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ROW WIDTH AND PLANT POPULATION EFFECTS ON GLYPHOSATE-RESISTANT SUGARBEET PRODUCTION IN MICHIGAN

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By

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ABSTRACT

ROW WIDTH AND PLANT POPULATION EFFECTS ON GLYPHOSATE-RESISTANT SUGARBEET PRODUCTION IN MICHIGAN

By

Jon-Joseph Quincy Armstrong

The 2008 commercial release of glyphosate-resistant (GR) sugarbeet provided growers with the opportunity to achieve excellent control of many weed species common to sugarbeet production with fewer herbicide active ingredients and fewer applications, while eliminating the potential for crop injury. GR sugarbeet may allow growers to reduce or potentially eliminate between-row cultivation and adopt planting in narrow rows. Field trials were conducted in 2006, 2007, and 2008 at multiple locations in Michigan to compare canopy cover, yield and quality, and weed control in GR sugarbeet planted in 38-, 51-, and 76-cm rows widths at plant populations of 54,000; 78,000; 101,000; and 124,000 plants/ha. In general, canopy cover developed more rapidly and was greater in 38- and 51-cm row widths and at higher plant populations. At the Saginaw Valley locations, GR sugarbeet planted in 51-cm rows produced the highest root yields. At the East Lansing location, root yields were highest in 38-cm rows compared with 76-cm rows in 2008. Sugarbeet quality, expressed as recoverable white sucrose per Mg of root (RWSMg), also increased as plant population increased.

Weed control in GR sugarbeet is affected by row width. Weed population densities and biomass were lower in narrow rows compared with 76-cm rows following a single glyphosate application when weeds were 10-cm tall. The greater canopy cover provided by narrow rows may reduce the number of glyphosate applications necessary for season-long weed control. When averaged over row width, GR sugarbeet root yield

was similar to yield of the weed-free treatment for all herbicide treatments where glyphosate was applied when weeds were 10-cm in height or smaller. However, root yields were reduced when glyphosate applications were delayed until weeds averaged 15-cm in height. Regardless of row width, initial glyphosate applications should be made before weeds reach 10-cm in height to maximize yield and minimize weed competition.

The increased cost of GR sugarbeet seed may influence adoption of narrow row sugarbeet production. At the Saginaw Valley locations, GR sugarbeet planted in 51-cm rows had an increase in gross margin of at least $200/ha compared with 38- and 76-cm rows, when payment price was adjusted for sugarbeet quality. At East Lansing, gross margins did not differ among all row widths and plant populations in 2007. In 2008, plant populations of 78,000; 101,000; and 124,000 plants/ha in 38-cm rows resulted in the highest gross margins. Despite observed increases in RWSMg at higher plant populations, results from this analysis suggest that row width has more of an impact on economic returns for GR sugarbeet production. The highest economic returns were for sugarbeet planted in narrow rows.

Additional herbicides may be necessary for satisfactory control of weeds that are more tolerant to glyphosate. In greenhouse trials, triflusulfuron was not effective for control of 5- or 10-cm tall velvetleaf, Powell amaranth, or common lambsquarters. Some combinations of glyphosate plus triflusulfuron were synergistic for weed control. All combinations of glyphosate and triflusulfuron were additive for control of common lambsquarters. However, triflusulfuron plus glyphosate applied to 5- and 10-cm weeds did not improve weed control beyond using glyphosate alone at 840 g/ha.

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CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Sugarbeet (*Beta vulgaris* L.), a member of the Chenopodiaceae family, is a biennial crop that is planted in early spring in most production regions. In the fall, before reproductive growth occurs, aboveground leaf growth is removed. Sugarbeet roots are then harvested and processed for sucrose production. In addition to sugar cane (*Saccharum* spp.), sugarbeet is one of the primary sources of sucrose in the United States. Sugarbeet was planted on an average of 544,000 hectares per year in the United States from 2000 to 2008 and total crop production was valued at over one billion dollars per year. Michigan is the fourth largest producer of sugarbeet in the United States and sugarbeet was grown on approximately 55,000 hectares in Michigan in 2008 (USDA-NASS 2009).

WEED CONTROL IN SUGARBEET

Weed control is often listed by sugarbeet producers as the most serious production problem they face (Carlson et al. 2008). Historically, growers have had few options for efficient and efficacious weed control in sugarbeet. Until the early 1970s, chemical weed control options were limited mostly to herbicides applied and incorporated prior to planting. These herbicides included cycloate, EPTC, and pyrazon (Schweizer and Dexter 1987). Growers also relied heavily on mechanical cultivation and hand labor to control weeds, because few chemical weed control programs provided sufficient control

(Griffiths 1994). In the mid-1960s, the herbicides phenmedipham and desmedipham were introduced (and later sold together as a premix). These herbicides provided growers with additional options for postemergence weed control. Though these products were used extensively, crop injury was a major concern when applied at labeled rates of 1.1 to 1.7 kg ai/ha. In the late 1970s, research was conducted investigating applications of the combination of phenmedipham + desmedipham split into two lower-rate applications ("standard split") of 0.56 or 0.84 kg ai/ha applied five to seven days apart. Split applications reduced crop injury, especially when beets were at the cotyledon to 2-leaf growth stage, and improved weed control (Dexter 1994). In 1998, reduced rate, or "micro-rate," herbicide programs were introduced (Dale et al. 2006). Micro-rate programs included phenmedipham + desmedipham (0.045 + 0.045 kg ai/ha) plus triflusulfuron (0.004 kg ai/ha) plus clopyralid (0.023 kg ai/ha) plus methylated seed oil (MSO) (1.5% v/v). Micro-rate applications provide good to excellent weed control while minimizing crop injury. However, applications had to be made in a timely manner to ensure satisfactory control. The first micro-rate application needed to be made when weeds are in the cotyledon growth stage, or less than 0.3-cm in height, with two to four subsequent micro-rate applications generally made every five to seven days (Dale and Renner 2005). Another benefit of the micro-rate herbicide program is that growers can make applications any time during the day, as opposed to standard-split herbicide program applications which must be made in the late afternoon or evening to avoid causing significant crop injury (Dale and Renner 2006). Additionally, because micro-rate applications are often broadcast applied, between-row cultivations were reduced. In fact, in eastern North Dakota and Minnesota between-row cultivations decreased from an average of 2.4 cultivations per field per year in 1998 to 1.7 in 2006 (Carlson et al. 2008).

GLYPHOSATE-RESISTANT CROPS

Corn (*Zea mays* L.), soybean (*Glycine max* [L.] Merr.), cotton (*Gossypium hirsutum* L.), canola (*Brassica rapa* L.), and alfalfa (*Medicago sativa* L.) are all commonly grown agronomic crops that have been engineered to be resistant to glyphosate. Many of these crops were rapidly adopted after their respective commercial releases and are now used extensively in the United States. Glyphosate-resistant soybean was commercially released in the United States in 1996. Adoption of glyphosate-resistant soybean increased from 54% of the total soybean hectares in the US in 2000 to 92% in 2008 (USDA-NASS 2008). Adoption of herbicide-resistant corn has progressed in a similar manner, increasing from 7% of total corn acreage in 2000 to 63% in 2008 (USDA-NASS 2008). Similarly, adoption of glyphosate-resistant sugarbeet varieties is expected to be very rapid. In Michigan, approximately half of the sugarbeet area in 2008 was planted to glyphosate-resistant varieties. This adoption was limited primarily by the availability of glyphosate-resistant seed. It is expected that over 90% of the sugarbeet hectares in Michigan will be planted with glyphosate-resistant sugarbeet varieties in 2009 (C. Guza, personal communication).

GLYPHOSATE-RESISTANT SUGARBEET

Glyphosate-resistant sugarbeet will provide growers the opportunity to achieve excellent control of many weed species common to sugarbeet production with fewer herbicide active ingredients and applications, while eliminating the potential for crop injury (Wilson et al. 2002). In previous studies, glyphosate has provided excellent control of many weed species with two or three glyphosate applications (Guza et al. 2002; Kniss et al. 2004; Wilson et al. 2002). Additionally, the time between herbicide applications may be longer with glyphosate-resistant sugarbeet compared with conventional sugarbeet herbicide programs, as weed height at time of application is generally not as limiting with glyphosate. Growers will also have a herbicide option for weeds that have developed resistance to one or more of the conventional sugarbeet herbicides.

Similar to trends of improved weed control following the adoption of micro-rate applications, growers may be able to reduce or potentially eliminate between-row cultivation with the use of glyphosate-resistant sugarbeet. Previous research has shown that between-row cultivation, in the absence of weeds, does not improve sugarbeet yield or quality (Dexter et al. 1999). As a result, growers may be able to adopt narrow-row planting practices.

Row width and plant population effects. Numerous studies on the effect of row width and plant population on crop yield have been conducted with many agronomic crops. Results of these studies have been somewhat inconsistent and vary among crops; however, the general outcome trends towards increased yields in narrower rows due to increased light radiation interception (Andrade et al. 2002). Widdicombe and Thelen (2002) reported corn grain yields were highest in 38-cm rows compared with 56- and 76-cm rows. They also reported grain yields were highest at the highest plant population. However, there was no interaction between row width and plant population, indicating that yield increases in narrow rows occurred across all plant populations. Johnson and Hoverstad (2002) also reported higher corn yields when corn was planted in 51-cm rows compared with 76-cm rows in two of three years. Higher yields have also been reported in soybean planted in narrow rows. Harder et al. (2007) observed higher grain yields in 19- and 38-cm rows compared with 76-cm rows at each of four populations. However, not all studies have shown increased yields in narrow rows. Pedersen and Lauer (2003) compared yields in corn and soybean that were planted in 19-, 38-, and 76-cm rows and found that the highest yield in corn was in 38- and 76-cm rows for corn and there were no differences in yield among the three soybean row widths.

Faster and more complete canopy cover can occur for crops planted in narrow rows. The greater canopy cover can also provide more shade of bare soil between rows, thereby reducing late-season weed emergence and growth (Johnson and Haverstad 2002). Yelverton and Coble (1991) observed a significant decrease in weed density and biomass in soybean planted in narrows rows compared with wide rows. Dalley et al. (2004b) also observed similar results of reduced weed biomass in narrow-row soybean. In three of four years, soybean planted in 19- and 38-cm rows had significantly less weed growth after an initial glyphosate application at 10-cm weeds compared with 76-cm rows. In both studies, the reduction in weed growth was attributed to the greater canopy cover provided by the narrow rows.

Sugarbeet is typically grown in row widths that range from 56- to 76-cm. In the Red River Valley production area of northwestern Minnesota and eastern North Dakota, 97% of the sugarbeet hectares are planted in 56-cm rows (Grove et al. 2007). In

Michigan, a majority of the sugarbeet hectares are planted using 71- or 76-cm rows. Similar to results from corn and soybean, previous research has shown a trend toward increased sugarbeet yield when planted in narrow rows. Yonts and Smith (1997) found that the highest sugar yield was obtained with 56-cm rows, when compared with 35- and 76-cm rows. Stebbing et al. (2000) showed an increase in root and sugar yield (recoverable white sugar per hectare) with 46-cm rows compared with 56- and 76-cm rows in one of two years. The authors attributed yield increases in 46-cm rows to reduced intra-plant competition due to more spacing between plants within the row. In addition to increased yield, sugarbeet planted in narrow rows can provide greater canopy cover to suppress weed growth. Alford et al. (2004) reported that weed biomass averaged over multiple herbicide treatments was reduced significantly when sugarbeet was planted in 38- and 56-cm rows compared with 76-cm rows, due to earlier and greater canopy cover in the narrow row widths.

Planting sugarbeet in narrow row widths also allows for higher plant populations per area. These differences in within- and across-row plant spacing can have an effect on both sugarbeet yield and quality. Due to the reduced space between plants within the row and resulting smaller growth of each individual beet, a trend toward higher sucrose concentrations can be observed at higher plant populations (Yonts and Smith 1997). However, sucrose concentrations can also plateau at sugarbeet populations of more than 65,000 plants/ha, as observed by Yonts and Smith (1997). Winter (1989) also observed higher sucrose concentrations in sugarbeet planted at higher populations.

Multiple applications of glyphosate will be necessary to ensure satisfactory, season-long weed control in glyphosate-resistant sugarbeet. However, growers may be able to incorporate cultural weed control methods to reduce weed growth during the growing season. Dawson (1977) reported that annual weeds that emerge after July 1 can be suppressed by shade provided from sugarbeet stands that form complete canopies, i.e. sugarbeet planted in narrow rows. Planting glyphosate-resistant sugarbeet in narrow rows may provide to growers the opportunity to have adequate weed control with fewer herbicide applications and cultivations, while possibly improving yield and quality. Little research has been conducted to evaluate the effects of plant population and row spacing on weed growth, and sugarbeet yield and quality in glyphosate-resistant sugarbeet.

Glyphosate application timing. Glyphosate provides excellent control of many broadleaf and grass weeds over a wide range of growth stages. As a result of this flexibility in application timing, growers often delay glyphosate applications to maximize the number of weeds controlled and minimize the number of applications necessary for season-long control. However, delayed glyphosate applications can lead to yield losses due to the lengthened duration of competition between crop and weed. For example, in glyphosate-resistant corn, glyphosate applications should be made when weeds are 10-cm or less in height to prevent yield loss (Gower et al. 2003; Dalley et al. 2004a). Glyphosate-resistant soybean has generally been shown to tolerate weed competition for longer periods of time (Young et al. 2001; Coulter and Nafziger 2007). However, row width can also effect the time at which glyphosate must be applied to prevent yield loss due to weed competition. Dalley et al. (2004a) concluded that glyphosate applications should be made when weeds were 5-cm or less in corn planted in 38-cm rows and 15-cm or less in soybean planted in 19- and 38-cm rows to prevent yield loss. In corn and soybean planted in 76-cm rows, weeds needed to be controlled by 10-cm and 30-cm, respectively, to prevent yield loss. Despite this tolerance to relatively longer periods of weed competition in wider row widths, glyphosate must be applied before weeds reach a growth stage at which they will be difficult to control with standard use rates of glyphosate.

Previous research on application timing in glyphosate-resistant sugarbeet to prevent yield loss has shown varying results. Kemp and Renner (unpublished data) found that sugarbeet yields were similar for glyphosate application timings at weed heights up to 30-cm. Wilson et al. (2002) concluded that the optimum glyphosate application timing was when weeds were 10-cm in height. Again, despite tolerance to weed competition, applications should be made at a time when glyphosate will provide sufficient efficacy.

Economic considerations. The availability of glyphosate-resistant sugarbeet varieties provides growers a valuable tool for weed management. However, production costs for sugarbeet are considerable and can reach as high as $1500/ha (Burgener 2001). In addition to production expenses associated with planting, fertilization, fungicide and herbicide applications, and harvesting, growers will pay a technology fee of $106 per unit of 100,000 seeds when purchasing glyphosate-resistant sugarbeet seed, or approximately $129/ha at a seeding rate of 124,000 seeds/ha. To recover this added expense, growers must increase their economic returns by increasing yield and quality, reducing weed control expenses, or reducing seeding rates to minimize cost. Growers must balance the added expense of planting at higher seeding rates with the increases in sugarbeet quality often observed from planting at higher plant populations.

To account for the increases in costs of inputs when adopting glyphosate-resistant varieties, growers may adjust planting practices to maximize yield and economic return. Two ways growers can adjust planting practices are to plant at lower populations or to plant in narrow rows. As noted earlier, row width and plant population can effect root and sugar yield. All sugarbeet production in Michigan is contracted through the Michigan Sugar Company, a grower-owned cooperative. Grower payments through the Michigan Sugar Company are structured as tournament contracts (Knoeber 1989), where growers "compete" against one another, based on sugarbeet quality, to determine their payment per Mg of sugarbeet root. The Michigan Sugar Company uses a quality payment system price per ton of sugarbeet root paid to growers. In their formula, the price per Mg of sugarbeet that a grower delivers is calculated by multiplying ratio of the grower's recoverable white sucrose per Mg of sugarbeet root (RWSMg) to the overall company average RWSMg and multiplying it by the base price, adjusting the grower's per Mg price above or below the base price. As is the structure of tournament contracts, growers are incentivized to produce high quality sugarbeet (i.e. high RWSMg), rather than simply maximize root yield. Therefore, it will be even more important for growers to balance the added expense of planting at higher seeding rates with the increases in sugarbeet quality often observed from planting at higher plant populations.

