of volunteer corn in sugarbeet has a greater impact on biomass accumulation than nitrogen assimilation. However, the greenhouse temperature was 25 $\pm$ 5 C which was more conducive to volunteer corn growth than cooler temperatures which may be experienced early in the sugarbeet growing season. Spangler and Sprague (2013) showed that sugarbeet competed more effectively with common lambsquarters and Powell amaranth in terms of relative biomass, but Powell amaranth was more competitive than common lambsquarters. The upright architecture and larger leaf surface area of Powell amaranth was credited for greater suppression of sugarbeet above-ground growth. Tall weeds can interfere with above-ground biomass accumulation of sugarbeet by intercepting light (Scott and Jaggard 1993; Schweizer and Bridge 1982). Our results implicate that shading by volunteer corn may be more disruptive to sugarbeet growth than nitrogen acquisition.

Volunteer corn is capable of reducing the yield of sugarbeet. Sugarbeet was able to outcompete corn in equal mixtures in terms of relative nitrogen and relative biomass at nitrogen rates ranging from 0 kg N ha^{-1} to 168 kg N ha^{-1}. In field conditions if the density of volunteer corn is greater than the density of sugarbeet, volunteer corn will be more competitive for nitrogen and biomass accumulation than sugarbeet if adequate nitrogen is available. If nitrogen is more limited, sugarbeet may be able to outcompete corn in terms of relative nitrogen, but not likely for relative biomass. Results indicate that early-season competition for nitrogen is not the primary yield-reducing factor for sugarbeet growth and development from volunteer corn. Shading of sugarbeet by volunteer corn may be more harmful which would make timing of control highly critical. Biomass of larger, chemical-controlled corn will interfere with sugarbeet even after the growing point has rotted (Kniss et al. 2012). Growers utilizing chemical weed control options need to be conscientious of the duration volunteer corn remains standing in the field.

APPENDICES

APPENDIX B

CHAPTER 3 TABLES AND FIGURES

Table 3.1. Effect of nitrogen rate on volunteer corn aggressivity index (AI) values when competing with sugarbeet at proportions of 75:25, 50:50, 25:75 (sugarbeet: volunteer corn).[a]

	Relative nitrogen[b]			Relative biomass		
Nitrogen rate	75:25	50:50	25:75	75:25	50:50	25:75
0 kg N ha^{-1}	- 0.43 a	- 0.13 a	- 0.03 a	- 0.50 a	- 0.23 a	0.18 a
67 kg N ha^{-1}	- 0.48 a	- 0.14 a	0.45 b	- 0.48 a	- 0.11 a	0.52 b
101 kg N ha^{-1}	- 0.65 a	- 0.17 a	0.31 b	- 0.50 a	- 0.01 a	0.40 b
134 kg N ha^{-1}	- 0.45 a	- 0.23 ab	0.40 b	- 0.46 a	- 0.15 a	0.42 b
168 kg N ha^{-1}	- 0.52 a	- 0.40 b	0.32 b	- 0.46 a	- 0.25 a	0.38 b

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Volunteer corn AI values that are above zero indicated that volunteer corn is more competitive than sugarbeet and weed AI values that are less than zero indicated that volunteer corn is less competitive than sugarbeet.

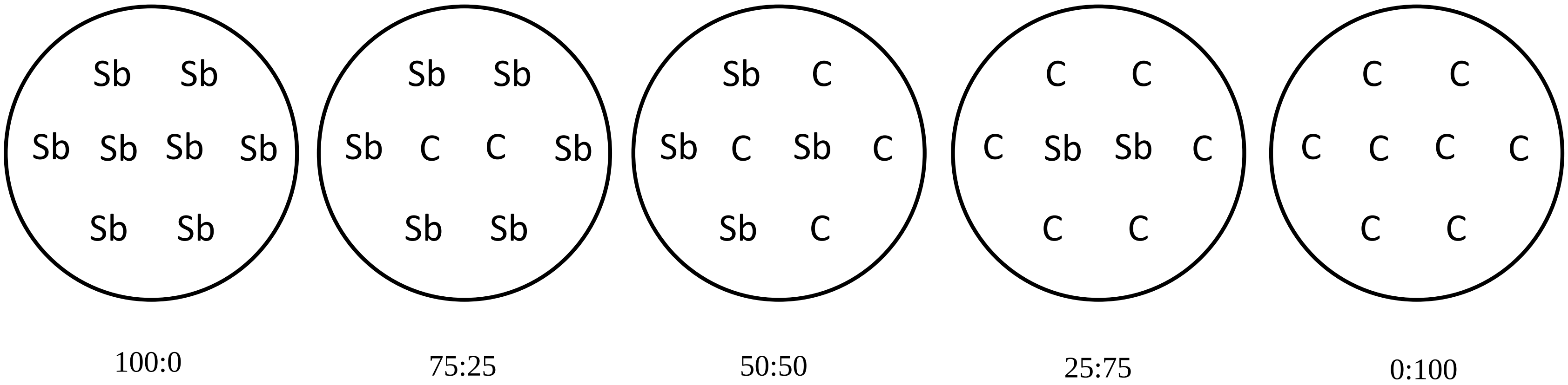

Figure 3.1. Sugarbeet (Sb) and volunteer corn (C) planting arrangements for replacement series experimental design. Pot volume was 3.1 L and the diameter at soil surface was 18 cm.

