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WEED CONTROL SYSTEMS IN SUGARBEET (*Beta vulgaris*): TIMING OF POST MICRO-RATE HERBICIDES USING GROWING DEGREE DAYS, AND VARIETY RESPONSE TO POST HERBICIDES

presented by

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Trevor M. Dale

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ABSTRACT

WEED CONTROL SYSTEMS IN SUGARBEET (*Beta vulgaris*): TIMING OF POST MICRO-RATE HERBICIDES USING GROWING DEGREE DAYS, AND VARIETY RESPONSE TO POST HERBICIDES

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Field and growth chamber studies were conducted to determine if sequential micro-rate herbicide treatments based on growing degree days (GDD) controlled weeds in sugarbeet. The micro-rate treatment (desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha, plus clopyralid at 0.023 kg ae/ha, plus methylated seed oil at 1.5% v/v) was applied three times, spaced every 97, 125, or 152 GDD with a base temperature of 1.1 C. In the growth chamber, common lambsquarters and redroot pigweed control was excellent when the micro-rate treatment was applied every 97 and 125 GDD; however, when the micro-rate treatment was applied every 152 GDD, redroot pigweed control decreased by 37%. In the field, common lambsquarters control was excellent with all GDD treatments in 2001 and 2002. *Amaranthus* spp. control was greater when micro-rates were applied every 7 d, every new leaf pair, or every 97 GDD compared to micro-rates applied every 152 GDD or when scouted (applications based on weed size) in 2001; however, control in all treatments was greater than 90%. In 2002, *Amaranthus* spp. control was 86% when the micro-rate was applied at the 7 d spacing and 80% when applied at the 152 GDD spacing. By applying the micro-rate treatment using GDD instead of every 7 d, two or three micro-rate applications could be eliminated while maintaining sucrose yields similar to, or greater, than with the 7 d spacing. Small plot trials and strip trials in grower fields determined if the micro-rate provided similar control to the same herbicide treatment applied twice at a higher rate (desmedipham plus phenmedipham at 0.56 kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 kg/ha, or desmedipham plus phenmedipham plus

ethofumesate at 0.28 kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 kg/ha), and if preemergence (PRE) herbicides were required with the micro-rate or standard-split applications. Common lambsquarters control was greatest with four micro-rate applications of desmedipham plus phenmedipham plus ethofumesate compared to four micro-rate applications of desmedipham plus phenmedipham when combined over all PRE treatments. When no PRE herbicides were applied, desmedipham plus phenmedipham plus ethofumesate applied in four micro-rate or two standard-split applications provided greater control of common lambsquarters than desmedipham plus phenmedipham applied as a micro-rate or a standard-split application. *Amaranthus* spp. control was excellent ranging from 96 to 100% with all postemergence (POST) herbicide treatments, and greater than 97% when combined over PRE herbicide treatments in 2002. Field and growth chamber studies were conducted to determine the response of several sugarbeet varieties and lines to micro-rate herbicide treatments. In the growth chamber, three micro-rate treatments spaced every 7 d reduced the leaf area of the fourteen sugarbeet varieties by 3 to 35%, and leaf dry weight by 11 to 59% when measured 7 d after the last herbicide application. The herbicides in the micro-rate reduced the leaf area of the USDA lines by 20 to 29% and leaf dry weights by 47 to 53%. The commercial variety Hilleshog E-17 and the USDA population 576 were the most tolerant to micro-rate herbicide treatments with a 3 and 20% reduction in leaf area, and 19 and 47% reduction in dry weight, respectively, compared to the untreated controls. In the field, three micro-rate herbicide treatments spaced every 7 d reduced the leaf area of the fourteen sugarbeet varieties by 3 to 40%, and leaf dry weights by 2 to 44% compared to the untreated controls. The two commercial varieties ACH 913 and ACH 1353 were the most tolerant to micro-rate herbicide treatments.