Potential tank-mix partner with glyphosate. Glyphosate provides excellent control of many weed species over many growth stages. However, several common weeds in sugarbeet producing regions of the United States, including common waterhemp (*Amaranthus rudis* L.), common ragweed (*Ambrosia artemisiifolia* L.), and giant ragweed (*Ambrosia trifida* L.), have been confirmed to be resistant to glyphosate (Heap 2009). Velvetleaf (*Abutilon theophrasti* Medik.) and common lambsquarters (*Chenopodium album* L.), two common weeds in sugarbeet production, have also exhibited some tolerance to glyphosate (Krausz et al. 1996; Young et al. 2001). To control glyphosate-resistant and/or –tolerant weeds, it may become necessary to tank-mix additional herbicides with glyphosate to achieve satisfactory weed control and prevent the future spread of difficult-to-control weeds (Hatzios and Penner 1985).

Triflusulfuron, an acetolactate synthase (ALS) inhibiting herbicide for postemergence broadleaf and grass control in sugarbeet, has been shown to provide good to excellent control of velvetleaf, depending on size (Starke et al. 1996), and some suppression of common lambsquarters and redroot pigweed (*Amaranthus retroflexus* L.) (Morishita and Downard 1995). Previous research has shown additive and antagonistic effects for mixtures of glyphosate and other ALS-inhibiting herbicides for control of common lambsquarters (glyphosate + thifensulfuron) and velvetleaf (glyphosate + imazethapyr and thifensulfuron), respectively (Lich et al. 1997). Combining an additional herbicide mode of action with glyphosate may improve control of problematic weeds and will give growers more options for controlling difficult-to-control weeds.

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CHAPTER 2

INFLUENCE OF ROW WIDTH AND PLANT POPULATION ON WEED GROWTH AND YIELD IN GLYPHOSATE-RESISTANT SUGARBEET

Abstract: Studies were conducted in 2006, 2007, and 2008 at multiple locations in Michigan to determine the effect of planting glyphosate-resistant sugarbeet in row widths of 38-, 51-, and 76-cm and at populations of 54,000; 78,000; 101,000; and 124,000 plants/ha on canopy development, weed growth and sugarbeet yield and quality. In general, sugarbeet canopy cover was greater and developed more rapidly in 38- and 51-cm row widths and at higher plant populations. For nontreated plots, weed density was similar for all row widths and plant populations. Following a single glyphosate application when weeds were 10-cm in height, weed biomass was reduced by 88% and 77% in 38- and 51-cm rows, respectively, compared to 76-cm rows at the Saginaw Valley locations. At East Lansing, a trend toward reduced density and biomass in narrow rows following a glyphosate application occurred. Differences in weed density and biomass following a glyphosate application among row widths and plant populations are likely due to the differences in crop canopy development. At the Saginaw Valley locations, glyphosate-resistant sugarbeet planted in 51-cm rows produced the highest root yields. At East Lansing where only 38- and 76-cm rows were investigated, root yields were similar for both row widths in 2007. However, in 2008 when moisture was not limiting, root yields were highest in 38-cm rows. Sugarbeet quality was similar among all row widths; however sugarbeet quality increased as population increased. Total sucrose yield, or recoverable white sucrose per hectare, followed the same pattern as root yield

and was generally highest in narrow rows. In addition to increased light interception leading to increased yields in narrow rows, planting sugarbeet in narrow rows is a useful form of cultural weed control, helping to shade out late-season weed growth.

Nomenclature: Glyphosate; sugarbeet, *Beta vulgaris* L.

Key words: Herbicide-resistant crops, plant population; row width; weed biomass.

INTRODUCTION

Glyphosate-resistant sugarbeet varieties were commercialized in 2008. In the first commercial year, approximately half of Michigan's sugarbeet area (32,000 of 61,000 hectares) was planted to glyphosate-resistant varieties. Adoption was limited primarily due to the availability of seed. It is expected that glyphosate-resistant sugarbeet varieties will be planted on more than 90% of the sugarbeet hectares Michigan in 2009 (C. Guza, personal communication). There are many positive attributes associated with the use of glyphosate for weed control in glyphosate-resistant sugarbeet. Glyphosate provides excellent weed control of many weed species common to sugarbeet production with fewer herbicide active ingredients and possibly fewer herbicide applications (Guza et al. 2002; Kniss et al. 2004). Unlike current herbicides used for weed control in sugarbeet, the potential for crop injury with glyphosate in glyphosate-resistant sugarbeet is nonexistent (Wilson et al. 2002). Additionally, weed height at the time of glyphosate application is generally not as limiting as herbicides currently used in sugarbeet.

Sugarbeet growers may be able to reduce or potentially eliminate between-row cultivation with the use of glyphosate in glyphosate-resistant sugarbeet due to improved weed control. As a result, growers may be able to adopt planting sugarbeet in narrow rows. Numerous studies on the effect of row width and plant population on crop yield have been conducted in many agronomic crops. Results of these studies have been inconsistent and vary among crops; however, the general outcome trends toward increased yields in narrower rows due to increased light radiation interception (Andrade et al. 2002). In addition to potential yield increases from faster and more complete canopy cover with narrow rows, greater canopy cover can also provide more shade of bare soil between rows, thereby reducing late-season weed emergence and growth (Johnson and Haverstad 2002). Yelverton and Coble (1991) observed a significant decrease in weed density and biomass in soybean planted in narrows rows compared with wide rows. Dalley et al. (2004) also observed a similar trend of reduced weed biomass in narrow-row soybean. In three of four years, soybean planted in 19- and 38-cm rows had significantly less weed growth after an initial glyphosate application compared with 76-cm rows. In both studies, the reduction in weed growth was attributed to the greater canopy cover provided by the narrow rows.

Sugarbeet is typically grown in row widths ranging from 56- to 76-cm. Similar to results from corn and soybean, previous research has shown a trend toward increased sugarbeet yields when planted in narrow rows. Yonts and Smith (1997) found that the highest sugar yield was obtained with 56-cm rows, when compared with 35- and 76-cm rows. Stebbing et al. (2000) showed an increase in root and sucrose yield in 46-cm rows compared with 56- and 76-cm rows in one of two years. The authors attributed the yield increases in 46-cm rows to the reduced intra-plant competition due to more spacing between plants within the row. In addition to increased yield, sugarbeet planted in narrow rows can provide greater canopy cover to suppress weed growth. Alford et al.

(2004) observed significantly reduced weed biomass production in 38- and 56-cm rows compared with 76-cm rows, due to earlier and greater canopy cover in the narrow row widths.

Planting sugarbeet in narrow row widths also allows for higher plant populations per area. These differences in within- and across-row plant spacing can have an effect on both sugarbeet yield and quality. Due to the reduced space between plants within the row and resulting smaller growth of each individual beet, a trend toward higher sucrose concentrations can be observed at higher plant populations (Yonts and Smith 1997). However, sucrose concentrations can also plateau at sugarbeet populations of more than 65,000 plants/ha, as observed by Yonts and Smith (1997). Winter (1989) also observed higher sucrose concentrations in sugarbeet planted at higher populations. These studies were conducted under irrigated conditions where water was not limiting.

Multiple applications of glyphosate will be necessary to ensure satisfactory, season-long weed control in glyphosate-resistant sugarbeet. However, growers may be able to incorporate cultural weed control methods to reduce weed growth during the growing season. Dawson (1977) reported that annual weeds that emerge after July 1 can be suppressed by shade provided from sugarbeet stands that form complete canopies, i.e. sugarbeet planted in narrow rows. Planting glyphosate-resistant sugarbeet in narrow rows may provide growers the opportunity to have adequate weed control with fewer herbicide applications and cultivations, while possibly improving yield and quality.

Little research has been conducted to evaluate the effects of plant population and row spacing on weed growth, and sugarbeet yield and quality in glyphosate-resistant sugarbeet on non-irrigated soils. Therefore, the objectives of this research were to: 1) determine the effect of planting glyphosate-resistant sugarbeet in three different row widths on weed growth and yield, and 2) evaluate the effect of multiple plant populations within each row width on sugarbeet yield and quality.

MATERIALS AND METHODS

Field trials were established in 2006, 2007, and 2008 at the Michigan State University Saginaw Valley Bean and Beet Research Farm near St. Charles, Michigan, and in 2007 and 2008 on commercial production fields near St. Charles and at the Michigan State University Agronomy Research Farm in East Lansing, Michigan. The soil at the Bean and Beet Research Farm was a Zilwaukee silty clay (fine, mixed, mesic Fluvaquentic Endoaquolls) with soil pH of 7.4 and 3.9% organic matter. The soil type at the commercial production fields was a Sloan silty clay loam (fine-loamy, mixed, mesic Fluvaquentic Endoaquolls) with soil pH of 7.5 and 10.5% organic matter in 2007 and soil pH of 7.2 and 3.3% organic matter in 2008. At East Lansing, the soil type was a Capac fine sandy loam (fine-loamy, mixed, mesic Aquic Glossudalfs) with soil pH of 6.9 and 2.5% organic matter. Experiments followed soybean (*Glycine max* [L.] Merr.), wheat (*Triticum aestivum* L.), and dry bean (*Phaseolus vulgaris* L.) in 2006, 2007, and 2008, respectively, at the Bean and Beet Research Farm. At the commercial production fields and East Lansing location, experiments followed corn (*Zea mays* L.) in 2007 and soybean in 2008. Fields were fall-plowed followed by field cultivation prior to planting in the spring. Fertilizer applications were standard for sugarbeet production in Michigan. The glyphosate-resistant sugarbeet variety, 'Beta 3H021A RR[1],' was planted in 38- and 76-cm rows at the Saginaw Valley Bean and Beet Research Farm in 2006. At all other sites, the glyphosate-resistant sugarbeet variety, 'Hilleshög 9028[2],' was planted. In 2007 and 2008, sugarbeet was planted in 38-, 51-, and 76-cm row widths at the two Saginaw Valley locations and 38- and 76-cm row widths at East Lansing. Sugarbeet was planted at a depth of 2.5-cm. Plot sizes were 3- or 4.57-m wide depending on location and 9.1 m long. At the four-leaf growth stage, sugarbeet stands were thinned to populations of 54,000; 78,000; 101,000; or 124,000 plants/ha in 2007 and 2008. In 2006, populations of 54,000; 78,000; and 101,000 plants/ha were investigated. Populations were held constant across row widths, leading to differences in within-row plant spacing for each population (Table 1). Precipitation data was collected at the Saginaw Valley Bean and Beet Research Farm and the East Lansing location during the growing season and is summarized by month in Table 2.

The experimental design was a split-split-plot with row width as the main plot factor, plant population as the sub-plot factor, and weed control treatment as the sub-sub-plot factor. All treatments were replicated four times. Weed-free plots were established each year and maintained with applications of glyphosate[3] at 840 g ae/ha plus ammonium sulfate (AMS) at 2% v/v starting at the cotyledon sugarbeet growth stage and repeated as needed. In 2007, nontreated plots were also used to determine the effect of row width and plant population on season-long weed growth. Due to excessive weed growth and the lack of sugarbeet growth in the nontreated plots, it was decided to replace the nontreated treatment with a single application of glyphosate at 840 g ae/ha plus AMS at 2% v/v when weeds averaged 10-cm in height in 2008. This treatment was used to determine the effect of row width and plant population on new weed emergence and growth after an initial glyphosate application.

Crop canopy measurements were taken in all weed-free plots at one to two week intervals beginning in early-June. Measurements were collected using the Sunscan Canopy Analysis System[4], consisting of a 1 m by 13 mm wand used to measure light beneath the crop canopy, a tripod-mounted sensor that measured both incident and diffuse light above the crop canopy, and a handheld computer[5] that recorded simultaneous measurements of light above and beneath the crop canopy. Measurements were taken at or near solar-noon by placing the wand on the soil perpendicular to the center rows of each plot and were converted to percent canopy cover using the formula: (1 – (below canopy measurement/above canopy measurement)) * 100.

Weed population density and aboveground biomass were collected from two 0.25 m^2 quadrats placed in the center of the plots for the nontreated and 10-cm weed height glyphosate application treatments in mid-August. Weed biomass was dried for 72 h in a forced air oven at 60 C and weighed. Common lambsquarters (*Chenopodium album* L.) and a combination of redroot pigweed (*Amaranthus retroflexus* L.) and Powell amaranth (*Amaranthus powellii* S. Watson) were the predominant weed species at the Bean and Beet Research Farm and the commercial production fields in 2007 and 2008. These weed species, plus a mixture of annual grass weed species, were present at the East Lansing locations in 2007 and 2008. In 2008, common purslane (*Portulaca oleracea* L.) was also present at East Lansing.

Two rows of sugarbeet were mechanically harvested and weighed from each plot in mid-September and a sub-sample of roots was analyzed for quality and purity by the Michigan Sugar Company[6]. Sugarbeet quality is expressed as kg of recoverable white sucrose per Mg of root (RWSMg). Total sucrose production is expressed as kg of recoverable white sucrose per hectare (RWSH).

Data were subjected to ANOVA using PROC MIXED in SAS[7] and treatment means for canopy cover, weed density and biomass, root yield, RWSMg, and RWSH were compared using Fisher's Protected LSD at the $p = 0.05$ significance level. Weed density and biomass data were log ($x + 1$) transformed for analysis. Back-transformed data are presented. Data were combined over environment, row width, or population and presented for main effects when significant interactions were not present.

RESULTS AND DISCUSSION

Crop canopy development. Despite similar rainfall totals for the 2006, 2007, and 2008 growing seasons (Table 2), canopy development was slower in 2007 than 2006 and 2008 due to dry conditions experienced during May, June, and July at the different locations. Canopy cover measurements varied by year, therefore data are presented separately for each year. Row width greatly influenced sugarbeet canopy cover in five out of the seven environments, and there was not a significant interaction between row width and plant population for sugarbeet canopy development at the Saginaw Valley locations or East Lansing location, so main effects of row width and plant population can be presented. In 2006 at the Saginaw Valley location, all measurements for canopy cover were greater in 38-cm rows compared with 76-cm rows beginning with the first measurement 6 weeks after planting (WAP) (Figure 1a). Differences in canopy between the two row widths ranged from 4.6 to 13.5%. At 10 WAP canopy cover was 90% and 82% for sugarbeet planted in 38- and 76-cm rows, respectively. The sugarbeet canopy developed at a much slower rate in 2007 and canopy cover was similar among all row widths at the Saginaw Valley locations until 9 WAP (Figure 2a). Lower precipitation in May and June at the two Saginaw Valley locations as compared with the 30-year average most likely explains the slower canopy development in 2007 (Table 2). At 9 and 10 WAP, both 38- and 51-cm rows exhibited greater canopy cover than 76-cm rows. By 10 WAP, canopy cover was only 74% with narrow rows (38- and 51-cm) and 70% with 76-cm rows.

Canopy development was more rapid in 2008 than 2007. In 2008 at the Saginaw Valley locations, canopy cover was greater in 38-cm rows compared with 51- and 76-cm rows starting 8 WAP (Figure 3a). By 9 WAP and continuing through the final measurement timing, canopy cover was greatest in both 38- and 51-cm rows. At the final measurement 11 WAP, canopy cover was 91% in narrow rows (38- and 51-cm) and only 84% in 76-cm rows. At East Lansing in 2007 and 2008, canopy cover was similar between the 38- and 76-cm row widths (Figures 4a and 5a). In 2007 sugarbeet canopy only reached 72% cover by 14 WAP and in 2008 canopy cover was only 74% by 11 WAP.

Sugarbeet plant populations did not have as great of an effect on canopy cover as row width. Averaged across all row widths, canopy cover was similar among the three populations investigated at the Saginaw Valley location in 2006 (Figure 1b). This trend was similar for the two Saginaw Valley locations in 2007, except at the initial measurement timing at 7 WAP, where sugarbeet planted at the highest population of 124,000 plants/ha had significantly greater canopy closure than the lower plant populations (Figure 2b). In 2008, canopy cover was also greatest in the two highest plant populations at the first measurement timing at 7 WAP (Figure 3b). At 8 WAP, sugarbeet planted at the highest population of 124,000 plants/ha provided the greatest canopy cover. However, by 13 WAP, canopy cover was similar among all plant populations.