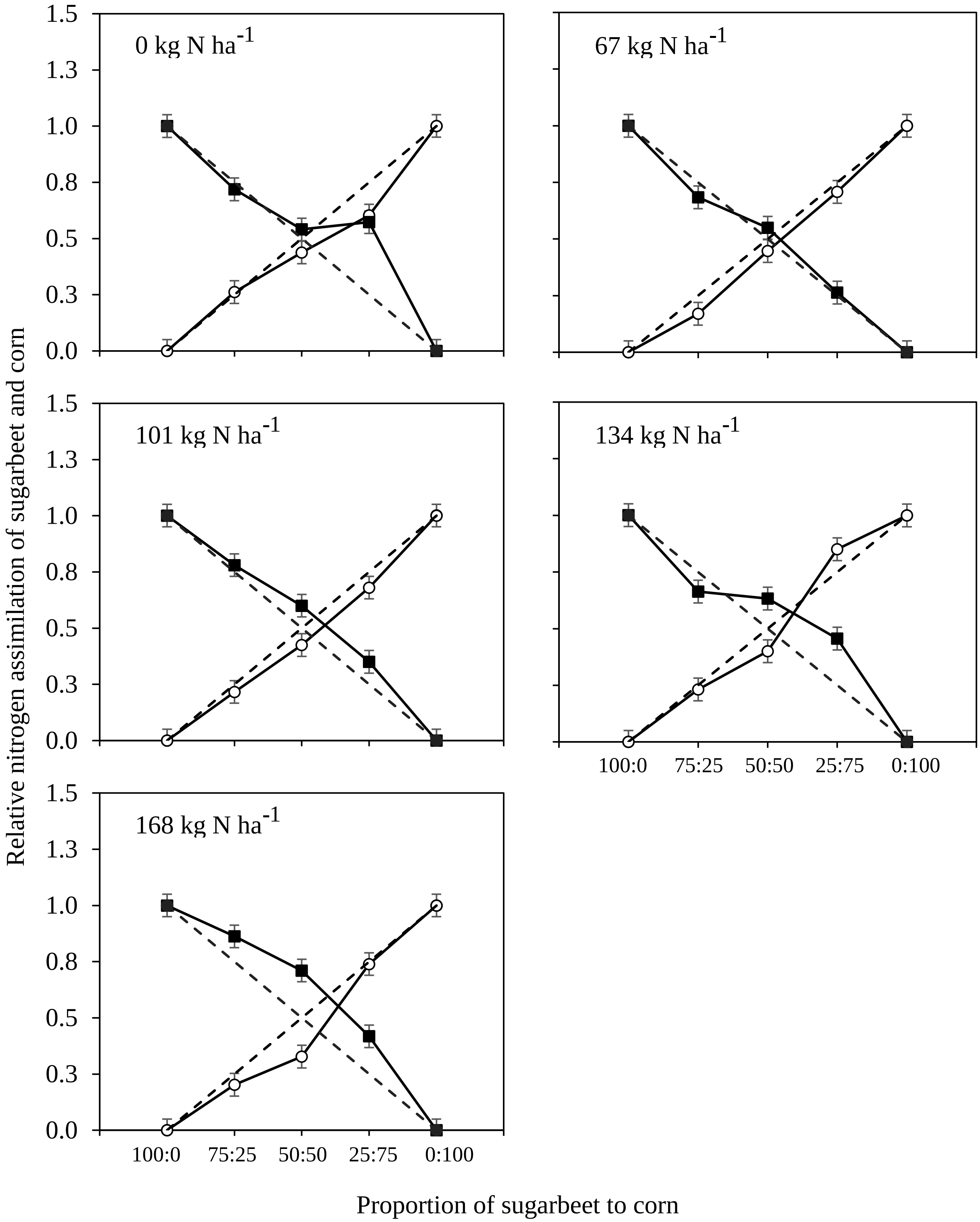

Figure 3.2. Relative nitrogen assimilation of glyphosate-resistant sugarbeet (■) competing with volunteer glyphosate-resistant corn (○) at 0, 67, 101, 134, and 168 kg N ha^{-1}. Vertical bars represent standard error of the mean.

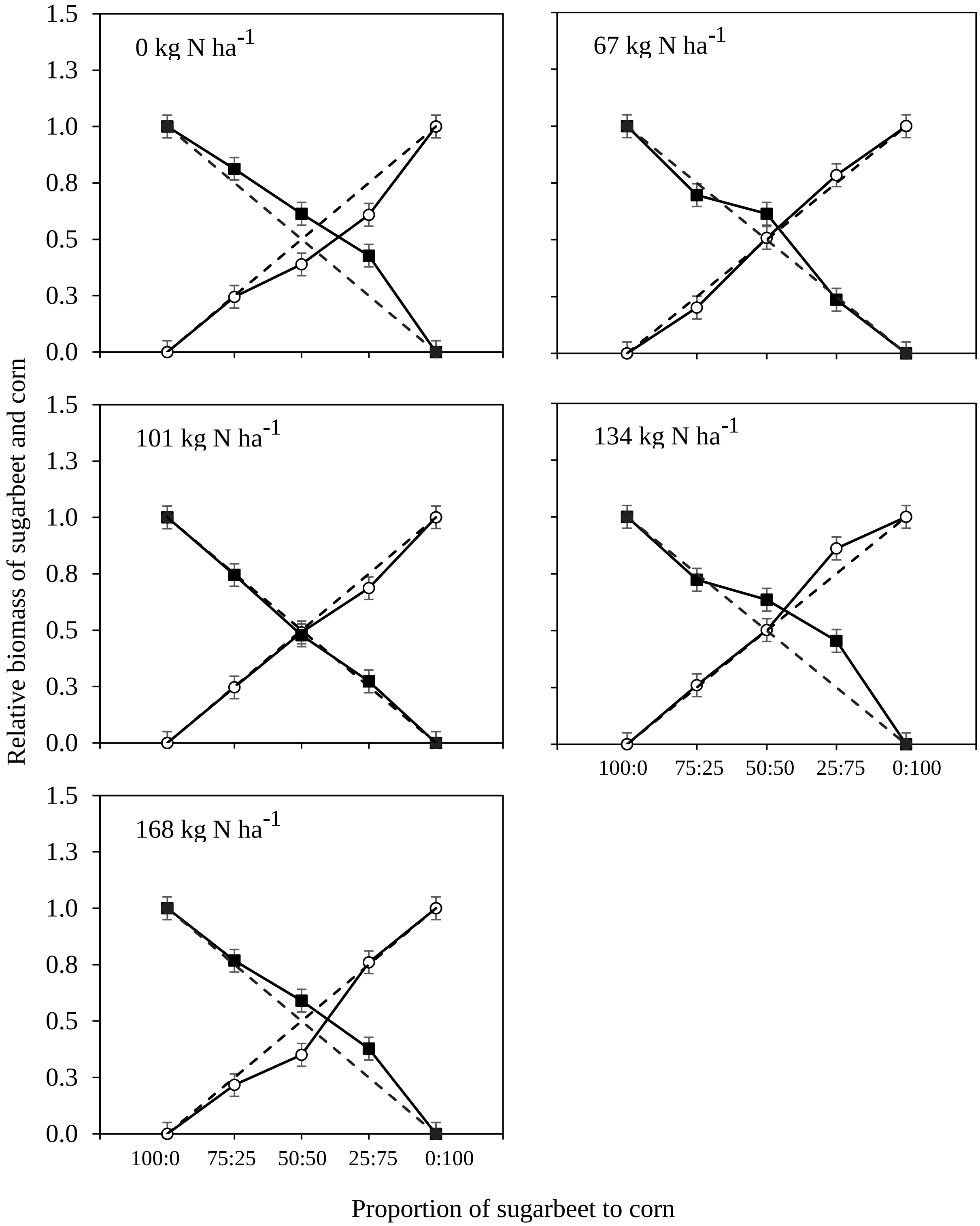

Figure 3.3. Relative biomass of glyphosate-resistant sugarbeet (■) competing with volunteer glyphosate-resistant corn (○) at 0, 67, 101, 134, and 168 kg N ha^{-1}. Vertical bars represent standard error of the mean.

APPENDIX C

PROTOCOL FOR THE TOTAL NITROGEN ANALYSIS OF PLANT TISSUE USING THE MICRO-KJELDAHL BLOCK DIGESTION METHOD

1. Assign 54 ground plant tissue samples to their respective 54 digestion tubes.

2. Weigh out 0.150 grams of a ground plant tissue sample onto Top (Republic Tobacco L.P., 2301 Ravine Way, Glenview, IL 60025-7627) cigarette papers.

    a. Fold the cigarette paper in half, followed by the sides and the top of the paper to contain the sample in the cigarette paper. Roll the paper into a ball and drop it into the correct digestion tube.

    b. Add an empty piece of cigarette paper to digestion tube 55.

    c. Weigh 0.150 grams of HSRM onto cigarette paper, fold and drop it into digestion tube 56. This is a plant standard and it can be obtained from the Michigan State University Soil and Plant Nutrient Laboratory.