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CHAPTER 1

REVIEW OF LITERATURE

INTRODUCTION

Sugarbeet (*Beta vulgaris* L.) and sugarcane (*Saccharum* spp.) are the two major sources of sucrose production in the United States. Sugarbeet is grown in temperate regions of the United States and sugarcane is grown in tropical and subtropical regions. The first sugarbeet processing factory in the United States was built in 1838 in Northhampton, MA (Cooke and Scott 1993a). Sugarbeet is a biennial and is a member of the *Chenopodiaceae* family. Most of the sugarbeet grown in the United States is for sucrose and is harvested prior to the reproductive growth stage, except for a limited area in Oregon and Utah where seed is produced (Cooke and Scott 1993b). Sugarbeet was grown on 665,354 hectares in the United States in 2002 (Anonymous 2003a). In 2002, 63,482 tons of sucrose was produced in the United States, and beet sugar accounted for 43% of the total production. The sucrose from the sugarbeet crop contributed over one billion dollars to the United States economy in 2001 (Anonymous 2003b).

In the United States, there are five major regions where sugarbeet is grown. These regions include the Red River Valley of Minnesota and North Dakota, the Great Lakes region of Michigan, Ohio, and Ontario, the Northwest including Idaho and Oregon, the Intermountain region including Colorado, Nebraska, and Wyoming, Montana, and the Western region including California (Cooke and Scott 1993c). This wide range in growing regions provides some universal and some specific production problems within each region. Most of the sugarbeet grown in the Intermountain region, Northwest region, and California is irrigated; however, most of the sugarbeet grown in the Red River Valley region and the Great Lakes region is not irrigated. In California, sugarbeet is planted in the late fall and is harvested nearly 12 months later, whereas all other sugarbeet is planted in the spring and harvested in the fall of the same year. One of the major limitations of sugarbeet production is the inability to process sucrose from the sugarbeet rapidly without loosing significant amounts of sucrose to respiration in storage (Anonymous 1998). This is a major advantage to the Northern climate of the Red River Valley where sugarbeet can be frozen and stored which extends the processing of sugarbeet into May.

WEED COMPETITION IN SUGARBEET

Sugarbeet is often the most important cash crop in the rotation, and is typically followed by a cereal crop like wheat or corn. Although sugarbeet growers face many challenges, weed control continues to be the most serious production problem (Luecke and Dexter 2003a), and weeds occur in all sugarbeet production areas (Schweizer and Dexter 1987). Competition from uncontrolled annual weeds can suppress sugarbeet so severely that no crop is produced (Schweizer and Dexter 1987). Sugarbeet is a low growing crop and many weeds grow taller than sugarbeet. Weeds that become taller will be more competitive for light interception than those weeds that do not overtop the crop. Crop loss due to competition is only one of the problems that weeds may cause. Weeds may also cause harvest problems, reduce the quality of the harvested product, produce seed that increases future weed problems, act as co-hosts for insects and diseases, increase tillage needed for weed control, and reduce animal and human health (Dexter 2003).

Weeds that emerge soon after planting sugarbeet are more competitive than late emerging weeds (Dawson 1965). Approximately 70% of the weeds found in sugarbeet crops are broadleaves and 30% are grasses (Cooke and Scott 1993). Broadleaf weeds generally are considered more competitive than grasses (Brimhall et al. 1965). For example, one green foxtail plant per sugarbeet plant reduced yield by 26% in Wyoming, compared to 70% for one redroot pigweed (*Amaranthus retroflexus* L.) plant (Brimhall et al. 1965). In Washington, uncontrolled barnyardgrass reduced yields by 49%, compared with 94% for common lambsquarters (Dawson 1965). In Nebraska, weeds that emerged with sugarbeet and grew the entire season reduced root yield 90% (Wicks and Wilson 1983). Dawson (1965) found sugarbeet growing in Washington State needed a 12-week, weed-free period to produce optimum yields.