Similar to the effect of row width on canopy cover, canopy cover was similar among all plant populations in 2007 and 2008 at the East Lansing location (Figures 4b and 5b). Particularly in 2007, increased water use at higher plant populations and reduced soil moisture conditions may have limited canopy development (Moraghan 1972).

Weed density and biomass. Among the nontreated plots in 2007, weed density was similar for all row widths and plant populations at the Saginaw Valley locations (Table 3). This was likely due to the slow growth habit of sugarbeet, preventing it from competing with faster growing weeds early in the season. At East Lansing, weed density was also similar among row width and plant population. Weed biomass was similar for 38- and 76-cm row widths, but was significantly reduced at populations of 101,000 and 124,000 plants/ha compared with 54,000 and 78,000 plants/ha.

For plots that received a single glyphosate application when weeds were 10-cm in height, very few weeds emerged after the glyphosate application (Table 4). Weed population density and biomass was influenced by row width and plant density at the Saginaw Valley locations. Compared with 76-cm rows, subsequent weed growth was reduced by 88% and 77% in 38- and 51-cm rows, respectively. Following a single glyphosate application, weed densities were also lower in 38- and 51-cm rows compared with 76-cm rows. Weed densities were similar among all plant populations following a glyphosate application to 10-cm weeds. However, weed biomass decreased from 10.8

to1.0 g/m^2 as plant population increased from 54,000 to 124,000 plants/ha. These results are similar to those of Dalley et al. (2004) and Harder et al. (2007), who observed reduced weed growth following a glyphosate application in soybean planted in narrow rows. At East Lansing, though weed densities and biomass were similar among row widths, a trend toward reduced density and biomass in narrow rows following a glyphosate application was present. Row width and plant population did not affect weed density or biomass. Differences in weed density and biomass following a glyphosate application among row width and plant population are likely due to the differences in crop canopy development. Though it is unlikely a single application of glyphosate will provide satisfactory season-long weed control, glyphosate-resistant sugarbeet planted in narrow rows may suppress late-season weed growth and require fewer herbicide applications than sugarbeet planted in wide rows.

Sugarbeet root yield and quality. In 2006, glyphosate-resistant sugarbeet root yields increased from 59.1 Mg/ha in 76-cm rows to 76.4 Mg/ha in 38-cm rows in 2006 (Table 5). RWSMg was similar among row widths; however RWSH was greater in 38-cm rows due to the increase in root yield. When averaged over row width, root yield, RWSMg, and RWSH were similar for the three plant populations that were investigated (Table 5).

Data from the Saginaw Valley locations in 2007 and 2008 were combined across year and location because no significant interaction was observed for any of the response variables. In 2007 and 2008 at the Saginaw Valley locations, root yield for glyphosate-resistant sugarbeet planted in 51-cm rows was 79.1 Mg/ha, an increase of 4.9 and 5.2 Mg/ha compared with 38- and 76-cm rows, respectively (Table 6). Though RWSMg was similar among all row widths, RWSH was also greatest in 51-cm rows due to increases in root yield. When data were combined across row width, root yields were similar for all plant populations (Table 6). RWSMg increased from 115.4 kg/Mg at 54,000 plants/ha to 120.1 kg/Mg at 124,000 plants/ha. These results are similar to those reported by Ransom et al. (1998), who also observed increases in RWSMg at higher plant populations of glyphosate-resistant sugarbeet.

Data from the East Lansing location was combined across year where significant year by row width or plant population interactions were not present. In 2007 when moisture limiting during April, May, and August, root yields and RWSH were similar for both 38- and 76-cm rows (Table 7). In 2008, growing conditions were more favorable and root yields in 38-cm rows were 10.2 Mg/ha higher than in 76-cm rows. In addition to root yield, RWSH was also significantly greater in the narrow row width. For data combined over row width, root yield and RWSMg were not influenced by plant population. In 2007, glyphosate-resistant sugarbeet in populations of 101,000 and 124,000 plants/ha resulted in the highest total sucrose yields, providing increases of at least 400 kg/ha over populations of 54,000 and 78,000 plants/ha (Table 8). In 2008, RWSH increased by at least 800 kg/ha for all populations greater than 54,000 plants/ha.

At most environments in this study, glyphosate-resistant sugarbeet root and sugar yields were greater in narrow rows compared with 76-cm rows. In trials at the Saginaw Valley locations where 38-, 51-, and 76-cm row widths were compared, the highest root and sugar yields were observed in 51-cm rows. Root yield was similar among 38- and 76-rows at the East Lansing location in 2007; however, 38-cm rows provided greater root yields than 76-cm rows in 2008. In addition to increased light interception leading to increased yields in narrow rows, planting sugarbeet in narrow rows is also a useful form of cultural weed control, helping to shade out late-season weed growth. Narrow row suppress late-season weed growth, which may reduce the number of glyphosate applications necessary for satisfactory weed control.

The differences in root yield between the Saginaw Valley locations and the East Lansing location may be explained by the differences in soil texture and water holding capacity between locations. The sandy loam soil texture at the East Lansing location would not have the same water holding capacity as the silty clay soil at the Bean and Beet Research Farm or the silty clay loam soil at the commercial production fields. As a result, under the dry conditions experienced in 2007, yield losses due to insufficient soil moisture were more evident at the East Lansing site (Morillo-Velarde and Ober 2006). Likewise, differences in root yield between years at the East Lansing location may best be explained by differences in precipitation during the growing season. Though root yields were similar among all plant populations in these studies, growers should choose planting densities that are appropriate for the soil moisture conditions to achieve maximum yield and sugarbeet quality. From these studies, soils with greater water holding capacities produced higher yields than soils with a coarser texture and less water holding capacity. Because sugarbeet planted at higher populations will use more water than low populations (Moraghan 1972), growers should consider the field's soil texture when determining seeding density. However, based on the yield results from these studies, plant populations do not need to be increased when switching to narrow row widths.

SOURCES OF MATERIALS

[1] Betaseed, Inc., 1788 Marschall Rd., P.O. Box 195, Shakopee, MN 55379.

[2] Syngenta Seeds Inc., 1020 Sugarmill Rd., Longmont, CO 80501.

[3] Roundup WeatherMAX, Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167.

[4] Delta-T Device LTC, 128 Low Rd., Burwell, Cambridge CB5 0EJ, England.

[5] Psion Digital, 1810 Airport Exchange Blvd., Suite 500, Erlanger KY 41018.

[6] Michigan Sugar Company, 2600 S. Euclid Ave., Bay City, MI 48706

[7] The SAS System for Windows, Version 9.1, SAS Institute Inc., 100 SAS Campus Dr., Cary, NC 27513.

Table 1. Within-row plant spacing and the number of plants/30-m of row for glyphosate-resistant sugarbeet planted in three row widths and at four plant populations.

	38-cm rows		51-cm rows		76-cm rows	
Population	Plant spacing	Plants/30-m	Plant spacing	Plants/30-m	Plant spacing	Plants/30-m
Plants/ha	cm	#	cm	#	cm	#
54,000	48	63	30	100	24	125
78,000	34	88	25	120	17	177
101,000	26	115	20	150	13	231
124,000	21	143	16	188	11	273

Table 2. Monthly and 30-yr average precipitation at the Saginaw Valley Bean and Beet Research Farm near St. Charles in 2006, 2007, and 2008 and at East Lansing in 2007 and 2008.[a]

	St. Charles				East Lansing		
Month	2006	2007	2008	30-yr ave.	2007	2008	30-yr ave.
	mm						
April	47	76	52	72	66	49	83
May	105	39	28	71	97	30	68
June	68	27	99	83	89	110	78
July	60	66	100	70	13	95	76
August	59	122	53	96	140	12	87
Total	339	330	332	392	405	296	392

[a] Precipitation data were collected from the Michigan Automated Weather Network (http://www.agweather.geo.msu.edu/mawn/).

Table 3. Weed population density and biomass in untreated plots in 2007 at the Saginaw Valley locations and East Lansing location. Data are presented as main effects since row width by plant population interaction was not significant.[a]

	Saginaw Valley[b]		East Lansing	
Main effects	Weed density	Weed biomass	Weed density	Weed biomass
Row width	weeds/m^2	g/m^2	weeds/m^2	g/m^2
38-cm	58 a	814.8 a	84 a	486.1 a
51-cm	64 a	894.7 a	—[c]	—
76-cm	64 a	912.3 a	88 a	525.4 a
Population				
(plants/ha)				
54,000	65 a	887.1 a	79 a	680.4 a
78,000	49 a	791.1 a	82 a	618.2 a
101,000	75 a	751.2 a	93 a	399.8 b
124,000	59 a	829.7 a	90 a	387.8 b

[a] Means within column for each main effect followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.
[b] Data were combined across the Saginaw Valley Bean and Beet Research Farm and commercial production field locations.
[c] 51-cm rows were not investigated at the East Lansing location.

Table 4. Weed population density and biomass in plots which received a single glyphosate application when weeds were 10-cm in height in 2008 at the Saginaw Valley locations and East Lansing location. Data are presented separately for main effects since the interaction between row width and plant population was not significant.[a,b]

	Saginaw Valley[c]		East Lansing	
Main effects	Weed density	Weed biomass	Weed density	Weed biomass
Row width	weeds/m^2	g/m^2	weeds/m^2	g/m^2
38-cm	0.5 a	1.6 a	19 a	6.7 a
51-cm	0.6 a	3.1 a	—[d]	—
76-cm	2.1 b	13.5 b	22 a	10.6 a
Population				
(plants/ha)				
54,000	1.3 a	10.8 a	14 a	10.2 a
78,000	1.3 a	7.2 ab	27 a	6.8 a
101,000	0.8 a	3.9 bc	14 a	6.9 a
124,000	0.5 a	1.0 c	32 a	10.4 a

[a] Means within column for each main effect followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] Herbicide treatment consisted of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v.

[c] Data were combined across the Saginaw Valley Bean and Beet Research Farm and commercial production field locations.

[d] 51-cm rows were not investigated at the East Lansing location.

Table 5. Root yield, recoverable white sucrose per Mg of root (RWSMg), and recoverable white sucrose per ha (RWSH) for glyphosate-resistant sugarbeet planted in two row widths at three populations at the Saginaw Valley Bean and Beet Research Farm in 2006. Data are presented separately for main effects since the interaction between row width and plant population was not significant.[a,b]

Main effects	Root yield	RWSMg	RWSH
Row width	Mg/ha	kg/Mg	kg/ha
38-cm	76.4 a	122.8 a	9410 a
76-cm	59.1 b	122.3 a	7210 b
Population			
(plants/ha)			
54,000	66.2 a	122.6 a	8080 a
78,000	66.7 a	122.2 a	8170 a
101,000	70.3 a	122.9 a	8680 a

[a] Means within column followed by the same lowercase letter for each main effect are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.
[b] All plots were kept weed free with applications of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v as needed.

Table 6. Root yield, recoverable white sucrose per Mg of root (RWSMg), and recoverable white sucrose per ha (RWSH) for glyphosate-resistant sugarbeet in three row widths at four populations at the Saginaw Valley locations in 2007 and 2008. Data were combined across years and are presented separately for main effects since the interaction between row width and plant population was not significant.[a,b,c]

Main effects	Root yield	RWSMg	RWSH
Row width	Mg/ha	kg/Mg	kg/ha
38 cm	81.8 b	119.1 a	9660 b
51 cm	87.2 a	118.4 a	10240 a
76 cm	81.5 b	116.8 a	9460 b
Population			
(plants/ha)			
54,000	83.5 a	115.4 b	9580 b
78,000	81.0 a	117.6 ab	9470 b
101,000	84.3 a	119.2 a	9940 ab
124,000	85.2 a	120.1 a	10160 a

[a] Means within column followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] All plots were kept weed free with applications of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v as needed.

[c] Data were combined across the Saginaw Valley Bean and Beet Research Farm and commercial production field locations.

Table 7. Root yield, recoverable white sucrose per Mg of root (RWSMg), and recoverable white sucrose per ha (RWSH) for glyphosate-resistant sugarbeet in two row widths at the East Lansing location. Data were combined across plant populations.[a,b]

Row width	Root yield		RWSMg	RWSH	
	2007	2008	2007 & 2008	2007	2008
	Mg/ha		kg/Mg	kg/ha	
38 cm	48.8 a	69.1 a	106.7 a	4800 a	7780 a
76 cm	51.2 a	58.9 b	105.1 a	5000 a	6650 b

[a] Means within column followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] All plots were kept weed free with applications of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v as needed.

Table 8. Root yield, recoverable white sucrose per Mg of root (RWSMg), and recoverable white sucrose per ha (RWSH) for glyphosate-resistant sugarbeet in four plant populations at the East Lansing location. Data were combined across row widths.[a,b]

	Root yield	RWSMg	RWSH	
Population	2007 & 2008	2007 & 2008	2007	2008
Plants/ha	Mg/ha	kg/Mg	kg/ha	
54,000	52.2 a	105.1 a	4600 b	6760 b
78,000	56.9 a	102.6 a	4200 b	7710 a
101,000	60.2 a	107.5 a	5800 a	7190 ab
124,000	57.3 a	109.3 a	5000 ab	7580 a

[a] Means within column followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] All plots were kept weed free with applications of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v as needed.

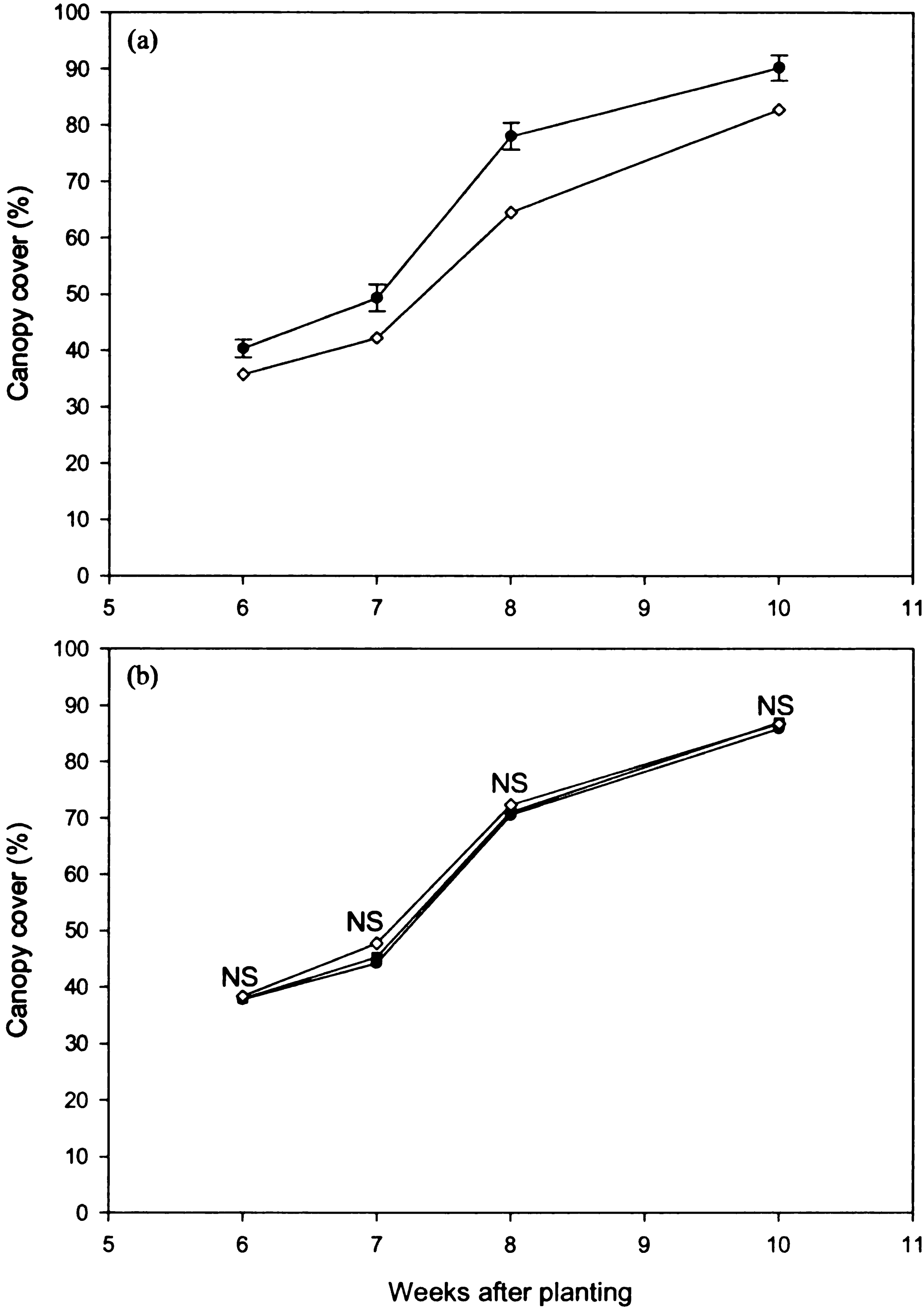

Figure 1. Canopy cover development for glyphosate-resistant sugarbeet planted in (a) 38-(●) and 76-cm rows (◇) and (b) populations of 54,000 (●), 78,000 (■), and 101,000 (◇) at the Saginaw Valley Bean and Beet Research Farm in 2006. Vertical bars represent Fisher's protected LSD at the $p = 0.05$ significance level. NS = not significant.