3. Add 1 catalyst tablet to each digestion tube (ST AUTO 1.5 grams K_2SO_4 and 0.015 grams of Se, Alfie Packers, Inc., 8901 J. Street, Suite 10, Omaha, NE 68127).

4. Under a hood, add 7 mL of concentrated sulfuric acid to each digestion tube.

5. Set the digestion tubes in the digestion block. Turn the controller on and set it to digest the samples for 2 hours at 375 C. It will take approximately 1 hour for the digestion block to heat to 375 C.

6. After the digestion is completed, let the digestions tubes cool until they can be handled. It will take approximately 1 hour or longer for the digestion tubes to cool. To speed up this process, elevate the digestion tubes above the digestion block.

7. Dilute each sample to 75 mL with deionized water.

    a. While vortexing, slowly pour about 50 mL of room temperature deionized water from a beaker into each digestion tube. Make sure any precipitate that may have formed on the sides of the tube or in the solution is re-dissolved.

    b. After the solution has cooled to near room temperature, bring the volume up to 75 mL with a pipette. Adding the final volume of water after the solution has cooled will prevent it from evaporating.

8. Label plastic scintillation vials with the digestion tube number (1-56), their corresponding sample identification number, your name, the date, your primary investigator, and the digestion type (plant tissue total nitrogen).

9. Place a rubber stop on top of a digestion tube, and invert the tube at least 7 times to re-dissolve the solution.

10. Filter about 20 mL of the solution through Whatman No. 2 filter paper and into the corresponding labeled plastic scintillation vial. The vial should not be filled to the brim.

11. Repeat the inversion and filtering for each digestion tube until all 56 vials are filled.

12. Cap the vials and place them in a vial box. Label the outside of the box with the range of sample identification numbers, your name, the date, your primary investigator, and the digestion type (plant tissue total nitrogen).

13. Take the samples to the MSU Soil and Plant Nutrient Laboratory to determine the total nitrogen content in the diluted digest solutions.

14. Dispose of the remaining solution in the digestion tubes into a hazardous waste container. Place used filter papers and gloves into a sealed plastic bag and dispose in a trashcan.

15. Wash the digestion tubes, funnels, and any other dirty dishes using an acid wash procedure.

APPENDIX D

DETERMINATION OF SOIL NITRATE-NITROGEN: LACHAT

I. Reagents
   a. Extract Solution
      i. 1 M KCl – Dissolve 745.5 g oven dry KCl in about 8 liters pure water. Make to 10 liters and thoroughly mix.
   b. Nitrate-N Standards
      i. To a 1 liter volumetric flask add .7221 g oven dry KNO3. Make to volume with the extracting solution. This gives a 100 ppm NO3-N solution.
      ii. Make working standards of 2, 4, 6, 8, and 10 ppm by adding 2, 4, 6, 8, and 10 ml of the 100 ppm N solution to 100 mL volumetric flasks. Make to volume with the extracting solution and thoroughly mix.

II. Extraction
   a. Procedure
      i. Weigh out 10 g dry soil and place in a 125 mL Erlenmeyer flask.
      ii. Add 50 mL 1 M KCl.
      iii. Shake for 30 minutes at 180-200 oscillations per minute.
      iv. Filter through No. 2 Whatman filter paper.

III. Solution Analysis
   a. Procedure
      i. Standardize the LaChat unit with the standard N solutions.
      ii. Nitrate-N content of the filtered soil extracts is determine by using the nitrate-reduction method (QuikChem No. 10-107-04-1-A) through the LaChat rapid flow injection unit.

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CHAPTER 4

CONTROL OF GLYPHOSATE-RESISTANT VOLUNTEER CORN IN GLYPHOSATE-RESISTANT SUGARBEET

Abstract

Volunteer glyphosate-resistant (GR) corn is one of the most common weed problems found in glyphosate-resistant sugarbeet grown in Michigan. Field trials were conducted in 2012 and 2013 at the Michigan State University Agronomy Farm in East Lansing and at the Saginaw Valley Research and Extension Center near Richville, Michigan to examine the impact of the time of GR volunteer corn control on GR sugarbeet yield and quality with two different herbicides. Glyphosate-resistant sugarbeet was planted at 124,000 plants ha^{-1} in 76-cm rows. Directly after, 'F_2' glyphosate-resistant corn seed was planted approximately 13-cm off the center sugarbeet rows at densities of 1.2 and 1.72 plants m^{-2} in 2012 and 2013, respectively. Drought and cool early-season temperatures delayed volunteer corn emergence until the two-leaf sugarbeet stage in 2012. Volunteer corn was replanted at East Lansing in 2013 due to fatal germination resulting in emergence at two-leaf sugarbeet. Volunteer corn emerged simultaneously with sugarbeet at Richville in 2013. Treatments with clethodim and quizalofop were applied at five different times based on the corn growth stage (V2-V10). Clethodim and quizalofop were equally effective at controlling GR volunteer corn in GR sugarbeet. However, volunteer corn biomass remained at harvest when control was not implemented before the V8 growth stage at three of four site-years. Uncontrolled volunteer corn reduced yield by 38% at East Lansing in 2012 and at Richville in 2013. Yield reductions were not detected at Richville in 2012 or East Lansing in 2013. At Richville in 2013, corn removed at the V4 and V10 growth stage reduced sugarbeet yield by

10% and 34%, respectively. Regression analysis of yield and volunteer corn removal time at Richville in 2013 indicated a 10% sugarbeet yield reduction when volunteer corn was not controlled within 4.4 weeks after planting.

Nomenclature: 'F_2' volunteer corn, *Zea mays* L.; sugarbeet, *Beta vulgaris* L. 'Hilleshög 9173RR'

Key words: Glyphosate-resistant; clethodim; quizalofop; volunteer corn control

Introduction

In 2008, glyphosate-resistant (GR) sugarbeet was planted on 60% of U.S. hectarage and increased to 95% by 2009 (ERS 2012). In 2014, Michigan sugarbeet hectarage was 100% GR (Greg Clark, Michigan Sugar Company, personal communication). Glyphosate is an inexpensive herbicide, controls a broad range of weed species, and is easily broken down in the soil. The window of time for weed control in GR sugarbeet is wider than in conventional sugarbeet because glyphosate is able to control larger weeds. While this system is more elastic, understanding the time at which weeds need to be controlled without reducing sugarbeet yield and quality remains critical.