Although growers spend significant time and money to control weeds, 1 to 5% of the total annual weed population usually escapes control and competes with the crop (Schweizer and Dexter 1987). Even low densities of tall, broadleaf weeds can reduce root yields. For example, in Wyoming, eight redroot pigweed plants/30 m of row reduced yields 16% (Brimhall 1965). In Colorado, yields were decreased when one common sunflower (Schweizer and Bridge 1982), four kochia (Schweizer 1973), four to six common lambsquarters (Schweizer 1983), or nine to eleven Powell amaranth (Schweizer and Lauridson 1985) plants/30 m of row competed all season. In Minnesota, a density of one redroot pigweed plant plus one wild oat plant/m of row reduced yields by 24% (Dexter and Evans 1985).

HISTORY OF HERBICIDE USE IN SUGARBEET

In the 1940s, weeds were controlled in sugarbeet primarily with mechanical implements, such as cultivators, rotary hoes, and tine weeders, and by cross cultivation, short-handled hoes, and hand weeding by "stoop" labor (Schweizer and Dexter 1987). Hand labor was required because sugarbeet seed was multigerm so thinning and weed control occurred simultaneously. Chemical weed control, if used, was confined to inorganic chemicals, such as sodium and potassium chloride which were applied at rates of 225 to 450 kg/ha (Grigsby and Stahler 1950). In the late 1940s, researchers began to evaluate organic chemicals, such as propham, sodium TCA, and endothall (Cormany and Eckroth 1952). In the early 1950s, preemergence (PRE) mixtures of TCA plus endothall were used extensively to control grasses and broadleaf weeds (Cormany 1954). Annual grasses were controlled effectively for the first time with dalapon (Warren 1954). In the 1950s, EPTC and pebulate were developed as preplant soil incorporated treatments and used principally in the semiarid regions of the United States (Bandeen et al. 1959, Anderson and Jones 1963). In the 1960s, diallate and mixtures of diallate plus pebulate were used to control wild oats (Sullivan et al. 1963), and trifluralin, EPTC, chlorpropham, and propham were developed for use as layby treatments. Also in the 1960s, researchers evaluated pyrazon, cycloate, desmedipham, and phenmedipham; herbicides still used today. Clopyralid was discovered in 1961, but was not marketed in the United States until 1987 and was registered for use in sugarbeets in 1988 (Vencill 2002).

Since the 1960s, there have been very few registrations of herbicides in sugarbeet. The most recent herbicide registrations were sethoxydim and clopyralid in the 1980s, and clethodim, quizalofop, and triflusulfuron in the 1990s. Sethoxydim, clethodim, and quizalofop effectively control annual and perennial grass weeds postemergence (Vencill 2002). Both clopyralid and triflusulfuron are very effective broadleaf herbicides with very different weed spectrums and modes of action. Clopyralid is the only growth regulator herbicide and triflusulfuron is the only acetolactase synthase (ALS) inhibiting herbicide for selectively controlling weeds in sugarbeet. Triflusulfuron controls kochia (not ALS resistant) and velvetleaf (Dexter et al. 2001; Starke and Renner 1996), and clopyralid controls several thistle species, common ragweed, and common cocklebur very well (Vencill 2002). These weed species are very competitive and were very difficult to control with other registered herbicides. Since the 1960s, registration of propham, sodium TCA, endothall, dalapon, pebulate, diallate, trifluralin, and chlorpropham have been discontinued in sugarbeet.

Preemergence herbicide use has decreased significantly since the registration of clopyralid and triflusulfuron, two very effective postemergence (POST) herbicides. Luecke and Dexter (2002b) reported that PRE herbicide use has steadily declined from 96% of the sugarbeet hectares in 1984 to 4% in 2002. The option of greater POST weed control with clopyralid and triflusulfuron has given growers the option of not using PRE herbicides which are very expensive, and often provide only sporadic weed control, depending upon environmental conditions and soil types (Renner and Powell 1991; Hendrick et al. 1974). However, Michigan sugarbeet growers still applied PRE herbicides on approximately 75% of the sugarbeet ha in 2001 and 60% in 2002[1]. Due to the great expense, the PRE herbicides are applied in a band over the crop row and then growers depend on POST herbicides and/or between-row cultivation for weed control.