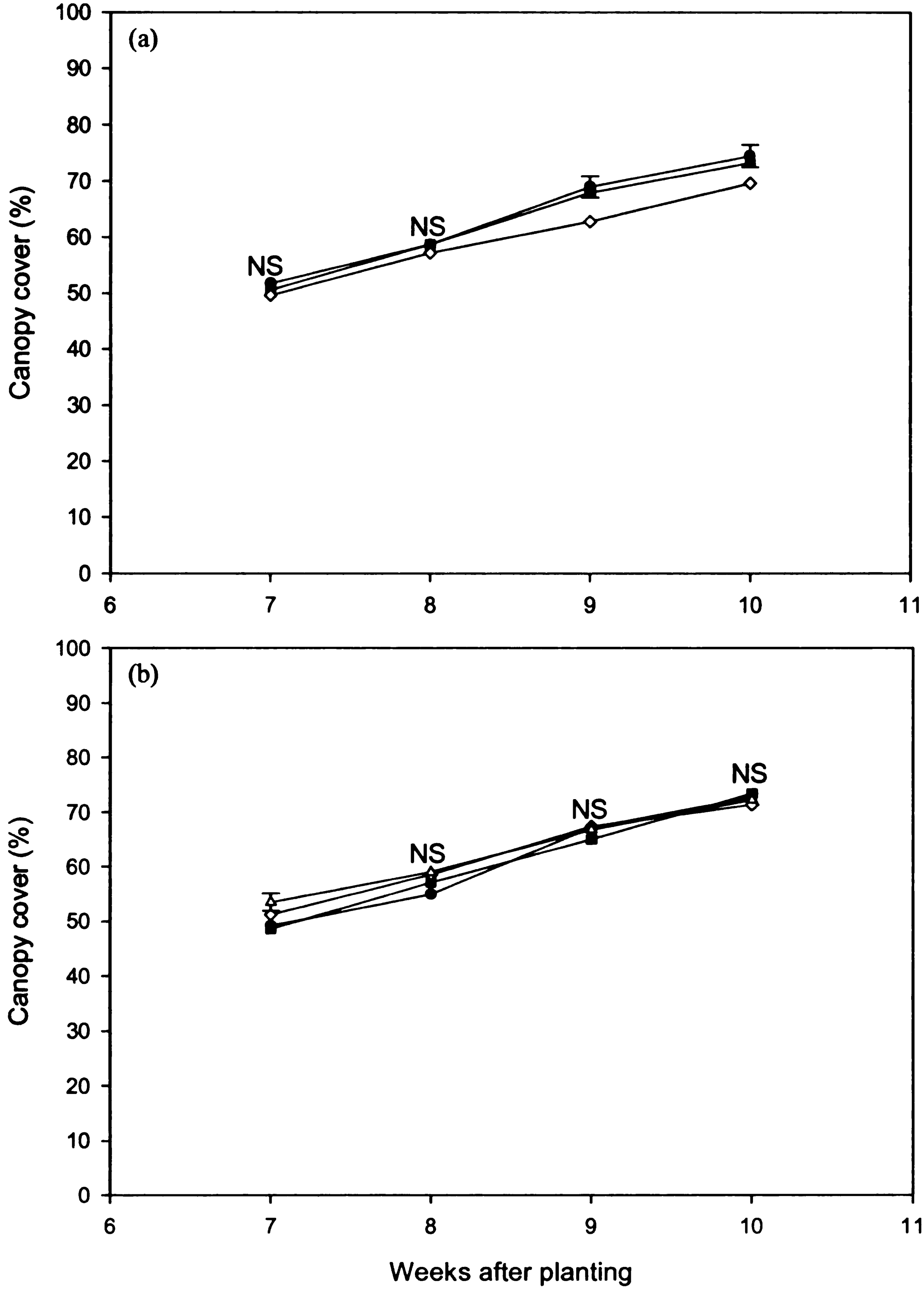

Figure 2. Canopy cover development for glyphosate-resistant sugarbeet planted in (a) 38- (●), 51- (■), and 76-cm rows (◇) and (b) populations of 54,000 (●), 78,000 (■), 101,000 (◇), and 124,000 plants/ha (△) at the Saginaw Valley locations in 2007. Vertical bars represent Fisher's protected LSD at the $p = 0.05$ significance level. NS = not significant.

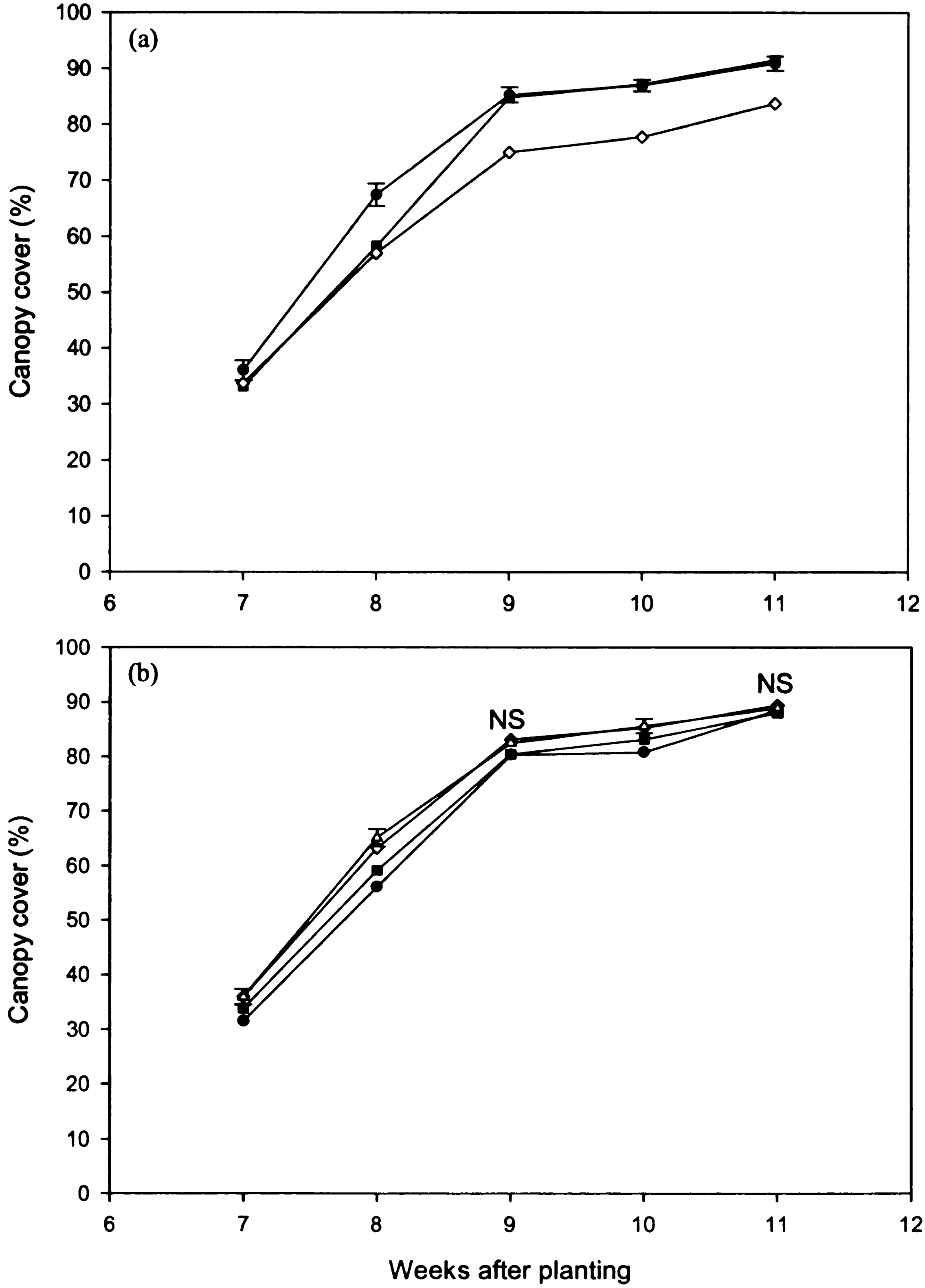

Figure 3. Canopy cover development for glyphosate-resistant sugarbeet planted in (a) 38- (●), 51- (■), and 76-cm rows (◊) and (b) populations of 54,000 (●), 78,000 (■), 101,000 (◊), and 124,000 plants/ha (△) at the Saginaw Valley locations in 2008. Vertical bars represent Fisher's protected LSD at the $p = 0.05$ significance level. NS = not significant.

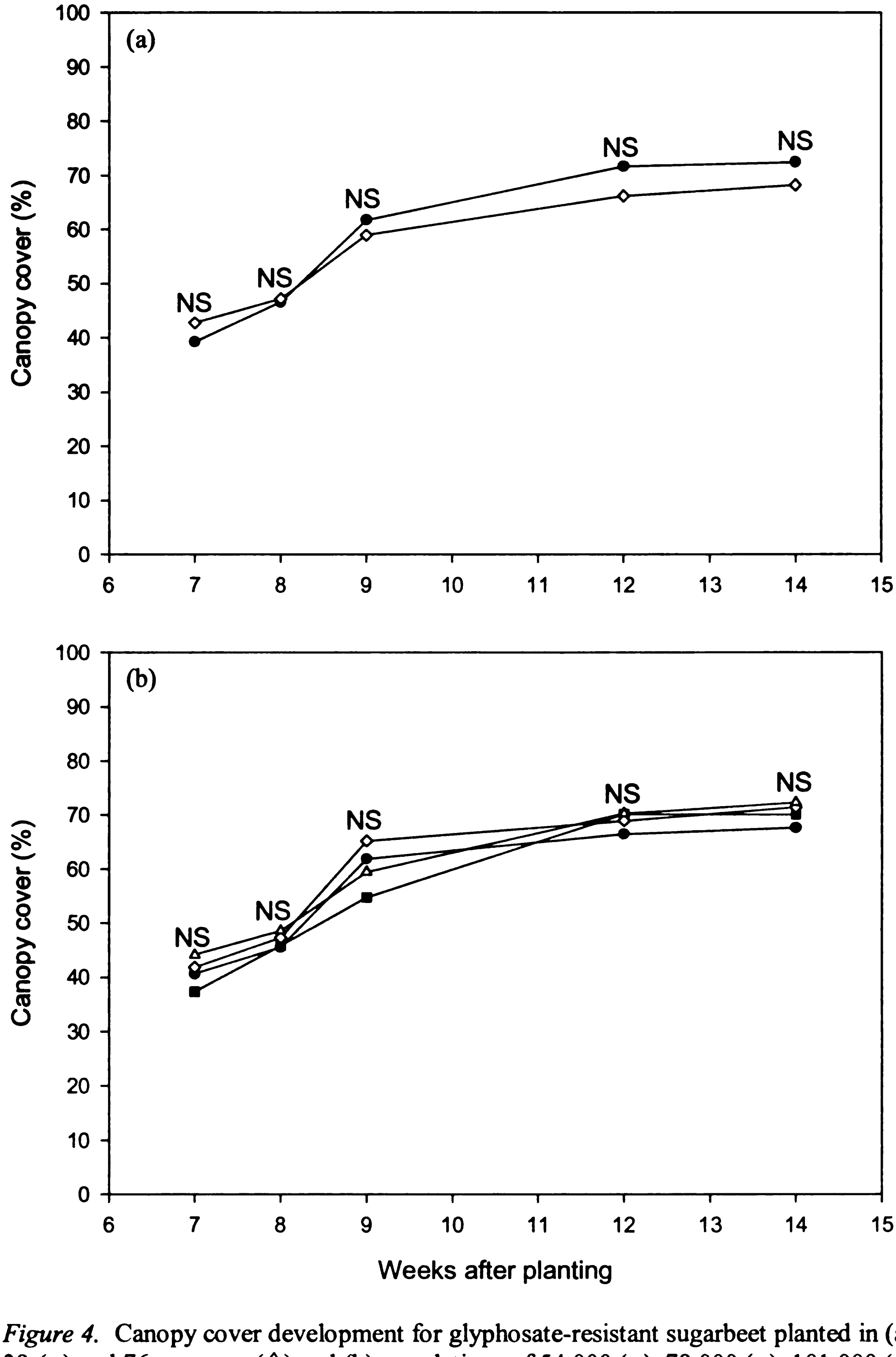

Figure 4. Canopy cover development for glyphosate-resistant sugarbeet planted in (a) 38-(●) and 76-cm rows (◊) and (b) populations of 54,000 (●), 78,000 (■), 101,000 (◊), and 124,000 plants/ha (△) at East Lansing in 2007. NS = not significant.

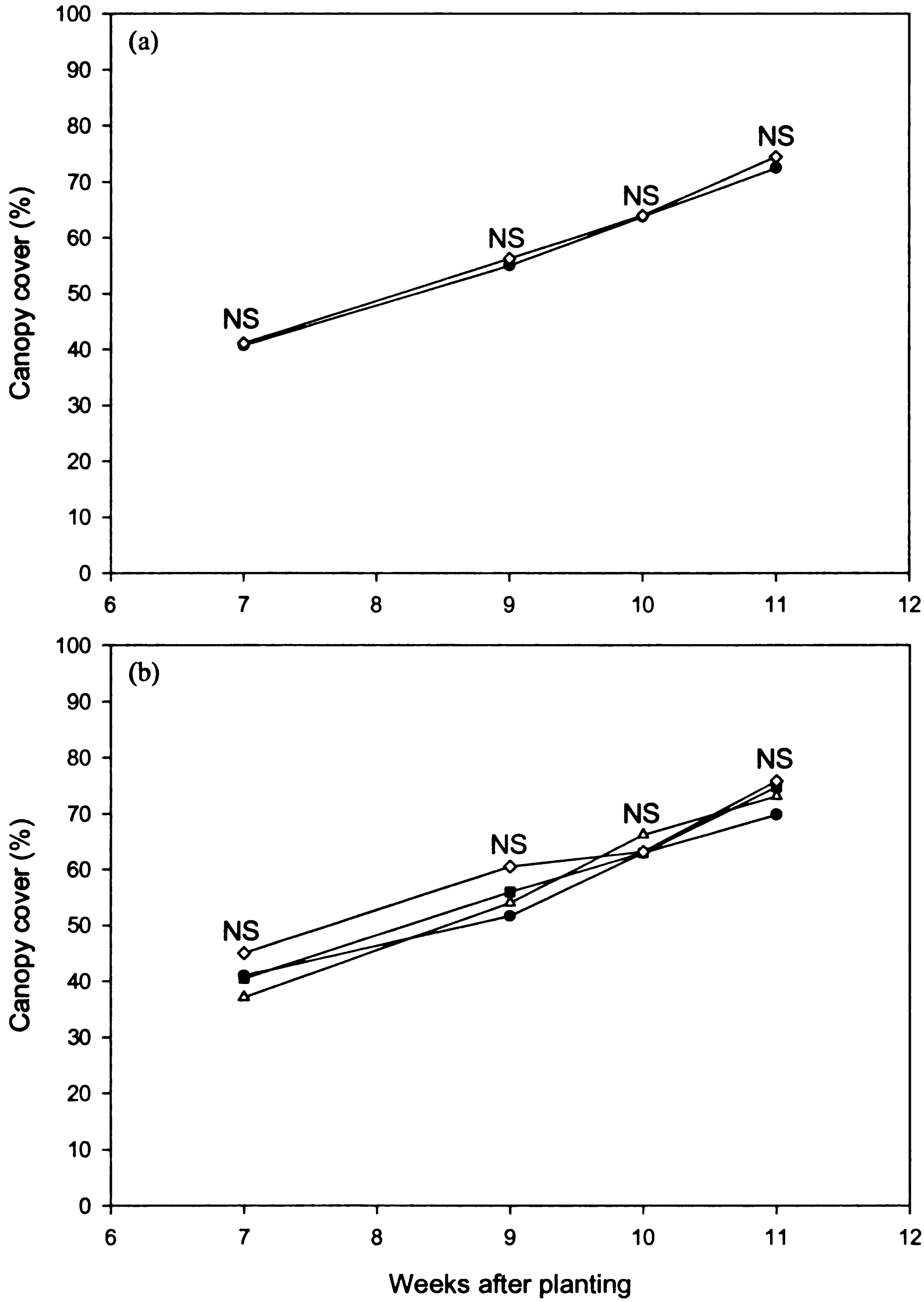

Figure 5. Canopy cover development for glyphosate-resistant sugarbeet planted in (a) 38-(●) and 76-cm rows (◇) and (b) populations of 54,000 (●), 78,000 (■), 101,000 (◇), and 124,000 plants/ha (△) at East Lansing in 2008. NS = not significant.