Early research conducted in GR sugarbeet grown in Michigan found the critical time of weed removal was 8 weeks after planting (WAP) in 1998 and prior to 15 WAP in 1999 when weed densities were lower (Kemp et al. 2009). Uncontrolled weeds beyond these times resulted in 10% yield reductions in sugarbeet. The most predominant weed species were pigweed spp. (*Amaranthus spp.*) and common lambsquarters (*Chenopodium album* L.). Weeds competing season-long reduced yield by 66%. The recommendation of Armstrong and Sprague (2010) was to control weeds before they reach 10 cm in height. Sugarbeet yield loss occurred when glyphosate was applied to weeds 15 cm tall. Spangler et al. (2014) found that sugarbeet yield was highest when weeds were controlled before the 2 cm height compared with weed control implemented at 8-, 15-, and 30-cm weed heights when nitrogen was limited. If control is implemented before or at the sugarbeet two-leaf stage, there is a risk of weed emergence occurring afterwards and, therefore additional weed control measures will be needed (Armstrong and Sprague 2010; Sprague et al. 2014; Wilson 1998). In another study, sugarbeet yield was not significantly reduced when plots were kept weed-free until the 8-10 leaf stage of sugarbeet, but was reduced by 38% when weeds were allowed to compete with sugarbeet beyond the four-leaf stage (Jursík et al. 2008). More urgent weed control times, such as 1.6 weeks after sugarbeet emergence, have been proposed for weeds in irrigated sugarbeet systems (Mesbah et al. 1995).

Sugarbeet is a poor early-season competitor because of its slow growth rate, and is especially susceptible to yield and quality reductions from weeds with fast and upright early-season growth characteristics (Schweizer and Bridge 1982). In Michigan crop rotations, 34% of sugarbeet follow corn (G. Clark, Agronomist, Michigan Sugar Company, Bay City, MI, personal communication). As a result, GR volunteer corn is a common problem for GR sugarbeet growers. Weed management options other than glyphosate are required to remove 'F_2' GR volunteer corn from the field.

Lipid synthesis-inhibiting herbicides provide excellent control of volunteer GR corn. The lipid synthesis-inhibiting herbicides, clethodim, quizalofop, and fenoxaprop applied to V5-V7 volunteer corn provided 94%, 99%, and 98% control, respectively (Deen et al. 2006). In another study, clethodim (0.86 kg ha^{-1}), quizalofop (1.20 kg ha^{-1}), and sethoxydim (0.30 kg ha^{-1}) provided 100%, 100%, and 94% control of volunteer GR corn (1.2 plants m^{-2}) when applied at the sugarbeet two-leaf stage, and 100%, 74%, and 85% control when applied at the sugarbeet eight-leaf stage, respectively (Kniss et al. 2012). Sugarbeet yield was reduced by 5% if volunteer corn (1.2 plants m^{-2}) remained in the field longer than 3.5 WAE. Alternatively, hand-weeded corn could remain in the field almost 6 WAE because shading diminished immediately. Environmental conditions which effect the emergence times of sugarbeet and corn influence the effectiveness of removal strategies and impact on sugarbeet yield and quality.

Previous research addressing GR volunteer corn interference in GR sugarbeet has been conducted in the Western sugarbeet-growing region of United States, but management strategies have not been determined for the Eastern sugarbeet growing region. Sugarbeet grown in the west often requires irrigation. Precipitation levels are significantly greater in Michigan and sugarbeet are produced on dryland, predominantly in soils with high water holding capacities. The interaction between crops and weeds is variable based on growing conditions and resources (Patterson 1995). Critical control times and herbicide effectiveness are expected to vary by region. The objectives of this research were to: 1) determine the optimal time for control of GR volunteer corn, and 2) compare the effectiveness of two lipid synthesis inhibiting herbicides, clethodim and quizalofop.

Materials and Methods

Field research was conducted at the Michigan State University Agronomy Farm at East Lansing, Michigan, and the Saginaw Valley Research and Extension Center near Richville, Michigan, in 2012 and 2013. The soil at East Lansing was a Capac loam (fine-loamy, mixed, active, mesic Aquic Glossudalfs) with a pH of 6.6 and an organic matter content of 2.8%. The soil at Richville was a Tappan-Londo loam (fine-loamy, mixed, active, calcareous, mesic Typic

Epiaquolls and fine-loamy, mixed, semiactive, mesic Aeric Glossaqualfs) with a pH of 7.8 and an organic matter content of 2.2%. All fields were chisel plowed in the fall and leveled with a soil finisher in the spring. Nitrogen fertilizer was applied as urea and incorporated prior to planting at recommended rates at each location.

Glyphosate-resistant sugarbeet 'Hilleshög 173 RR' (Syngenta Seeds Inc., 1020 Sugarmill Rd., Longmont, CO 80501) were planted in 76-cm rows at a population of 124,000 seeds ha^{-1}. Sugarbeet was planted on April 12, 2012 and May 3, 2013 in East Lansing and on April 4, 2012 and May 2, 2013 in Richville. Immediately following sugarbeet planting, GR 'F_2' 'DeKalb 46-61' (Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO 63167) volunteer corn was hand-planted at 1.2 and 1.72 plants m^{-2} in 2012 and 2013, respectively. Volunteer corn was planted 13 cm off the sugarbeet row, and alternated each side of each harvest row. The corn density in 2012 was selected based on research that assessed sugarbeet yield loss from volunteer corn in Nebraska and Wyoming (Kniss et al. 2012). Volunteer corn planting density was increased in 2013 based on Michigan results from 2012 (see Chapter 2) which showed significant sugarbeet yield reductions occurring at 1.72 volunteer corn plants m^{-2}. Corn seeds were planted 5 cm deep, staggered 13 cm off the two sugarbeet harvest rows, and evenly distributed throughout each plot. Multiple seeds were planted in each spot to ensure establishment and were subsequently thinned to one plant.

Fatal germination of volunteer corn occurred at East Lansing in 2013 as a result of shallow planting. Volunteer corn was then replanted, and was uniformly established by the sugarbeet two-leaf stage. All corn that survived the first plantings was removed by hand.

The experiment was arranged as a two-factor randomized complete block design with 4 replications. Plots were 3 m by 9 m in size. The first factor was herbicide treatment for volunteer corn control, clethodim and quizalofop. The second factor was herbicide application timing based on corn growth stage (V2, V4, V6, V8, and V10). Additional treatments included a no volunteer corn control and a no removal control. Application rates for clethodim and quizalofop were selected based on recommended label rates for volunteer corn size. Clethodim was applied at 0.11 kg ha^{-1} (V2, V4), 0.16 kg ha^{-1} (V6, V8), and 0.21 kg ha^{-1} (V10). Quizalofop was applied at 0.028 kg ha^{-1} (V2, V4), 0.035 kg ha^{-1} (V6, V8), and 0.056 kg ha^{-1} (V10). Each herbicide application included glyphosate (0.84 kg ae ha^{-1}) and AMS (2% w w^{-1}). When quizalofop was applied a non-ionic surfactant at 0.125% v v^{-1} was also included. Glyphosate + ammonium sulfate (0.84 kg ae ha^{-1} + 2% w w^{-1}) were applied to the entire plot area at the sugarbeet 2- and 6-leaf stages to keep plots weed-free throughout the season.

Volunteer corn control was evaluated throughout the growing season on a scale from 0 to 99%, with 0 indicating no volunteer corn control and 99% indicating complete control. Prior to sugarbeet harvest, the remaining volunteer corn in each plot was harvested for aboveground dry biomass. Sugarbeet roots from the two center rows of each plot were mechanically harvested and weighed. Sub-samples (10 roots $plot^{-1}$) were sent to the Michigan Sugar Company laboratory (Michigan Sugar Company, 2600 S. Euclid Avenue, Bay City, MI 48706) for sugar concentration measurements. Harvest dates were October 17, 2012 and October 15, 2013 at East Lansing and September 11, 2012 and September 25, 2013 at Richville.