HISTORY OF HERBICIDE RATE REDUCTION IN SUGARBEET

Research on the use of reduced-rate, split-applications of phenmedipham began in 1972 (Dexter 1994). In a typical experiment at one location, split applications (50% of the standard use rate applied twice, seven to fourteen d apart) gave less sugarbeet injury and superior weed control compared with a single full-rate application. Desmedipham applied at 0.28 kg/ha followed by (fb) 0.28 kg/ha 7 to 14 d later, controlled weeds better and tended to injure sugarbeet less than desmedipham at 1.12 kg/ha or split applications of 0.56/0.56 kg/ha. The selectivity of desmedipham and phenmedipham is based on the rate of metabolism in the sugarbeet and weeds. Sugarbeet metabolized 83 and 94% of the translocated phenmedipham and

[1] Renner, K. A. Annual sugarbeet grower survey 2002.

desmedipham, respectively, in 24 h (Hendrick et al. 1974). However, desmedipham metabolism by wild mustard and redroot pigweed was significantly less. This difference in the rate of metabolism is at least partially responsible for the greater weed control and reduction in sugarbeet injury when using reduced-rate, split or multiple applications. Split applications at reduced herbicide rates were widely used by 1980, and were the primary POST weed control option until 1998 when the micro-rate was registered. However, when growers use split-rates, treatments still have to be applied in the evening hours to avoid excessive injury to sugarbeet.

In 1996, Warner (Warner 1996) discovered a synergism among desmedipham, triflusulfuron, and clopyralid. The significant rate reductions of 65 to 75%, with the addition of a methylated seed oil (MSO), resulted in weed control similar to that achieved by standard rates. Further research with this combination resulted in the micro-rate, currently used on a majority of the sugarbeet hectares grown in the United States since 1998. The micro-rate system utilizes a combination of desmedipham, or desmedipham plus phenmedipham (1:1), or desmedipham plus phenmedipham plus ethofumesate (1:1:1) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.03 kg ae/ha plus MSO at 1.5% v/v applied multiple times. The micro-rate was registered in Minnesota and North Dakota in 1998, and Michigan, Nebraska, Wyoming, Montana, and Idaho in 2000. In 2002, nearly all sugarbeet grown in the United States was treated with reduced herbicide rates at least two times and many sugarbeet ha were treated three to five times. Advantages of the micro-rate include the ability to apply herbicides throughout the day, reduced sugarbeet injury, reduced between-row cultivation, and reduced herbicide use. However, application timing with respect to weed size becomes more critical with the micro-rate compared to the standard rate, and typically four micro-rate applications are required for complete weed control compared to two to three applications with standard-rate applications.

CURRENT AND PREVIOUS WEED CONTROL STRATEGIES IN SUGARBEET

Weed control in sugarbeet involves herbicides, cultivation, and hand labor. In recent years, the use of herbicides has increased while cultivation and hand labor has decreased. In a recent survey growers in eastern North Dakota and western Minnesota indicated that sugarbeets were treated with herbicides 4.3 times in 2002, compared to 3.2 times in 1990 (Luecke and Dexter 2003b). This suggests that the implementation of the micro-rate increased the total applications by one compared to the traditional standard-split, because the standard-split was usually preceded by a PRE treatment. Survey respondents reported the number of hand weeded ha had declined from 72% in 1995 to 32% in 2002. In addition to the decrease in hand weeded ha, the number of cultivations also decreased from 3.2 times in 1992 to 1.9 times in 2002.