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CHAPTER 3

WEED MANAGEMENT IN WIDE- AND NARROW-ROW GLYPHOSTATE-RESISTANT SUGARBEET

Abstract: Planting glyphosate-resistant sugarbeet in narrow rows may provide growers the opportunity to improve weed control with fewer herbicide applications and cultivations. Field studies were conducted in 2007 and 2008 at multiple locations in Michigan to compare weed management, sugarbeet yield and quality in glyphosate-resistant sugarbeet planted in 38-, 51-, and 76-cm rows. At all locations, weed population densities and biomass were less after glyphosate treatments than conventional herbicide treatments. Weed population densities and biomass were lower in narrow rows compared with 76-cm rows following a single glyphosate application when weeds were 10-cm tall. This suggests that the greater canopy cover provided by narrow rows may potentially reduce the number of glyphosate applications necessary for season-long weed control. When averaged over row width, glyphosate-resistant sugarbeet root yield was similar to the weed free treatment for all herbicide treatments where glyphosate was applied when weeds were 10-cm in height or smaller. However, root yields were reduced when glyphosate applications were delayed until weeds averaged 15-cm in height. When averaged over all herbicide treatments, sugarbeet root and sugar yields were highest in the narrow row widths. Regardless of row width, initial glyphosate applications should be made before weeds reach 10-cm in height to maximize yield and minimize crop competition with weeds.

Nomenclature: Glyphosate; sugarbeet, *Beta vulgaris* L.

Key words: Herbicide-resistant crops, row width, weed biomass.

INTRODUCTION

Weed control is often listed by sugarbeet producers as their most serious production issue (Carlson et al. 2008). Glyphosate-resistant sugarbeet was fully commercialized in 2008. The use of glyphosate in glyphosate-resistant sugarbeet may provide growers the opportunity for excellent control of many weed species common to sugarbeet production with fewer herbicide active ingredients and applications (Guza et al. 2002; Kniss et al. 2004), while eliminating the potential for crop injury (Wilson et al. 2002). Growers may also be able to reduce or potentially eliminate between-row cultivation with the use of glyphosate-resistant sugarbeet. Additionally, the time between herbicide applications may be longer with glyphosate-resistant sugarbeet compared with conventional sugarbeet herbicide programs, because weed height at the time of application is generally not as limiting with glyphosate. As a result of this flexibility in application timing, growers may delay glyphosate applications to maximize the number of weeds controlled and minimize the number of applications necessary for season-long control. However, delayed glyphosate applications have led to yield losses due to the lengthened duration of competition between crop and weed in corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.) (Gower et al. 2003; Dalley et al. 2004a). Previous research on application timing in glyphosate-resistant sugarbeet has shown that sugarbeet is generally tolerant of early-season weed competition. Kemp and Renner (unpublished data) found that sugarbeet yields were similar for glyphosate application timings at weed heights up to 30-cm. Wilson et al. (2002) concluded that the optimum glyphosate application timing was when weeds were 10-cm in height. Despite some tolerance to early-season weed competition, applications should be made at a time when glyphosate will provide sufficient control.

Numerous studies on the effect of row width on crop yield have been conducted with many agronomic crops. Results of these studies have been somewhat inconsistent and vary among crop; however, the general outcome trends towards increased yields in narrower rows due to increased light radiation interception (Andrade et al. 2002). Narrow rows also provide more complete canopy cover that shades bare soil between rows, thereby reducing late-season weed emergence and growth (Johnson and Haverstad 2002). Yelverton and Coble (1991) observed a significant reduction in weed density and biomass in soybean planted in narrows rows compared with wide rows. Dalley et al. (2004b) also observed a similar trend of reduced weed biomass in narrow-row soybean. In three of four years, soybean planted in 19- and 38-cm rows had significantly less weed growth after an initial glyphosate application compared with 76-cm rows. In both studies, the reduction in weed growth was attributed to the greater canopy cover provided by narrow rows.

Sugarbeet is typically grown in row widths ranging from 56- to 76-cm, depending on growing region. In Michigan, a majority of sugarbeet production occurs in 71- or 76-cm row widths (C. Guza, personal communication). Similar to results from corn and soybean, previous research has shown an inverse relationship between sugarbeet row width and yield. Cattanach and Schroeder (1979) summarized 31 prior research trials comparing wide and narrow row sugarbeet production and concluded that narrow rows produce higher sugar yields than wide rows. In their own trials, Cattanach and Schroeder

(1979) observed higher root and sugar yields in 51-cm rows when compared with 76-cm rows. Yonts and Smith (1997) found that the highest sugar yield was obtained with 56-cm rows, when compared with 35- and 76-cm rows. Stebbing et al. (2000) showed an increase in root and sugar yield with 46-cm rows compared with 56- and 76-cm rows in one of two years. The authors attributed yield increases in 46-cm rows to the reduced intra-plant competition due to greater within-row distance between plants. In a comparison of glyphosate-resistant sugarbeet planted in 28- and 56-cm, Giles et al. (2001) found the highest sugar yields in the narrower row width.

Planting glyphosate-resistant sugarbeet in narrow rows may provide growers the opportunity to improve weed control with fewer herbicide applications and cultivations, while potentially improving yield and quality. Though previous research has been conducted examining the effects of row width on sugarbeet yield and weed growth in conventional sugarbeet varieties, no research has been published comparing different weed management strategies in wide and narrow row glyphosate-resistant sugarbeet. Therefore, the objective of this research was to evaluate weed management and sugarbeet yield and quality in glyphosate-resistant sugarbeet planted in wide and narrow row widths.

MATERIALS AND METHODS

Field studies were conducted in 2007 and 2008 at three locations, two in the Saginaw Valley region at the Michigan State University Saginaw Valley Bean and Beet Research Farm and on commercial production fields near St. Charles, Michigan, and a third location at the Michigan State University Crop and Soil Sciences Research Farm in

East Lansing, Michigan. The soil at the Saginaw Valley Bean and Beet Research Farm was a Zilwaukee silty clay (fine, mixed, mesic Fluvaquentic Endoaquolls) with soil pH of 7.4 and 3.9% organic matter. The soil type at the commercial production fields was a Sloan silty clay loam (fine-loamy, mixed, mesic Fluvaquentic Endoaquolls) with soil pH of 7.5 and 10.5% organic matter in 2007 and soil pH of 7.2 and 3.3% organic matter in 2008. At the East Lansing site, the soil type was a Capac fine sandy loam (fine-loamy, mixed, mesic Aquic Glossudalfs) with soil pH of 6.9 and 2.5% organic matter. Experiments followed soybean, wheat (*Triticum aestivum* L.), and dry bean (*Phaseolus vulgaris* L.) in 2006, 2007, and 2008, respectively, at the Bean and Beet Research Farm. At the commercial production fields and East Lansing location, experiments followed corn in 2007and soybean in 2008. Fields were fall-plowed followed by field cultivation prior to planting in the spring. Fertilizer applications were standard for sugarbeet production in Michigan. A glyphosate-resistant sugarbeet variety, 'Hilleshög 9028[1],' was planted at a depth of 2.5-cm in mid- to late-April. Sugarbeet was planted in 38-, 51-, and 76-cm row widths at the Saginaw Valley locations. At the East Lansing location, only 38- and 76-cm row widths were investigated. Plots were 11 rows (38-cm row width), eight rows (51-cm row width), and six rows wide (76-cm row width) by 9.1 m long at the Bean and Beet Research Farm and commercial production fields. At the East Lansing location, plots were seven and eight rows wide (38-cm row width) in 2007 and 2008, respectively, and four rows wide (76-cm rows) by 9.1 m long. Sugarbeet populations were thinned to a uniform density of 77,000 plants/ha in all row widths when sugarbeet were at the four-leaf growth stage.

The experiment was set-up as a split-plot design, with row width as the main plot factor and weed control treatment as the sub-plot factor. All treatments were replicated four times. Treatments were glyphosate[2] at 840 g ae/ha plus ammonium sulfate (AMS) at 2% v/v applied at various weed heights and conventional herbicide programs applied as micro-rate or standard-split treatments. Weed control treatments, application timings, and sugarbeet growth stage at application are summarized in Table 9. Micro-rate herbicide treatments consisted of desmedipham + phenmedipham at 45 + 45 g/ha plus triflusulfuron at 4.4 g/ha plus clopyralid at 26 g/ha plus methylated seed oil (MSO) at 1.5% v/v applied four times on 125 GDD (base 1.1 C) intervals starting after planting. Standard-split herbicide treatments consisted of desmedipham + phenmedipham at 180 + 180 g/ha plus triflusulfuron at 35 g/ha plus clopyralid at 104 g/ha applied twice, starting 222 GDD after planting with the second application made 236 GDD following the first application. A non-ionic surfactant at 0.25% v/v was included with the second standard-split application. Weed free and nontreated control plots were also established. Weed free plots were maintained with applications of 840 g ae/ha plus AMS at 2% v/v as needed, starting at 2-cm weeds. Herbicide applications were made using a tractor-mounted compressed-air sprayer calibrated to deliver 178 L/ha at 207 kPa through AirMix 11003[3] nozzles.

Common lambsquarters (*Chenopodium album* L.) and a combination of redroot pigweed (*Amaranthus retroflexus* L.) and Powell amaranth (*Amaranthus powellii* S. Watson) were the predominant weed species at the Saginaw Valley Bean and Beet Research Farm and commercial production fields in 2007 and 2008. These weed species plus a mixture of annual grass weed species was present at the East Lansing location in 2007 and 2008. In 2008, common purslane (*Portulaca oleracea* L.) was also present.

Weed population counts and aboveground weed biomass was harvested from two 0.25 m^2 quadrats placed in the center of each plot in mid-August. Weed biomass was dried for 72 h in a forced air oven at 60 C and weighed. Two rows of sugarbeet were mechanically harvested from each plot and weighed in mid-September and a sub-sample of roots was analyzed for quality and purity by the Michigan Sugar Company[4]. Sugarbeet quality is expressed as kg of recoverable white sucrose per Mg of root (RWSMg). Total sucrose production is expressed as kg of recoverable white sucrose per hectare (RWSH).

Data were subjected to ANOVA using PROC MIXED in SAS[5] and treatment means for weed counts and biomass and sugarbeet root yield, RWSMg, and RWSH were compared using Fisher's Protected LSD at the $p = 0.05$ significance level. Weed count and biomass data were log $(x + 1)$ transformed for analysis and the back-transformed data are presented. Interactions between main effects were also analyzed using the SLICE option in the LSMEANS statement (Littell et al. 1996). Data were combined over environment, row width, or treatment when interactions were not significant.

RESULTS AND DISCUSSION

Weed population density and biomass. There was not an interaction between herbicide treatment and row width; therefore weed population counts and biomass data were combined over row width. This indicates that weeds responded similarly to the weed control treatments, regardless of sugarbeet row width. Data are presented separately for studies that had all three row widths (Saginaw Valley Bean and Beet Research Farm and commercial production fields) and those that only compared 38- and 76-cm row widths (East Lansing). Overall weed populations were lower at the Saginaw Valley locations compared with the East Lansing location (Table 10); however, weed biomass in the nontreated plots was greater at the Saginaw Valley locations.

At the Saginaw Valley locations, weed densities were similar among all glyphosate treatments (Table 10), and weed densities and biomass were lower than in the conventional herbicide treatments. Weed biomass was lowest in treatments that had two glyphosate applications. Overall, the lowest weed density and biomass was in the treatment where the initial glyphosate was applied when weeds were 5-cm in height with a second application when weeds were 10-cm in height.

At the East Lansing location, data were also combined over row width because there was not a herbicide treatment by row width interaction. Weed density and biomass was lowest in the treatment where the initial glyphosate application was made when weeds were 5-cm in height (Table 10). Among all glyphosate treatments, treatments that consisted of two applications resulted in the lowest weed density and biomass at the end of the growing season. All treatments that contained glyphosate resulted in lower weed densities and less weed biomass compared with the conventional herbicide treatments.

Though the interaction of row width and herbicide treatment was not significant, significant differences among row widths were observed for weed population density and biomass following a single glyphosate application when weeds were 10-cm tall. At the Saginaw Valley locations, weed population counts and biomass were reduced in the 38-

and 51-cm rows compared with the 76-cm rows (Table 11). Likewise, weed biomass was reduced in the 38-cm rows compared with the 76-cm rows at the East Lansing location. Alford et al. (2004) observed significant reductions in weed biomass in sugarbeet planted 38- and 56-cm rows compared with 76-cm rows, due to earlier and greater canopy cover in the narrow row widths. These results indicate that sugarbeet planted in narrow rows can suppress late-season weed growth, particularly following an initial glyphosate application to control early-season weeds. Greater canopy cover in narrow rows may potentially reduce the number of glyphosate applications necessary for season-long weed control compared with wide rows.

Sugarbeet root yield and quality. Interactions between herbicide treatment and row width were not significant. When averaged over row width, glyphosate-resistant sugarbeet root yield was similar to the weed free treatment for all herbicide treatments where glyphosate was applied when weeds were 10-cm or less in height (Table 12). However, due to increased length of competition with weeds, root yields were reduced when glyphosate applications were delayed until weeds averaged 15-cm in height. Additionally at the East Lansing location, yields were reduced in the conventional herbicide treatment. Despite differences in root yield, RWSMg and RWSH were similar among all herbicide treatments.

When averaged over all herbicide treatments, sugarbeet root yields were highest in the 38- and 51-cm rows compared with 76-cm rows at the Saginaw Valley locations (Table 13). RWSMg was also greatest in 38- and 51-cm rows. Likewise, at the East Lansing location, root yield and RWSMg were greatest in 38-cm rows. As a result of higher root yield and RWSMg, RWSH was also highest in narrow rows. Because plant populations were kept constant across row width, it is likely that narrower rows produced higher yields due to increased light interception, reduced within-row competition among sugarbeet plants, and reduced competition with weeds.

Glyphosate-resistant sugarbeet varieties will offer producers the opportunity to reduce or potentially eliminate between-row cultivation and potentially take advantage of planting in narrow rows. Regardless of row width, multiple applications of glyphosate will be necessary to ensure season-long weed control and initial glyphosate applications should be made when weeds are 10-cm or less in height to prevent yield loss from competition with weeds. In addition to increased yield, sugarbeet planted in narrow rows can provide greater canopy cover to suppress weed growth later in the growing season. Results from this research will provide sugarbeet growers information for maximizing sugarbeet yield and quality, while reducing the effects of weed competition, when adopting glyphosate-resistant sugarbeet varieties and planting in narrow rows.

SOURCES OF MATERIALS

[1] Syngenta Seeds Inc., 1020 Sugarmill Rd., Longmont, CO 80501.

[2] Roundup WeatherMAX, Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167.

[3] AirMix 11003, Greenleaf Technologies, P.O. Box 1767, Covington, LA 70434.