Precipitation and temperature data for each location were obtained from the Michigan State University Enviro-weather Automated Weather Station Network (http://www.agweather.geo.msu.edu/mawn/), which maintains stations less than a mile from both field locations (Tables 4.1 and 4.2).

Data were analyzed using the PROC MIXED in SAS 9.3 (SAS Institute Inc, Cary NC). Assumptions of normality and homogeneity of variances were confirmed with a stem-and-leaf plot and Levene's test ($p \leq 0.05$), respectively. Data from each year and location were analyzed separately when there were significant interactions. Main effects are presented for herbicide treatment and volunteer corn removal timing when interactions were not significant. Treatment means were compared using Fisher's protected LSD at $\alpha \leq 0.05$ level of significance. Regression analysis was conducted using SigmaPlot version 11.0 (Systat Software Inc., San Jose, CA) to examine the critical period for volunteer corn removal in sugarbeet. Yield results were transformed into a percentage of the control treatment (no volunteer corn) by replication, and then normalized so the highest yield was equal to 100 percent. Data were then fit to the logistic equation (Equation 1; Kemp et al. 2009; Knezevic et al. 2002):

$$Y = [(1/\exp\,(c \cdot (T\text{-}d))+f)]+[(f\text{-}1)/f] \cdot 100, \qquad [1]$$

where Y is sugarbeet yield expressed as a percentage, T is time expressed in weeks after planting (WAP), d is the point of inflection, and c and f are constants. The model was a poor fit for three of four site-years (data not shown). Results are presented for Richville 2013.

Results and Discussion

Growing conditions. Early-season weather conditions altered volunteer corn emergence times and significantly impacted the competitive potential of GR volunteer corn in GR sugarbeet (Table 4.3). In 2012, drought conditions in Michigan were severe. East Lansing and Richville received 4 cm and 3 cm of rainfall, respectively, in the first month after planting, whereas a typical April receives nearly 8 cm (Table 4.1). Sugarbeet and volunteer corn were both stunted by drought conditions, but volunteer corn was further inhibited by cool early-season temperatures (Table 4.2). Sugarbeet emergence was unaffected by the cool weather, but cool conditions delayed emergence of volunteer corn until sugarbeet was at the two-leaf stage. Soil temperatures need to be > 10 C for corn to germinate (Blacklow, 1972).

In 2013, precipitation at East Lansing and Richville totaled 8 cm and 9 cm, respectively, in the first 30 d after planting (Table 2.1). Abundant rainfall continued through June at East Lansing and promoted rapid growth of sugarbeet and corn. Soil temperatures were ideal for germination of corn and sugarbeet (Table 2.2). At Richville, volunteer corn emerged simultaneously with sugarbeet. However, at East Lansing fatal germination of volunteer corn led to replanting and volunteer corn emerged at the two-leaf sugarbeet stage. Weather conditions in previous research have caused variations in corn emergence time, and have altered the magnitude of interference with sugarbeet (Kniss et al. 2012).

Volunteer corn control and biomass. Years and locations are presented separately as a result of significant interactions when analyzing volunteer corn control and biomass. No significant interactions occurred between herbicide treatment and application time so main effects are presented. Combined over application timing, clethodim and quizalofop provided equally effective control of volunteer corn 14 days after treatment (DAT) in three of the four site-years, East Lansing in 2012, Richville in 2012, and East Lansing in 2013 (Table 4.4). At Richville in 2013, clethodim (86%) controlled volunteer corn more effectively than quizalofop (82%). Averaged over application timing, end-of-season corn biomass was similar between clethodim and quizalofop at each site-year (Table 4.5). Similarly in GR soybean, clethodim and quizalofop were more effective at controlling GR volunteer corn than fenoxaprop, in two of four site-years and four of four site-years, respectively (Deen et al. 2006). Clethodim and quizalofop controlled $\geq$ 96% of GR volunteer corn in GR sugarbeet, and were more effective than sethoxydim (Kniss et al. 2012).

Volunteer corn control was significantly affected by the time of herbicide application at each site-year (Table 4.4). Control implemented at or before the V4 corn growth stage was $\geq$ 98%. Control implemented at the V6 growth stage was significantly reduced, however still adequate, at East Lansing in 2012, Richville in 2012, and Richville in 2013 with 94%, 90%, and 92%, respectively. At East Lansing in 2013, a significant reduction in volunteer corn control occurred at the V8 corn stage, control fell from 96% at V6 to 71% at V8 corn. Control of volunteer corn at the V10 growth stage at East Lansing and Richville was 73% and 76%, respectively in 2012, and 42% and 39%, respectively in 2013.

The time of herbicide application for volunteer corn control significantly impacted corn biomass remaining at harvest (Table 4.5). In 2012, no corn biomass remained in the field at harvest if control was implemented at the V2 stage. In 2013, corn biomass was completely removed by herbicide applications at the V2, V4, and V6 growth stage, and also by the V8 application time at Richville. At East Lansing in 2012, Richville in 2012, East Lansing in 2013, and Richville in 2013, biomass remaining at harvest from the V10 removal time was 15%, 10%, 49%, and 40% of the no removal control (Table 4.5). When no control strategies were implemented significantly greater quantities of volunteer corn biomass remained at harvest with 2130, 920, 1300, and 3810 kg ha^{-1} at East Lansing and Richville in 2012, and at East Lansing and Richville in 2013, respectively (data not shown).

The effectiveness of weed control is affected by the time of implementation. At East Lansing and Richville in 2012 and 2013, volunteer corn control decreased as the duration of interference increased. Subsequently, longer durations of interference resulted in larger quantities of corn biomass remaining at harvest. Volunteer corn was completely controlled when management strategies are implemented at the sugarbeet two-leaf stage, providing all volunteer corn had emerged (Kniss et al. 2012). Control implemented at the sugarbeet eight-leaf stage is more effective when environmental conditions result in delayed or ongoing emergence of volunteer corn. In our research, control timings were based on corn stages as opposed to sugarbeet stages which prevented applying herbicide before corn had emerged. Corn control was $\geq$ 98% when implemented at the V2 and V4 growth stages. The sugarbeet stages varied widely by site-year. When herbicide was applied at the V2 corn growth stage, sugarbeet was at the 4-leaf stage at East Lansing in 2012, 6-leaf stage at Richville in 2012, 8-leaf stage at East Lansing in 2013, and 2-leaf stage at Richville in 2013 (Table 4.3). Environmental conditions, especially early-season, have a significant impact on the competitive potential of volunteer corn in sugarbeet.

Sugarbeet quality and yield. As a result of significant interactions, data were separated by year and location for analysis of sugar content and RWSMg. Interactions between herbicide treatment and volunteer corn control time were not significant so main effects are presented. Mean sugar concentration was 18.2% at East Lansing in 2012, 16.5% at Richville in 2012, 17.4% at East Lansing in 2013, and 20.2% at Richville in 2013 (Table 4.6). However, sugar percentages were consistent within site-years and were not significantly affected by herbicide treatment or volunteer corn removal time. RWSMg was also not significantly affected by herbicide treatment or volunteer corn removal time (Table 4.6). RWSMg means were 131, 121, 130, and 153 kg Mg^{-1} at East Lansing in 2012, Richville in 2013, East Lansing in 2013, and Richville in 2013, respectively. Previous research in GR sugarbeet has also reported no effect of weed removal time (8-cm, 15-cm, or 30-cm weed heights) on sugar quality (Spangler et al. 2014).