[4] Michigan Sugar Company, 2600 S. Euclid Ave., Bay City, MI 48706

[5] The SAS System for Windows, Version 9.1, SAS Institute Inc., 100 SAS Campus Dr., Cary, NC 27513.

Table 9. Herbicide treatments, rates and application timings in glyphosate-resistant sugarbeet.

Herbicide treatment	Rate/ha	Application timing	Sugarbeet growth stage
Glyphosate + AMS[a]	840 g ae + 2% v/v	5 cm weeds + 10 cm weeds	2-4 leaf + 8-12 leaf
		10 cm weeds + 10 cm weeds	6-8 leaf + 10-12 leaf
		10 cm weeds	6-8 leaf
		15 cm weeds	8-10 leaf
Micro-rate: Desmedipham + phenmedipham + triflusulfuron + clopyralid + MSO	45 g + 45 g + 4.4 g + 26 g + 1.5% v/v	Applied four times: 125 GDD intervals beginning after planting (base 1.1 C)	coty. + coty.–2 leaf + 2-4 leaf + 4-8 leaf
Standard-split: Desmedipham + phenmedipham + triflusulfuron + clopyralid (+ NIS in second application)	180 g + 180 g + 35 g + 104 g (+ 0.25% v/v)	Applied two times: 222 GDD after planting, 236 GDD after first application (base 1.1 C)	coty.–2 leaf + 2-4 leaf

[a] Abbreviations: AMS, ammonium sulfate; coty., cotyledon; GDD, growing degree days; MSO, methylated seed oil; NIS, nonionic surfactant.

Table 10. Weed populations and biomass for herbicide treatments when averaged over row width at the Saginaw Valley locations where 38-, 51- and 76-cm row widths were compared and at the East Lansing location where 38- and 76-cm row widths were compared. Data were combined across 2007 and 2008 for the respective locations.[a]

	Saginaw Valley[b]		East Lansing	
Herbicide treatment[c]	Weed density	Weed biomass	Weed density	Weed biomass
	weeds/m^2	kg/ha	weeds/m^2	kg/ha
5-cm fb.[d] 10-cm weeds[e]	0.7 b	0.6 a	0.3 ab	0.3 a
10-cm fb. 10-cm weeds	1.0 b	1.0 ab	1.0 b	0.6 a
10-cm weeds	1.2 b	1.3 b	16.7 d	7.6 c
15-cm weeds	1.3 b	1.5 b	6.0 c	2.9 b
Conventional treatment[f]	8.6 c	31.1 c	37.6 e	79.7 d
Weed free	0 a	0 a	0 a	0 a
Nontreated	28.3 d	543.5 d	65.7 f	367.7 e

[a] Means within column followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] Data were combined across the Saginaw Valley Bean and Beet Research Farm and commercial production field locations.

[c] Herbicide treatments were combined over all row widths investigated at each location.

[d] Abbreviation: fb., followed by.

[e] Herbicide treatments based on weed size consisted of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v.

[f] Conventional treatments were applied as either micro-rate or standard-split applications (Table 9).

Table 11. Weed populations and biomass following a single glyphosate application when weeds were 10-cm tall at the Saginaw Valley locations where 38-, 51- and 76-cm row widths were compared and at the East Lansing location where 38- and 76-cm row widths were compared. Data were combined across 2007 and 2008 for the respective locations.[a]

	Saginaw Valley[b]		East Lansing	
Row width	Weed density	Weed biomass	Weed density	Weed biomass
	weeds/m^2	kg/ha	weeds/m^2	kg/ha
38-cm	0.6 a	0.4 a	11.8 a	4.6 a
51-cm	0.9 a	0.7 a	—[c]	—
76-cm	2.7 b	3.9 b	23.3 a	12.2 b

[a] Means within column followed by the same lowercase letter are not different according to Fisher's Protected LSD at the p = 0.05 significance level.
[b] Data were combined across the Saginaw Valley Bean and Beet Research Farm and commercial production field locations.
[c] 51-cm rows were not investigated at the East Lansing location.

Table 12. Sugarbeet root yield, recoverable white sucrose per Mg of root (RWSMg), and recoverable white sucrose per hectare (RWSH) for herbicide treatment when averaged over row width at the Saginaw Valley locations where 38-, 51- and 76-cm row widths were compared and at the East Lansing location where 38- and 76-cm row widths were compared. Data were combined across 2007 and 2008 for the respective locations.[a]

	Saginaw Valley[b]			East Lansing		
Herbicide treatment[c]	Root yield	RWSMg	RWSH	Root yield	RWSMg	RWSH
	Mg/ha	kg/Mg	kg/ha	Mg/ha	kg/Mg	kg/ha
5-cm fb.[d] 10-cm weeds[e]	82.8 a	116.4 a	9560 a	60.8 a	100.7 a	6120 bc
10-cm fb. 10-cm weeds	82.9 a	116.8 a	9630 a	61.5 a	106.3 a	6720 ab
10-cm weeds	83.1 a	116.3 a	9550 a	59.3 a	107.6 a	6460 abc
15-cm weeds	76.8 b	116.0 a	8910 a	52.1 b	104.3 a	5630 c
Conventional treatment[f]	81.3 ab	114.7 a	9250 a	54.4 b	106.3 a	5990 b
Weed free	82.2 a	115.7 a	9430 a	62.6 a	108.6 a	7240 a
Nontreated	45.0 c	—[g]	—	16.7 c	105.5 a	1550 d

[a] Means within column followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] Data were combined across the Saginaw Valley Bean and Beet Research Farm and commercial production field locations.

[c] Herbicide treatments were combined over all row widths investigated at each location.

[d] Abbreviation: fb., followed by.

[e] Herbicide treatments based on weed size consisted of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v.

[f] Conventional treatments were applied as either micro-rate or standard-split applications (Table 9).

[g] Sufficient sugarbeet samples could not be collected for quality and purity analysis due to competition from weeds.

Table 13. Sugarbeet root yield, recoverable white sucrose per Mg of root (RWSMg), and recoverable white sucrose per hectare (RWSH) for row width when averaged over herbicide treatment at the Saginaw Valley locations where 38-, 51- and 76-cm row widths were compared and at the East Lansing location where 38- and 76-cm row widths were compared. Data were combined across 2007 and 2008 for the respective locations.[a]

	Saginaw Valley[b]			East Lansing		
Row width[c]	Root yield	RWSMg	RWSH	Root yield	RWSMg	RWSH
	Mg/ha	kg/Mg	kg/ha	Mg/ha	kg/Mg	kg/ha
38-cm	82.8 a	116.6 a	9590 a	56.8 a	107.5 a	6400 a
51-cm	82.5 a	117.2 a	9660 a	—[d]	—	—
76-cm	78.6 b	114.1 b	8920 b	48.1 b	103.7 b	4940 b

[a] Means within column followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] Data were combined across the Saginaw Valley Bean and Beet Research Farm and commercial production field locations.

[c] Herbicide treatments were combined over all row widths investigated at each location.

[d] 51-cm rows were not investigated at the East Lansing location.

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CHAPTER 4

ADJUSTMENTS IN PLANTING PRACTICES TO MAXIMIZE ECONOMIC RETURN IN GLYPHOSATE-RESISTANT SUGARBEET

Abstract: In Michigan, sugarbeet production is contracted using a quality payment system that adjusts the price paid per Mg of root weight according to the quality of the sugarbeet root. Sugarbeet quality, or kg of recoverable white sucrose per Mg of root (RWSMg), can be influenced by many factors including row width and plant population. With the introduction of glyphosate-resistant sugarbeet, growers may consider adjusting production practices, such as planting in narrow rows, to maximize sugarbeet production. However, the higher cost of glyphosate-resistant sugarbeet seed may persuade growers to reduce seeding rates to reduce production costs. The objective of this research was to determine how row width and plant population can influence root yield, sugarbeet quality, and economic return in glyphosate-resistant sugarbeet. Studies were conducted in 2007 and 2008 at multiple locations in Michigan to determine the effect of planting glyphosate-resistant sugarbeet in row widths of 38-, 51-, and 76-cm and populations of 54,000; 78,000; 101,000; and 124,000 plants/ha. Gross margins were calculated using a base price weighted according to RWSMg and a constant base price. At the Saginaw Valley locations, 51-cm rows had the highest root yields and an increase in gross margin of at least $200/ha compared with 38- and 76-cm rows, when the base price was adjusted for quality. Using a constant base price, 38- and 76-cm had similar gross margins, but were still significantly lower than 51-cm rows. At the East Lansing location, root yields and gross margins were similar for 38- and 76-cm rows in 2007. In 2008, 38-cm rows

provided a 10.2 Mg/ha root yield advantage over 76-cm rows. In 2008, plant populations of 78,000; 101,000; and 124,000 plants/ha in 38-cm rows resulted in the highest gross margins. Despite observed increases in RWSMg at higher plant populations, results from this analysis suggest that economic returns for sugarbeet production are influenced primarily by root yields and are highest for sugarbeet planted in narrow rows.

Nomenclature: Glyphosate; sugarbeet, *Beta vulgaris* L.

Key words: Economic analysis, herbicide-resistant crops, plant population; profitability; row width.

INTRODUCTION

Sugarbeet root quality is the most important factor affecting processing efficiency (Dutton and Huijbregts 2006). Sugarbeet quality can be expressed by many different factors, including sucrose and non-sucrose concentration in the root and clear juice purity. From a practical standpoint, many sugarbeet processors define sugarbeet quality as the kg of recoverable white sucrose per Mg of sugarbeet root weight (RWSMg). RWSMg factors in the sucrose concentration of the root and the extractable clear juice purity. Sugarbeet root quality is influenced by environmental and production factors including: variety selection, planting and harvest date, nitrogen fertility, row width, plant population, and storage (Dutton and Huijbregts 2006; Asadi 2007). Previous research has shown that sucrose concentration in the sugarbeet root is generally higher in narrow rows and at high plant populations (Yonts and Smith 1997). Under these conditions there is less space between plants within and between rows. Yonts and Smith (1997) observed a trend of higher sucrose concentrations, due to the smaller growth of each individual beet at higher populations. However, sucrose concentration did not increase at plant populations more than 65,000 plants/ha. Winter (1989) also observed higher sucrose concentrations in sugarbeet planted at higher populations.

All sugarbeet production in Michigan is contracted through the Michigan Sugar Company, a grower-owned cooperative. Sugarbeet contracts through the Michigan Sugar Company are structured as tournament contracts to motivate growers to produce sugarbeet with high RWSMg levels (Knoeber 1989). Under the terms of this contract structure, growers "compete" against one another to determine their payment per Mg of sugarbeet root. The Michigan Sugar Company uses a quality payment system based on the formula:

$$P_{grower} = P_{base} \times (Grower\ RWSMg/Company\ average\ RWSMg)$$

where P_{grower} is the final price per ton of sugarbeet root paid to the grower and P_{base} is the base price per ton of sugarbeet root paid by Michigan Sugar Company. In this formula, P_{grower} is calculated by multiplying P_{base} by the ratio of the grower's RWSMg to the overall company average RWSMg. P_{grower} can be adjusted above or below P_{base}, depending on the ratio of the RWSMg values. As is the structure of tournament contracts, growers are incentivized to produce high quality sugarbeet (i.e. sugarbeet with high RWSMg), rather than simply maximize root yield.

Weed control is often listed by sugarbeet growers as the most difficult task they face in production (Carlson et al. 2008). Similar to other glyphosate-resistant crops, the commercial release of glyphosate-resistant sugarbeet in 2008 may provide growers the opportunity to improve weed control with fewer herbicides, applications, and cultivations and improve control of weed that are resistant to other herbicide modes of action. Production costs for sugarbeet are considerable and can reach as high as $1500/ha (Burgener 2001). In addition to production expenses associated with planting, fertilization, fungicide and herbicide applications, and harvesting, growers will pay a technology fee of $106 per unit of 100,000 seeds when purchasing glyphosate-resistant sugarbeet seed, or approximately $130/ha at a seeding rate of 124,000 seeds/ha. To recover this added expense, growers must increase their economic returns by increasing yield and quality, reducing weed control expenses, or reducing seeding rates to minimize cost. Growers must also balance the added expense of planting at higher seeding rates with the increases in sugarbeet quality often observed from planting at higher plant populations.

In Michigan, a majority of sugarbeet production occurs in 71- or 76-cm row widths, with a target final plant population of approximately 78,000 plants/ha (C. Guza, personal communication). With the benefits of glyphosate-resistant sugarbeet for improved weed control and reduced need for between-row cultivation, growers may be able to adopt narrow rows for planting. Previous research has compared yields and economic returns from conventional and glyphosate-resistant sugarbeet (Kniss et al. 2004), however, no research has been published comparing glyphosate-resistant sugarbeet production in multiple row widths and populations and the impact of these production practices on economic return. Therefore, the objective of this research was to determine how adjustments in row width and plant population influence economic return for glyphosate-resistant sugarbeet production in Michigan.

MATERIALS AND METHODS

Field trials were conducted in 2007 and 2008 at the Michigan State University Agronomy Research Farm in East Lansing, the Michigan State University Saginaw Valley Bean and Beet Research Farm, and on commercial production fields near St. Charles, Michigan. At the East Lansing location, the soil type was a Capac fine sandy loam (fine-loamy, mixed, mesic Aquic Glossudalfs) with soil pH of 6.9 and 2.5% organic matter. The soil at the Bean and Beet Research Farm was a Zilwaukee silty clay (fine, mixed, mesic Fluvaquentic Endoaquolls) with soil pH of 7.4 and 3.9% organic matter. The soil type at the commercial production fields was a Sloan silty clay loam (fine-loamy, mixed, mesic Fluvaquentic Endoaquolls) with soil pH of 7.5 and 10.5% organic matter in 2007 and soil pH of 7.2 and 3.3% organic matter in 2008. Fields were fall-plowed followed by field cultivation prior to planting in the spring. Fertilizer applications were standard for sugarbeet production in Michigan. The glyphosate-resistant sugarbeet variety, 'Hilleshög 9028[2],' was planted in 38-, 51-, and 76-cm row widths to a depth of 2.5-cm. At East Lansing, only 38- and 76-cm row widths were investigated. At the 4-leaf growth stage, stands were thinned to densities of 54,000; 78,000; 101,000; or 124,000 plants/ha. Populations were held constant across row widths, leading to differences in within-row plant spacing for each population (Table 14). Weed-free plots were established for all years of the study and maintained with applications of glyphosate[3] at 840 g ae/ha + ammonium sulfate (AMS) at 2% v/v as needed. Two rows of sugarbeet were mechanically harvested and weighed from each plot in mid-September and a sub-sample of roots was analyzed for quality and purity by the Michigan Sugar Company[4]. Sugarbeet quality is expressed as kg of recoverable white sucrose per Mg of root (RWSMg).

A split-plot experimental design was used for these studies, with row width as the main plot factor and plant population as the sub plot factor. A partial budget analysis was conducted to compare economic returns for sugarbeet root yield and quality as influenced by row width and plant population. Gross margins were calculated using the formula:

$$Gross\ margin = (Y \times (RWSMg_{plot} / RWSMg_{trial}) \times P_{base}) -$$

$$(W + (S_{rate} \times (S_{cost} + T) / 100{,}000))$$

where Y is root yield/ha, $RWSMg_{plot}$ and $RWSMg_{trial}$ represent the RWSMg values for individual plots and the overall average for each trial, respectively, P_{base} is base price paid per ton of sugarbeet root, W is weed control expense per ha including herbicide and application expenses, S_{rate} is seeding rate per ha, T is the cost of the technology fee per unit of 100,000 seeds, and S_{cost} is the cost of seed per unit of 100,000 seeds minus the technology fee. In this analysis, root yields and RWSMg values for each individual plot were used and RWSMg values were compared to the trial average for each year and location. A base price of \$44/Mg of sugarbeet root was assumed. Base prices of \$37 and \$51/Mg were also used to determine sensitivity of gross margin to changes in price. In addition to calculating gross margins using a weighted base price, gross margins were also calculated using a constant base price regardless of sugarbeet quality to compare two methods for determining economic return. Because sugarbeet stands were thinned to stand, a seeding rate of 167% of the desired population was used to calculate the total cost of seed, assuming 60% germination and establishment. Herbicide expenses for applications of glyphosate at 840 g ae/ha + AMS at 2% v/v were estimated using price sheets from two agrichemical distributors in mid-Michigan. Herbicide application expenses were derived from custom work estimates compiled by Stein (2008). Based on weed control data from prior studies (Chapter 3), two applications were assumed for glyphosate-resistant sugarbeet planted in 38- and 51-cm row widths and three applications were assumed for 76-cm row widths. All variable costs used in the partial budget analysis are summarized in Table 15.