Data were separated by year and location for yield and RWSH analysis as a result of significant interactions. Main effects for herbicide treatment and volunteer corn control time are presented since there was not a significant interaction. Herbicide treatment did not affect sugarbeet yield or RWSH at Richville in 2012 or at Richville in 2013 (Table 4.7). Biomass remaining in the field at harvest was similar for volunteer corn treated with clethodim and quizalofop at each site-year (Table 4.5). Yield differences between herbicide treatments also did not occur at East Lansing in 2013 (Table 4.7). However, at East Lansing in 2012, plots treated with quizalofop had higher yield and RWSH than plots treated with clethodim. Differences in yield and RWSH were not supported by the volunteer corn control or biomass results for the two herbicides (Table 4.4; Table 4.5).

At East Lansing in 2012, sugarbeet root yield and RWSH were reduced by 38% and 35%, respectively, when volunteer corn was not controlled (Table 4.7). At Richville in 2013, sugarbeet yield was reduced by 10% if volunteer corn was not controlled at or before the V4 corn growth stage. Yield was reduced by 34% when volunteer corn was controlled at the V10 growth stage. RWSH was also reduced if corn was not controlled by V4, and further reduced if control was implemented at V10. RWSH reductions were similar to yield reductions with 11% loss observed at the V4 growth stage and 35% loss by V10 corn.

Environmental conditions may help explain the variation of responses in our study. At Richville in 2012 and at East Lansing in 2013, no yield or RWSH differences were observed in response to corn removal time. Volunteer corn growth was poor at Richville in 2012 and at East Lansing in 2013 as a result of early-season environmental conditions. Delayed emergence of volunteer corn until the sugarbeet two-leaf stage, and drought conditions in 2012 may have reduced the competitive potential of volunteer corn. Alternatively, high levels of precipitation at East Lansing in 2013 promoted rapid growth of sugarbeet and corn. Sugarbeet canopies at each site-year were able to develop quicker and were further along compared with East Lansing in 2012 and Richville in 2013. The sugarbeet growth stage at the V2 application time, for example, was 4-, 6-, 8-, and 2-leaf at East Lansing and Richville in 2012, and at East Lansing and Richville in 2013, respectively (Table 4.3). Sugarbeet remained competitive throughout the season and were able to suppress volunteer corn.

When removal of GR volunteer corn was evaluated in GR sugarbeet in Wyoming and Nebraska, the yield response of sugarbeet was dependent upon the emergence time of corn in relation to sugarbeet (Kniss et al. 2012). Corn emerging prior to sugarbeet reduced yield by up to 40%, while corn emerging at the same time or later reduced yield by up to 18%. Control was implemented at the sugarbeet two-leaf stage was effective when all corn had emerged. Control was more effective at the sugarbeet eight-leaf stage when corn emerged later in the season.

In Michigan, the maximum sugarbeet yield reduction caused by volunteer corn interference was 38%, which occurred at East Lansing in 2012 and at Richville in 2013 (Table 4.7). Yield reductions did not occur at Richville in 2012 or at East Lansing in 2013. Yield reductions of sugarbeet was influenced by early-season weather conditions and time of volunteer corn emergence. Environmental conditions inhibiting the growth of corn at Richville in 2012 included drought, cool early-season temperatures that resulted in delayed germination of corn (Table 4.1; 4.2). East Lansing also experienced these conditions in 2012, but drought was less severe early in the season and volunteer corn was able to grow above the sugarbeet canopy quickly. Competitive pressure of volunteer corn was poor at East Lansing in 2013 likely due to fatal germination and the replanting of volunteer corn which resulted in emergence at two-leaf sugarbeet. Abundant early-season rainfall promoted rapid corn growth, but also promoted rapid sugarbeet growth which was able to suppress corn. Results agree with research conducted by Kniss et al. (2012) that corn emerging after sugarbeet will be less competitive than corn emerging prior to sugarbeet. However, extensive yield loss was observed in Michigan when corn and sugarbeet emerged at the same time. Yield was reduced by 10% when volunteer corn (1.7 plants m^{-2}) interfered with sugarbeet for $\geq$ 4.4 WAP (Figure 4.1). Kniss et al. (2014) estimated that yield was reduced by 5% when corn (1.2 plants m^{-2}) interfered for > 3.5 weeks after emergence (WAE). Corn controlled mechanically could remain in the field for a greater period of time (6 WAE) without causing yield loss. Slow degradation of necrotic biomass extends the duration of interference (Marquardt and Johnson 2006).

Early-season environmental conditions impacted the magnitude of volunteer corn interference resulting in variable responses by sugarbeet among years and locations. Corn emerging after sugarbeet was less competitive than corn emerging before or with sugarbeet. Despite the size of volunteer corn, both clethodim and quizalofop controlled volunteer corn. When competition began at sugarbeet emergence, yield was reduced by 10% if control wasn't implemented within 4.4 weeks after planting. Yield was reduced by 34% when volunteer corn remained in the field at the V10 growth stage. When volunteer corn emergence and growth was delayed until the sugarbeet two-leaf stage, removal time required to avoid yield loss was extended to the V10 stage. Research by Kemp et al. recommended weed control be implemented 8 weeks after planting (WAP) to prevent 10% yield reduction in sugarbeet. The primary weeds were small-seeded broadleaves, which were 2.5 cm in height 2 to 3 WAP. Volunteer corn was more competitive with sugarbeet due to its morphology and needs to be controlled earlier. Clethodim and quizalofop can both be tank-mixed with glyphosate. The cost of clethodim and quizalofop were \$12.50 ha^{-1} and \$8.27 ha^{-1}, respectively, in 2013 when applied at the V2 and V4 corn growth stages (Helena Chemical Company, personal communication). Growers need to consider late-emerging volunteer corn when assessing the value and timing of an application in order to avoid the need for multiple applications. Volunteer corn emergence will be effected by fall and spring tillage practices which can alter seed depth. Volunteer corn seed remaining on the soil surface in the fall is more prone to decay, predation, and fatal germination than buried seed. In soybean, volunteer corn controlled 8 weeks after soybean emergence, reduced yield by 12% (Beckett and Stoller 1988). Soybean would be more competitive with volunteer corn than sugarbeet due to its upright growth and branching habits. The slow growth of sugarbeet is not as conducive to suppressing volunteer corn growth. While yield loss did not occur at two of four site-years, volunteer corn biomass remained in the field at harvest if control was implemented after the V6 growth stage. Growers in Michigan need to consider the value of removing volunteer corn, even at low masses, to avoid difficulties with topping and harvest of sugarbeet.