All data were subjected to ANOVA using PROC MIXED in SAS[5] and treatment means for gross margin were compared using Fisher's Protected LSD at the $p = 0.05$ significance level. Multiple significance levels up to $p = 0.20$ were also used to compare treatment means, however statistical significance among treatments remained similar to the $p = 0.05$ level. Data were combined over environment, row width, or population and presented for main effects when significant interactions were not present.

RESULTS AND DISCUSSION

Data are presented separately for studies that had all three row widths (Saginaw Valley Bean and Beet Research Farm and commercial production fields) and those that only compared 38- and 76-cm row widths (East Lansing). Data were combined across year where significant interactions involving these effects were not present. A significant interaction between row width and plant population was not observed for gross margins at the Saginaw Valley locations and data are presented separately for row width and plant population. The lack of significant interaction between row width and plant population indicates that economic returns for a certain row width would be similar for all plant populations within that row width.

When averaged over all plant populations, glyphosate-resistant sugarbeet planted in 51-cm rows had the highest root yield (Table 16). Similar to root yield, the highest gross margins were observed in 51-cm rows when calculated using a weighted base price based on the RWSMg value for each plot compared to the overall average RWSMg for each environment. Compared with 38- and 76-cm rows, gross margins in 51-cm rows were at least \$200/ha greater. When a constant base price of \$44 per Mg of sugarbeet root was used to calculate gross margins, 51-cm row widths also resulted in the highest returns at \$3290/ha. Gross margins for 38- and 76-cm rows were significantly lower at \$3050 and \$3000/ha, respectively. Based on the experimental data in this analysis, gross margins were similar for both the weighted and constant base price payment calculation methods. When comparing among plant populations, RWSMg increased at higher plant populations at the Saginaw Valley locations and root yields were statistically similar among all plant populations (Table 16). Despite the increase in RWSMg at higher populations, the increase was not great enough to influence gross margin, as gross margins were statistically similar among all plant populations (Table 16). Separation of treatment means of gross margins were similar among all prices used in this analysis (data not presented). Similar results were also observed at the East Lansing location in

2007 and 2008, where root yields, RWSMg, and gross margins were similar among all plant populations (Table 18).

At the East Lansing location, root yields and RWSMg were similar among 38- and 76-cm rows in both 2007 and 2008 (Table 17). Due to dry conditions during June and July of 2007 when precipitation totals were 60 and 52 mm below the 30 year average at St. Charles and East Lansing, respectively, root yields were comparably lower than in 2008 (Chapter 2). Sugarbeet root yields and RWSMg were similar for all plant populations (Table 18). As a result, regardless of the method used to calculate gross margin, gross margins were similar for all row width and plant population combinations in 2007 (Table 19). When growing conditions were more favorable in 2008, root yields were 10.2 Mg/ha higher in 38-cm rows than 76-cm rows. For gross margins, an interaction between row width and plant population was observed at East Lansing in 2008. Comparing across all row width and plant populations, gross margins were highest in populations of 78,000; 101,000; and 124,000 plants/ha in 38-cm rows when either a weighted base price or constant base price was used to calculate gross margin. Separation of treatment means of gross margins were similar among base prices of $37/Mg to $51/Mg (data not presented).

Results from this analysis indicate that economic returns for glyphosate-resistant sugarbeet production can be influenced by row width. At locations where 38-, 51-, and 76-cm row widths were compared, root yields and economic returns were highest in 51-cm rows. At locations where 38- and 76-cm row widths were compared, root yields and economic returns were highest in 38-cm rows when moisture was not limiting. Gross margins were similar whether or not sugarbeet quality was used to adjust the base price for grower payments. Planting in narrow rows may also potentially further reduce weed control costs because of increased canopy cover and suppressed weed growth, requiring fewer herbicide applications for season-long weed control.

Though planting at higher populations did increase sugarbeet quality, root yields were similar among all plant populations at all locations. Overall, RWSMg values for individual plots ranged from 20% below to 16% above the respective trial average, but nearly 75% of all data points fell within 5% of the trial average. The purpose a tournament contract, in the case of sugarbeet production contracted with the Michigan Sugar Company, is to provide an incentive for growers to produce sugarbeet with high RWSMg levels for the sugarbeet processor. Under the quality payment system, growers receive a proportionally higher price per Mg of sugarbeet root for higher quality sugarbeet. However, based on sugarbeet root yield and quality data from this analysis, RWSMg values deviated very little from the overall average and thus, sugarbeet quality had a relatively small effect on the price per Mg of sugarbeet root and overall profitability. Therefore, despite increases in RWSMg in higher plant populations, results from this analysis suggest that economic returns for sugarbeet production are influenced primarily by higher root yields achieved by planting in narrow rows.

The higher cost of glyphosate-resistant sugarbeet seed may persuade growers to reduce planting densities. Sugarbeet growers will also be reluctant to adjust production practices due to expenses associated with purchasing or modifying equipment for planting and harvesting in narrow rows. Other factors, including the age of their current equipment (Krause and Black 1995) and crops in their rotation that could also be switched to narrow-row production, can also influence the decision to adopt or the rate at which adoption of narrow row production will occur. Additionally, costs associated with potential increases in disease pressure in sugarbeet planted in narrow rows and increased soil fertility requirements with higher yields should also be considered. Results of this analysis suggest that economic returns are similar regardless of plant population, and that profitability is highest for glyphosate-resistant sugarbeet production in narrow rows

SOURCES OF MATERIALS

[1] Betaseed, Inc., 1788 Marschall Rd., P.O. Box 195, Shakopee, MN 55379.

[2] Syngenta Seeds Inc., 1020 Sugarmill Rd., Longmont, CO 80501.

[3] Roundup WeatherMAX, Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167.

[4] Michigan Sugar Company, 2600 S. Euclid Ave., Bay City, MI 48706.

[5] The SAS System for Windows, Version 9.1, SAS Institute Inc., 100 SAS Campus Dr., Cary, NC 27513.

Table 14. Within-row plant spacing and number of plants per 30-m of row for glyphosate-resistant sugarbeet in three row widths and four plant populations.

	38-cm rows		51-cm rows		76-cm rows	
Population	Plant spacing	Plants/30-m	Plant spacing	Plants/30-m	Plant spacing	Plants/30-m
Plants/ha	cm	#	cm	#	cm	#
54,000	48	63	30	100	24	125
78,000	34	88	25	120	17	177
101,000	26	115	20	150	13	231
124,000	21	143	16	188	11	273

Table 15. Summary of variable costs used in the partial budget analysis comparing glyphosate-resistant sugarbeet planted in three row widths and four plant populations. A base price of $44/Mg of sugarbeet root was assumed.

Seed cost	$100/unit[a]
Technology fee	$106/unit
Total seed cost by plant population[b]:	
54,000 plants/ha	$111/ha
78,000 plants/ha	$161/ha
101,000 plants/ha	$208/ha
124,000 plants/ha	$255/ha
Herbicide application	$15/application[c]
Glyphosate + ammonium sulfate (840 g ae/ha +2% v/v)	$35/ha[d]
Total herbicide cost by row width:	
38-cm, 2 applications[e]	$100/ha
51-cm, 2 applications	$100/ha
76-cm, 3 applications	$150/ha

[a] 1 unit = 100,000 seeds

[b] A seeding rate of 167% of the desired population was used to calculate the total seed cost, assuming 60% germination and establishment.

[c] Herbicide application costs were derived from custom work estimates compiled by Stein (2008).

[d] Herbicide prices were estimated using price sheets from two agrichemical distributors in mid-Michigan.

[e] Based on prior studies (Chapter 3), two applications of glyphosate + ammonium sulfate were assumed for glyphosate-resistant sugarbeet planted in 38- and 51-cm row widths and three applications were assumed for 76-cm row widths.

Table 16. Root yield, recoverable white sucrose per Mg of root (RWSMg), and gross margins for glyphosate-resistant sugarbeet in three row widths and four plant populations at the Saginaw Valley locations in 2007 and 2008.[a,b,c]

Main effects	Root yield	RWSMg	Gross margin: Adjusted for quality[d]	Gross margin: Constant price[e]
Row width	Mg/ha	kg/Mg	$/ha	$/ha
38-cm	81.8 b	119.1 a	3090 b	3050 b
51-cm	87.2 a	118.4 a	3290 a	3290 a
76-cm	81.5 b	116.8 a	2960 b	3000 b
Population				
(plants/ha)				
54,000	83.5 a	115.4 b	3110 a	3210 a
78,000	81.0 a	117.6 ab	3040 a	3030 a
101,000	84.3 a	119.2 a	3130 a	3120 a
124,000	85.2 a	120.1 a	3150 a	3100 a

[a] Means within column for each main effect followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] All plots were kept weed free with applications of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v as needed.

[c] Data were combined across the Saginaw Valley Bean and Beet Research Farm and commercial production field locations.

[d] Gross margins were calculated using a base price ($44/Mg) adjusted for quality (RWSMg of each plot compared with the overall average RWSMg).

[e] Gross margins were calculated using a constant base price of $44/Mg.

Table 17. Root yield and recoverable white sucrose per Mg of root (RWSMg) for glyphosate-resistant sugarbeet in two row widths at East Lansing in 2007 and 2008.[a,b]

Row width	Root yield		RWSMg
	2007	2008	2007 & 2008
	Mg/ha		kg/Mg
38-cm	48.8 a	69.1 a	106.7 a
76-cm	51.2 a	58.9 b	105.1 a

[a] Means within column for each main effect followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.
[b] All plots were kept weed free with applications of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v as needed.

Table 18. Root yield and recoverable white sucrose per Mg of root (RWSMg) for glyphosate-resistant sugarbeet in four plant populations at East Lansing in 2007 and 2008.[a,b]

Population	Root yield	RWSMg
Plants/ha	Mg/ha	kg/Mg
54,000	52.2 a	105.1 a
78,000	56.9 a	102.6 a
101,000	60.2 a	107.5 a
124,000	57.3 a	109.3 a

[a] Means within column for each main effect followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.

[b] All plots were kept weed free with applications of glyphosate at 840 g ae/ha + ammonium sulfate at 2% v/v as needed.

Table 19. Gross margins for glyphosate-resistant sugarbeet in two row widths and four plant populations at East Lansing in 2007 and 2008.[a]

		2007		2008	
Row width	Population	Adjusted for quality[b]	Constant price[c]	Adjusted for quality	Constant price
	plants/ha	$/ha			
38-cm	54,000	1610 a	1570 a	1850 c	1890 d
	78,000	1700 a	1480 a	2780 a	2760 a
	101,000	2000 a	1910 a	2480 ab	2480 abc
	124,000	1500 a	1420 a	2700 a	2620 ab
76-cm	54,000	1510 a	1620 a	2130 bc	2230 bcd
	78,000	1570 a	1600 a	2100 bc	2040 cd
	101,000	1970 a	1900 a	1880 c	1910 cd
	124,000	1620 a	1570 a	1810 c	1860 d

[a] Means within column followed by the same lowercase letter are not different according to Fisher's Protected LSD at the $p = 0.05$ significance level.
[b] Gross margins were calculated using a base price ($44/Mg) adjusted for quality (RWSMg of each plot compared with the overall average RWSMg).
[c] Gross margins were calculated using a constant base price of $44/Mg.

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CHAPTER 5

GLYPHOSATE AND TRIFLUSULFURON COMBINATIONS FOR CONTROL OF VELVETLEAF, POWELL AMARANTH, AND COMMON LAMBSQUARTERS

Abstract: Combinations of other herbicides with glyphosate may be necessary for satisfactory weed control in glyphosate-resistant sugarbeet. Greenhouse experiments were conducted to characterize the response of 5- and 10-cm tall velvetleaf, Powell amaranth, and common lambsquarters to triflusulfuron and combinations of glyphosate and triflusulfuron. Combinations were labeled as synergistic, antagonistic, or additive for weed control and dry weight reduction. Triflusulfuron alone did not successfully control any of the weed species at either application timing. Combinations of glyphosate at 210 g ae/ha with triflusulfuron at 17.6 and 35.0 g ai/ha were synergistic for control and biomass reduction of 10-cm tall velvetleaf; however, none of these synergistic interactions provided greater control than glyphosate alone at the label recommended rate of 840 g/ha. Tank-mixtures of glyphosate at 105 g/ha with triflusulfuron at 4.4 g/ha and glyphosate at 210 g/ha with triflusulfuron at 17.6 g/ha were synergistic for Powell amaranth control. All combinations of glyphosate and triflusulfuron were additive for control of common lambsquarters. Tank-mixtures were predominantly additive for dry weight reduction of velvetleaf, Powell amaranth, and common lambsquarters. Combinations of triflusulfuron with glyphosate applied to 5- and 10-cm weeds does not improve weed control beyond using glyphosate alone at 840 g/ha.

Nomenclature: Glyphosate; triflusulfuron; common lambsquarters, *Chenopodium album* L. CHEAL; Powell amaranth, *Amaranthus powellii* S. Watson AMAPO; velvetleaf, *Abutilon theophrasti* Medik. ABUTH; sugarbeet, *Beta vulgaris* L.

Key words: Glyphosate-resistant, herbicide interaction.

INTRODUCTION

The commercial release of glyphosate-resistant sugarbeet in 2008 has given growers the opportunity to achieve excellent weed control of many weed species common to sugarbeet production with fewer herbicides and applications (Guza et al. 2002; Kniss et al. 2004), while eliminating the potential for crop injury (Wilson et al. 2002). In previous studies, glyphosate has provided excellent control of many weed species with two or three glyphosate applications (Guza et al. 2002; Wilson et al. 2002). Additionally, time between herbicide applications may be longer with glyphosate-resistant sugarbeet compared with conventional sugarbeet herbicide programs, as weed height at the time of application is generally not as limiting with glyphosate.

Glyphosate provides excellent control of many weed species over many growth stages. However, velvetleaf (*Abutilon theophrasti* Medik.) and common lambsquarters (*Chenopodium album* L.) have exhibited some tolerance to glyphosate (Krausz et al. 1996; Young et al. 2001). Furthermore, several weeds common in sugarbeet producing regions of the United States, including common waterhemp (*Amaranthus rudis* L.), common ragweed (*Ambrosia artemisiifolia* L.), and giant ragweed (*Ambrosia trifida* L.), have been confirmed to be resistant to glyphosate (Heap 2009). Triflusulfuron, an acetolactate synthase (ALS) inhibiting herbicide for postemergence broadleaf and grass control in sugarbeet, has been shown to provide good to excellent control of velvetleaf, depending on size (Starke et al. 1996), and some suppression of common lambsquarters and redroot pigweed (*Amaranthus retroflexus* L.), with minimal crop injury (Morishita and Downard 1995). Previous research has shown additive and antagonistic effects for mixtures of glyphosate and other ALS-inhibiting herbicides for control of 6-leaf common lambsquarters (glyphosate + thifensulfuron) and 4-leaf velvetleaf (glyphosate + imazethapyr and glyphosate + thifensulfuron), respectively (Lich et al. 1997). Starke and Oliver (1998) also observed antagonistic interactions for combinations of glyphosate with chlorimuron for control of 18-cm tall velvetleaf. Combining an additional herbicide mode of action with glyphosate will give sugarbeet growers more options for controlling weeds that may be more tolerant to glyphosate. Reports from the Red River Valley region have suggested that tank-mixes of glyphosate and triflusulfuron may improve control of common lambsquarters in glyphosate-resistant sugarbeet. However, these reports have not been verified. The objectives of this study were to 1) evaluate triflusulfuron for control of three broadleaf weed species if it is applied at weed heights optimal for glyphosate application and 2) determine if combinations of triflusulfuron with glyphosate would improve weed control beyond using glyphosate alone.