APPENDICES

APPENDIX E

Table 4.1. Monthly precipitation at East Lansing, Michigan, and Richville, Michigan, in 2012 and 2013 and a 30-yr average.[a]

	2012		2013		
Month	East Lansing	Richville	East Lansing	Richville	30-yr avg.[c]
	cm		cm		cm
April	(3.9)[b]	(3.0)	--	--	7.7
May	6.2	9.9	(8.4)	(8.7)	8.5
June	2.7	2.8	11.5	4.4	8.8
July	3.7	9.2	5.6	5.2	7.2
August	5.3	10.2	11.0	4.7	8.2
September	5.5	4.1	1.8	1.5	8.9
October	9.2	--	11.8	--	6.4

[a] Enviro-weather Automated Weather Network. Michigan State University (2014) http://enviroweather.msu.edu Accessed December 22, 2014.

[b] Precipitation data in parenthesis is from the time of planting.

[c] The 30-yr average precipitation is from Lansing, Michigan (1981-2010).

Table 4.2. Average air and soil temperatures 1-3 weeks after planting (WAP) at East Lansing, Michigan, and Richville, MI in 2012 and 2013.[a]

	2012		2013	
Weeks after planting[b]	East Lansing	Richville	East Lansing	Richville
Air temperature	C		C	
Week 1	18	13	24	25
Week 2	15	17	19	18
Week 3	15	13	25	26
Soil temperature[c]				
Week 1	10	8	16	17
Week 2	10	11	14	12
Week 3	10	9	18	18

[a] Enviro-weather Automated Weather Network. Michigan State University (2014) http://enviroweather.msu.edu Accessed December 22, 2014, February 15, 2015.

[b] Sugarbeet was planted on April 12, 2012 and May 3, 2013 at East Lansing and on April 4, 2012 and May 2, 2013 at Richville.

[c] Temperature of the soil at a depth of 5 cm.

Table 4.3. Sugarbeet growth stage at volunteer corn removal times at East Lansing and Richville, MI in 2012 and 2013.

	2012		2013	
Volunteer corn removal time[a]	East Lansing	Richville	East Lansing	Richville
	Sugarbeet leaf stage			
V2	4	6	8	2
V4	8	9	13	5
V6	10	11	17	8
V8	13	13	19	10
V10	13	13	20	15

[a] Corn removal timings were based on corn growth stage.

Table 4.4. Main effects of herbicide treatment and volunteer corn removal time on volunteer corn control 14 d after treatment at East Lansing and Richville, MI in 2012 and 2013.[a]

	2012		2013	
Main effects	East Lansing	Richville	East Lansing	Richville
Herbicide treatment	% control			
Clethodim[b]	90 a	82 a	87 a	86 a
Quizalofop[c]	88 a	81 a	88 a	82 b
Volunteer corn removal time[d]				
V2	99 a	99 a	99 a	99 a
V4	98 a	98 a	98 a	99 a
V6	94 b	90 b	96 a	92 b
V8	80 c	77 c	71 b	84 c
V10	73 d	76 c	42 c	39 d
No removal control	0 e	0 d	0 d	0 e
ANOVA	*p* value			
Herbicide treatment	0.9896	0.7942	0.4370	0.0229
V. corn removal time	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Herbicide x time	0.1521	0.1692	0.3225	0.1183

[a] Means followed by the same letter within a column are not statistically different at ($p \leq 0.05$).

[b] Clethodim was applied at 0.11 kg ha^{-1} (V2, V4), 0.16 kg ha^{-1} (V6, V8), 0.21 kg ha^{-1} (V10) with glyphosate 0.84 kg ae ha^{-1} + AMS 2% w w^{-1}

[c] Quizalofop was applied at 0.028 kg ha^{-1} (V2, V4), 0.035 kg ha^{-1} (V6, V8), 0.056 kg ha^{-1} (V10) with glyphosate 0.84 kg ae ha^{-1} + AMS 2% w w^{-1} + non-ionic surfactant 0.125% v v^{-1}

[d] Volunteer corn removal times were based on corn growth stage.

Table 4.5. Main effect of volunteer corn removal time on corn biomass remaining at harvest at East Lansing and Richville, MI in 2012 and 2013.[a] Biomass is expressed as a percentage of the no removal control.

	2012		2013	
Main effects	East Lansing	Richville	East Lansing	Richville
	% of no removal control			
Herbicide treatment				
Clethodim[b]	21 a	20 a	28 a	25 a
Quizalofop[c]	20 a	22 a	25 a	22 a
Volunteer corn removal time[d]				
No volunteer corn	0 a	0 a	0 a	0 a
V2	0 a	0 a	0 a	0 a
V4	1 a	0 a	0 a	0 a
V6	1 a	5 b	0 a	0 a
V8	6 b	12 c	11 a	0 a
V10	15 c	10 bc	49 b	40 b
No removal control	100 d	100 d	100 c	100 c
ANOVA	*p* value			
Herbicide treatment	0.8834	0.7660	0.6603	0.3577
V. corn removal time	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Herbicide x time	1.0000	0.9997	0.9929	0.5405

[a] Means followed by the same letter within a column are not significantly different ($p \leq 0.05$).

[b] Clethodim was applied at 0.11 kg ha^{-1} (V2, V4), 0.16 kg ha^{-1} (V6, V8), 0.21 kg ha^{-1} (V10) with glyphosate 0.84 kg ae ha^{-1} + AMS 2% w w^{-1}

[c] Quizalofop was applied at 0.028 kg ha^{-1} (V2, V4), 0.035 kg ha^{-1} (V6, V8), 0.056 kg ha^{-1} (V10) with glyphosate 0.84 kg ae ha^{-1} + AMS 2% w w^{-1} + non-ionic surfactant 0.125% v v^{-1}

[d] Volunteer corn removal times were based on corn growth stage.

Table 4.6. Main effects of volunteer corn removal time on the percent sugar and recoverable white sucrose per Megagram (RWSMg) of glyphosate-resistant sugarbeet at East Lansing and Richville, MI in 2012 and 2013.[a, b]

	Sugar				RWSMg			
	2012		2013		2012		2013	
Main effects	East Lansing	Richville	East Lansing	Richville	East Lansing	Richville	East Lansing	Richville
Herbicide treatment	%				$kg\ Mg^{-1}$			
Clethodim[b]	19.0 a	16.5 a	17.3 a	20.3 a	136 a	121 a	128 a	153 a
Quizalofop[c]	18.9 a	16.5 a	17.5 a	20.2 a	135 a	121 a	130 a	152 a
Volunteer corn removal time[c]								
No volunteer corn	18.7 a	16.8 a	17.9 a	20.3 a	133 a	125 a	134 a	154 a
V2	16.3 a	16.8 a	17.2 a	20.2 a	116 a	125 a	127 a	152 a
V4	18.8 a	16.3 a	17.4 a	20.2 a	134 a	119 a	129 a	152 a
V6	19.1 a	16.7 a	17.5 a	20.4 a	137 a	123 a	130 a	154 a
V8	16.6 a	16.2 a	17.6 a	20.2 a	120 a	119 a	131 a	152 a
V10	19.2 a	16.4 a	17.3 a	20.3 a	139 a	120 a	129 a	153 a
No control	18.8 a	16.3 a	17.2 a	20.0 a	135 a	119 a	127 a	151 a
ANOVA	*p* value				*p* value			
Herbicide treatment	0.6032	0.7955	0.2179	0.8037	0.3046	0.7412	0.2184	0.6912
V. corn removal time	0.0971	0.3695	0.4770	0.6744	0.1150	0.3107	0.4722	0.5767
Herbicide x time	0.0631	0.9263	0.7841	0.9985	0.1112	0.6560	0.9678	0.9651

[a] Means followed by the same letter within a column are not significantly different ($p \leq 0.05$).