MATERIALS AND METHODS

Velvetleaf, Powell amaranth (*Amaranthus powellii* S. Watson), and common lambsquarters, three weeds frequently found in Michigan sugarbeet production fields, were grown in 10 cm by 10 cm plastic pots filled with a commercial greenhouse potting mix[1]. Velvetleaf, Powell amaranth, and common lambsquarters were planted one plant per pot Greenhouse temperature was maintained at 25 ± 5 C with a 16-h photoperiod of natural sunlight supplemented with lighting to provide 1,000 μmol/m^2/s photosynthetic photon flux. Pots were watered daily to maintain adequate soil conditions for plant growth. Plants were fertilized with 50 ml of fertilizer solution containing 7 mg/L of 20% nitrogen, 20% P_2O_5, and 20% K_2O as needed.

Trials were set up as a two-factor randomized complete block design with four replications. Each trial was repeated twice. Factors were glyphosate[2] rate (0, 105, 210, 420, and 840 g ae/ha) and triflusulfuron[3] rate (0, 4.4, 8.8, 17.6, and 35.0 g ai/ha), representing 0x, 0.125x, 0.25x, 0.5x, and 1x of the label-recommended rate (Anonymous 2001; Anonymous 2007). A nonionic surfactant (NIS)[5] was included at 0.25% v/v in treatments containing only triflusulfuron. Ammonium sulfate was included at 2% v/v in all treatments containing glyphosate. Herbicide applications were made when weeds were 5 or 10 cm in height to determine the effect of weed size on control with the herbicide combinations. Applications were made using a single-nozzle track sprayer with an 8001 even flat fan nozzle[4] calibrated to deliver 187 L/ha at a pressure of 234 kPa and a speed of 1.6 km/hr. Visual estimates of weed control were taken 14 days after treatment (DAT) on a scale of 0% (no control) to 100% (complete control) based on injury. Plant height data were collected and above ground biomass was harvested 14 DAT. Plant samples were oven-dried at 60 C for 3 d and weights were recorded.

Herbicide combinations were determined to be synergistic, antagonistic, or additive by comparing the observed plant response with the expected plant response. The expected plant response was calculated using the equation $E = X + Y - XY/100$, developed by Colby (1967). In this equation, X and Y is the percent growth inhibition by herbicides A and B, respectively, and E is the expected percent growth inhibition by herbicides A and B. All treated plants were compared to a nontreated control. Data were subjected to ANOVA and analyzed using PROC MIXED in SAS 9.1[6]. Expected and observed plant response values were compared using the least significant difference (LSD) at $p = 0.05$ significance level. Herbicide combinations were labeled as synergistic, antagonistic, or additive if the observed response was greater than, less than, or similar to the expected response, respectively.

RESULTS AND DISCUSSION

Velvetleaf. Triflusulfuron alone provided a maximum of 28% control and 42% dry weight reduction of 5-cm tall velvetleaf (Table 20). Synergistic interactions were observed for velvetleaf control with several combinations with glyphosate at 210 and 420 g/ha (Table 21). However, the 840 g/ha rate of glyphosate provided 89% control and none of the combinations with triflusulfuron provided greater control than glyphosate alone. All herbicide combinations at the 5-cm weed height application timing were additive for biomass reduction. Triflusulfuron alone was also not effective at controlling 10 cm tall velvetleaf (Table 22). Most combinations of triflusulfuron and glyphosate were additive (Table 23). Synergistic activity was observed for control of velvetleaf for combinations of triflusulfuron at 17.6 and 35 g/ha with glyphosate at 105 and 210 g/ha. The only herbicide combination that resulted in a synergistic response for biomass reduction in 10 cm tall velvetleaf was triflusulfuron at 35 g/ha and glyphosate at 105 g/ha. At 10-cm weed height application timing, none of the herbicide combinations provided greater control than glyphosate alone.

Previous research has investigated velvetleaf control with triflusulfuron at the cotyledon, first-leaf, and second-leaf growth stage, with the greatest control observed when triflusulfuron was applied to velvetleaf at the cotyledon growth stage (Starke et al. 1996). In this study, triflusulfuron did not provide satisfactory control of 5- or 10-cm tall velvetleaf. However, synergistic interactions with glyphosate at sub-lethal rates indicate that it may be a useful tank-mix partner if applied to weeds less than 5-cm in height, should velvetleaf develop increased tolerance to glyphosate.

Powell amaranth. At the 5-cm application timing, Powell amaranth was the most susceptible weed species to glyphosate and glyphosate alone at 210 g/ha provided 82% control (Table 20). Triflusulfuron alone provided a maximum of 14% control and 30% dry weight reduction of 5-cm Powell amaranth. All herbicide combinations were additive for control of Powell amaranth at the 5-cm weed height application timing. Combinations of glyphosate at 105 g/ha and triflusulfuron at 4.4 and 8.8 g/ha were antagonistic for dry weight reduction (Table 21). All other combinations were additive for dry weight reduction. Powell amaranth the most susceptible weed species to glyphosate at the 10-cm weed height application timing, with 93% control at the 840 g/ha rate (Table 22). At the 10-cm application timing, triflusulfuron provided a maximum of 15% control and 16% dry weight reduction. Synergistic interactions for control were observed with combinations of glyphosate at 105 g/ha with triflusulfuron at 4.4 g/ha and glyphosate at 210 g/ha with triflusulfuron at 17.6 g/ha. For dry weight reduction, an antagonistic interaction was observed with the combination of glyphosate at 105 g/ha with triflusulfuron at 35.0 g/ha; however, a synergistic interaction was observed with glyphosate at 210 g/ha with triflusulfuron at 17.6 g/ha (Table 23).

Common lambsquarters. Triflusulfuron alone did not control 5-cm tall common lambsquarters (Table 20). All herbicide combinations were additive for common lambsquarters control at the 5-cm application timing. The combination of glyphosate at 210 g/ha and triflusulfuron at 17.6 g/ha was antagonistic for dry weight reduction, however all other combinations were additive (Table 21). Triflusulfuron alone provided 6% or less control of 10 cm tall common lambsquarters (Table 22). Glyphosate alone at 840 g/ha provided 68% control (Table 22) and 77% reduction in dry weight (Table 23), and all combinations with triflusulfuron were additive for control and dry weight reduction. Similar to velvetleaf and Powell amaranth, none of the herbicide combinations provided better common lambsquarters control than glyphosate alone.

Results from this study show that triflusulfuron was not effective at control 5- or 10-cm tall velvetleaf, Powell amaranth, or common lambsquarters. Some combinations of triflusulfuron and glyphosate at various rates were synergistic for control of velvetleaf and Powell amaranth. However, none of these synergistic interactions provided greater control of 5- and 10-cm tall weeds than glyphosate alone at 840 g/ha. Based on current university and industry recommendations to apply glyphosate for weed control in glyphosate-resistant sugarbeet at minimum rate of 840 g/ha, these results confirm that tank-mixing triflusulfuron with glyphosate does not improve weed control beyond using glyphosate alone. Should any of the broadleaf weed species evaluated in this study develop glyphosate-resistance, triflusulfuron would need to be applied when weeds are less than 5-cm tall, as it will not provide adequate weed control of 5- or 10-cm tall weeds. Furthermore, because several weed species have exhibited multiple resistance to both ALS-inhibiting herbicides and glyphosate (Heap 2009), combinations of glyphosate with herbicides of other modes of action should also be evaluated for improved control of glyphosate- resistant weeds.

SOURCES OF MATERIALS

[1] Baccto Professional Potting Mix, Michigan Peat Company, P.O. Box 980129, Houston, TX 77098.

[2] Roundup WeatherMAX, Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167.

[3] UpBeet, E. I. du Pont de Nemours and Co., Crop Protection, Wilmington, DE 19898.

[4] Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60187.

[5] Activator 90, Loveland Products, P.O. Box 1286, Greely, CO, 80632.

[6] The SAS System for Windows, Version 9.1, SAS Institute Inc., 100 SAS Campus Dr., Cary, NC 27513.

Table 20. Visual estimates of weed control compared to the untreated control 14 days after treatment for combinations of triflusulfuron and glyphosate for velvetleaf, Powell amaranth, and common lambsquarters 5-cm tall at time of application.[a]

Herbicide rate		Control					
		ABUTH[b]		AMAPO		CHEAL	
Glyphosate[c]	Triflusulfuron[d]	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
g ae/ha	g ai/ha	%					
0	0	—	0	—	0	—	0
0	4.4	—	3	—	3	—	10
0	8.8	—	6	—	11	—	21
0	17.6	—	13	—	14	—	13
0	35.0	—	28	—	13	—	11
105	0	—	45	—	59	—	9
105	4.4	46	50	64	53	11	29
105	8.8	47	55	68	54	18	23
105	17.6	52	66 (+)	65	56	22	21
105	35.0	59	65	63	68	21	22
210	0	—	43	—	82	—	46
210	4.4	44	62 (+)	84	72	47	50
210	8.8	46	57 (+)	87	69	51	54
210	17.6	50	70 (+)	85	80	54	40
210	35.0	58	74 (+)	84	67	52	44
420	0	—	64	—	86	—	85
420	4.4	66	82 (+)	88	92	85	75
420	8.8	66	85 (+)	89	89	86	77
420	17.6	69	82 (+)	88	95	87	79
420	35.0	74	80	87	92	87	81
840	0	—	89	—	99	—	96
840	4.4	90	91	99	99	96	94
840	8.8	90	89	99	98	97	95
840	17.6	91	94	99	98	97	91
840	35.0	92	97	99	97	97	96
LSD (0.05)[e]		—	9	—	18	—	14

[a] + and – denote a synergistic and antagonistic interactions for a given combination of triflusulfuron and glyphosate according to the LSD comparison of the observed and expected values calculated using Colby's method. Observed values without a + or – are additive.

[b] Abbreviations: ABUTH, velvetleaf; AMAPO, Powell amaranth; CHEAL, common lambsquarters; Exp., expected; Obs., observed.

[c] Treatments containing glyphosate also included ammonium sulfate at 2% v/v.

[d] Treatments containing only triflusulfuron also included nonionic surfactant at 0.25% v/v.

[e] LSD values may be used to compare observed values.

Table 21. Dry weight reduction compared to the untreated control 14 days after treatment for combinations of triflusulfuron and glyphosate for velvetleaf, Powell amaranth, and common lambsquarters 5-cm tall at time of application.[a]

Herbicide rate		Dry weight					
		ABUTH[b]		AMAPO		CHEAL	
Glyphosate[c]	Triflusulfuron[d]	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
g ae/ha	g ai/ha	% reduction					
0	0	—	0	—	0	—	0
0	4.4	—	12	—	18	—	26
0	8.8	—	18	—	18	—	17
0	17.6	—	25	—	30	—	22
0	35.0	—	42	—	22	—	24
105	0	—	49	—	69	—	18
105	4.4	54	58	80	63 (–)	31	37
105	8.8	57	56	75	60 (–)	31	24
105	17.6	61	70	77	66	40	35
105	35.0	70	70	77	79	34	36
210	0	—	47	—	77	—	65
210	4.4	54	66	84	80	71	72
210	8.8	57	65	82	74	72	72
210	17.6	60	72	84	86	78	57 (–)
210	35.0	70	76	82	78	73	61
420	0	—	68	—	92	—	89
420	4.4	73	81	95	93	91	85
420	8.8	75	82	94	90	91	86
420	17.6	76	81	94	92	93	86
420	35.0	82	82	94	92	92	86
840	0	—	83	—	96	—	95
840	4.4	85	87	97	95	96	82
840	8.8	86	84	97	96	96	94
840	17.6	87	87	97	94	96	82
840	35.0	90	90	97	95	96	93
LSD (0.05)[e]		—	10	—	14	—	16

[a] + and – denote a synergistic and antagonistic interactions for a given combination of triflusulfuron and glyphosate according to the LSD comparison of the observed and expected values calculated using Colby's method. Observed values without a + or – are additive.

[b] Abbreviations: ABUTH, velvetleaf; AMAPO, Powell amaranth; CHEAL, common lambsquarters; Exp., expected; Obs., observed.

[c] Treatments containing glyphosate also included ammonium sulfate at 2% v/v.

[d] Treatments containing only triflusulfuron also included nonionic surfactant at 0.25% v/v.

[e] LSD values may be used to compare observed values.

Table 22. Visual estimates of weed control compared to the untreated control 14 days after treatment for combinations of triflusulfuron and glyphosate for velvetleaf, Powell amaranth, and common lambsquarters 10-cm tall at time of application.[a]

Herbicide rate		Control					
		ABUTH[b]		AMAPO		CHEAL	
Glyphosate[c]	Triflusulfuron[d]	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
g ae/ha	g ai/ha	%					
0	0	—	0	—	0	—	0
0	4.4	—	1	—	6	—	3
0	8.8	—	1	—	9	—	1
0	17.6	—	4	—	12	—	5
0	35.0	—	9	—	15	—	6
105	0	—	31	—	30	—	3
105	4.4	31	28	33	53 (+)	6	7
105	8.8	32	28	36	50	4	11
105	17.6	34	47 (+)	38	45	8	12
105	35.0	37	50 (+)	40	46	9	9
210	0	—	25	—	59	—	6
210	4.4	26	33	61	68	9	13
210	8.8	26	27	61	69	8	8
210	17.6	29	43 (+)	64	85 (+)	11	7
210	35.0	32	53 (+)	64	72	12	8
420	0	—	51	—	70	—	53
420	4.4	52	53	72	72	55	52
420	8.8	52	45	71	71	54	61
420	17.6	54	50	73	87	55	61
420	35.0	56	58	73	77	56	56
840	0	—	69	—	93	—	68
840	4.4	70	65	94	99	68	72
840	8.8	70	66	93	99	69	79
840	17.6	71	74	94	99	69	77
840	35.0	73	80	93	97	69	76
LSD (0.05)[e]		—	12	—	16	—	13

[a] + and – denote a synergistic and antagonistic interactions for a given combination of triflusulfuron and glyphosate according to the LSD comparison of the observed and expected values calculated using Colby's method. Observed values without a + or – are additive.

[b] Abbreviations: ABUTH, velvetleaf; AMAPO, Powell amaranth; CHEAL, common lambsquarters; Exp., expected; Obs., observed.

[c] Treatments containing glyphosate also included ammonium sulfate at 2% v/v.

[d] Treatments containing only triflusulfuron also included nonionic surfactant at 0.25% v/v.

[e] LSD values may be used to compare observed values.

Table 23. Dry weight reduction compared to the untreated control 14 days after treatment for combinations of triflusulfuron and glyphosate for velvetleaf, Powell amaranth, and common lambsquarters 10-cm tall at time of application.[a]

Herbicide rate		Dry weight					
		ABUTH[b]		AMAPO		CHEAL	
Glyphosate[c]	Triflusulfuron[d]	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
g ae/ha	g ai/ha	% reduction					
0	0	—	0	—	0	—	0
0	4.4	—	1	—	13	—	16
0	8.8	—	0	—	9	—	12
0	17.6	—	3	—	8	—	10
0	35.0	—	0	—	16	—	15
105	0	—	13	—	45	—	12
105	4.4	14	16	51	45	24	16
105	8.8	13	5	49	43	22	21
105	17.6	16	18	49	39	20	20
105	35.0	13	33 (+)	51	39 (–)	23	17
210	0	—	13	—	53	—	15
210	4.4	15	15	57	62	26	26
210	8.8	14	11	55	69	25	15
210	17.6	17	19	55	78 (+)	23	9
210	35.0	14	21	56	70	26	16
420	0	—	30	—	64	—	59
420	4.4	31	22	67	77	62	66
420	8.8	30	17	66	70	63	68
420	17.6	33	24	66	76	62	69
420	35.0	30	33	67	71	62	60
840	0	—	42	—	81	—	77
840	4.4	43	46	82	82	79	78
840	8.8	42	36	82	81	79	85
840	17.6	45	43	81	85	78	83
840	35.0	42	52	82	84	79	77
LSD (0.05)[e]		—	15	—	12	—	14

[a] + and – denote a synergistic and antagonistic interactions for a given combination of triflusulfuron and glyphosate according to the LSD comparison of the observed and expected values calculated using Colby's method. Observed values without a + or – are additive.

[b] Abbreviations: ABUTH, velvetleaf; AMAPO, Powell amaranth; CHEAL, common lambsquarters; Exp., expected; Obs., observed.

[c] Treatments containing glyphosate also included ammonium sulfate at 2% v/v.

[d] Treatments containing only triflusulfuron also included nonionic surfactant at 0.25% v/v.

[e] LSD values may be used to compare observed values.

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