[b] Data are combined over herbicide treatments (clethodim and quizalofop) since there was not a significant herbicide by removal time interaction.

[c] Volunteer corn removal times were based on corn growth stage.

Table 4.7. Main effects of volunteer corn removal time on glyphosate-resistant sugarbeet root yield and recoverable white sucrose per hectare (RWSH) at East Lansing and Richville, MI in 2012 and 2013.[a, b]

	Yield				RWSH			
	2012		2013		2012		2013	
Main effects	East Lansing	Richville	East Lansing	Richville	East Lansing	Richville	East Lansing	Richville
Herbicide treatment	Mg ha^{-1}				kg ha^{-1}			
Clethodim[b]	47.8 b	66.4 a	65.1 a	42.2 a	6495 b	8092 a	8274 b	6438 a
Quizalofop[c]	52.0 a	68.0 a	68.7 a	39.4 a	7011 a	8217 a	8908 a	6006 a
Volunteer corn removal time[c]								
No volunteer corn	48.2 b	63.2 a	68.1 a	49.0 a	6306 b	7917 a	9060 a	7542 a
V2	49.0 b	71.3 a	68.5 a	45.4 ab	6522 b	8901 a	8656 a	6796 ab
V4	50.7 ab	65.1 a	68.4 a	44.3 b	6841 ab	7753 a	8853 a	6738 b
V6	56.8 a	66.0 a	68.2 a	43.5 b	7724 a	8076 a	8862 a	6701 b
V8	46.5 b	64.0 a	65.1 a	43.2 b	6279 b	7635 a	8707 a	6585 b
V10	46.5 b	70.0 a	64.3 a	32.2 c	6428 b	8439 a	8266 a	4927 c
No control	29.9 c	64.8 a	61.4 a	30.6 c	4104 c	7768 a	7838 a	4599 c
ANOVA	*p* value				*p* value			
Herbicide treatment	0.0077	0.2051	0.0839	0.0801	0.2152	0.7214	0.0206	0.0628
V. corn removal time	0.0144	0.4482	0.2179	< 0.0001	< 0.0001	0.1687	0.4441	< 0.0001
Herbicide x time	0.0841	0.3109	0.1097	0.4406	0.0552	0.5822	0.0634	0.3564

[a] Means followed by the same letter within a column are not significantly different ($p \leq 0.05$).

[b] Data are combined over herbicide treatments (clethodim and quizalofop) since there was not a significant herbicide by removal time interaction.

[c] Volunteer corn removal times were based on corn growth stage.

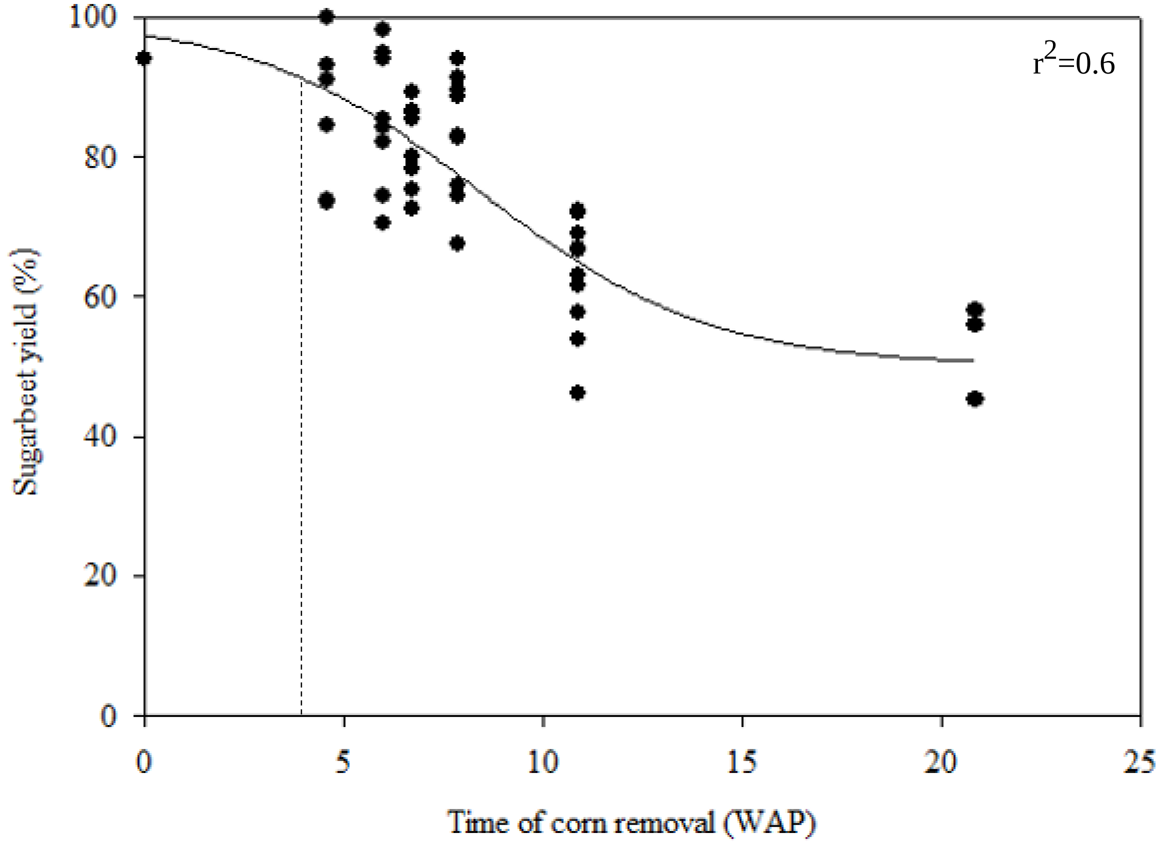

Figure 4.1. Effect of corn removal time on sugarbeet root yield at Richville, MI in 2013. Corn was removed at the V2, V4, V6, V8, and V10 corn growth stage, and uncontrolled corn was removed at harvest. The vertical dashed line represents 10% sugarbeet root yield loss, compared to the weed-free. Data were fit to the equation: $Y = [(1/\exp(0.35 \cdot (T\text{-}6.40))+2.01)]+[(2.01\text{-}1)/2.01] \cdot 100$, ($p < 0.0001$).

APPENDIX F

Table F.1. Corn development at East Lansing and Richville, MI in 2012 and 2013.

	2012		2013	
Volunteer corn removal time[a]	East Lansing	Richville	East Lansing	Richville
	WAP[b]			
V2	7.0	6.0	7.9	4.6
V4	9.0	7.6	8.4	6.0
V6	9.7	8.9	9.4	6.7
V8	11.3	9.9	11.1	7.9
V10	12.3	11.0	13.9	10.9

[a] Corn removal timings were based on corn growth stage.

[b] Weeks after planting.

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