Similar trends are occurring in Michigan as the use of PRE herbicides has decreased by 35% from 1998 to 2002, and the number of cultivations has declined to two or fewer on 65% of the sugarbeet during the same time period[1]. A typical weed control program prior to the registration of the micro-rate involved a PRE herbicide followed by 1 or 2 standard split POST treatments and 3 or 4 between-row cultivations. In 2002, most sugarbeet growers broadcast applied the micro-rate three- to- five times, did not use a PRE herbicide, and limited cultivation to one or two times.

POSTEMERGENCE HERBICIDE APPLICATION TIMINGS IN SUGARBEET

Herbicide rates have been reduced and split-applied since the early 1970s (Dexter 1994). This split-application has typically included a herbicide application at the cotyledon to two-leaf growth stage with subsequent applications occurring every 7-d after the initial treatment (Starke and Renner 1996, Morishita and Downward 1995, and Miller et al. 1997). However, researchers have also reported applying follow-up treatments based on "leaf-pair". This would typically include applying the first POST application at the cotyledon to two-leaf stage and follow-up treatments at the four-leaf and six-leaf stages depending on the number of applications (Wilson 1994, Wilson 1999, and Wilson et al. 2002). Both application methods can be difficult to manage. Growers following the 7-day schedule reduced the number of days between applications if rain or wind was predicted for the 7^{th} day. Timing herbicide applications based on leaf-pair is very difficult because there is so much variability in sugarbeet emergence in most field conditions. It is not uncommon to have sugarbeet ranging from cotyledon to six true leaves in the same field. In addition, sugarbeet leaves are not opposite so they do not appear in true pairs. Therefore, it is very difficult to differentiate between two, three, or even four leaf sugarbeet. Furthermore, new leaves develop rapidly with each new leaf requiring somewhat fewer GDD than the preceding one (Holen and Dexter 1996).

Split applications of herbicides and applying by calendar days or sugarbeet leaf-pairs is more effective than single applications, but may be subject to weather conditions and the judgment of the person scouting the field in their determining of a "new" leaf-pair. The average daily temperature typically increases significantly from the time of the first application to time of the last herbicide application especially when applying three or four treatments. Depending on environmental conditions the average daily temperature may also decline between applications. Both an increase and a decrease in temperature affects the emergence and growth of weeds and sugarbeet. Cool overcast conditions over extended time periods delays weed emergence and growth. Warm sunny conditions will progress weed and sugarbeet growth. Furthermore, temperature influences weed and crop species differently (Pearcy et al. 1981; Roman et al. 1999). Pearcy et al. (1981) compared the relative growth rate of common lambsquarters a C3 plant, and redroot pigweed at C4 plant at three different temperature regimes. The relative growth rate of common lambsquarters was greater than redroot pigweed when the day/night temperature was 17/14 C, however at 25/18 C the relative growth rate was similar, and at 34/28 C redroot pigweed growth rate was 26% greater than common lambsquarters. Thus, there is a clear shift from a competitive advantage for common lambsquarters at low temperatures to an advantage for redroot pigweed at high temperatures. Roman et al. (1999) also compared the growth rate of common lambsquarters and redroot pigweed at various temperature regimes, and found that both shoot and root growth differed between species depending on temperature, and the two species had different optimum temperatures. Therefore, improper application timings using the 7-d or leaf-pair schedules may result in excessive sugarbeet injury and herbicide use, and inadequate weed control.

THE USE OF GROWING DEGREE DAYS FOR CROP MANAGEMENT DECISIONS

Temperature is considered the primary factor determining the rate at which plants develop although other factors including daylength, moisture and light may modify the effects of temperature on the plant (Holen and Dexter 1996). Growers often use calendar days to predict plant development for management decisions. However, calendar days can be misleading, especially for early season crop growth stages when temperatures may be well below or above the historical average. Growing degree days (GDD) are a measure of the heat accumulation for a given period of time. GDD are able to predict crop and insect development regardless of differences in temperatures from year to year provided other environmental conditions are not limiting. Many different methods can be used to measure GDD, but the most common method by far is the "high/low" method, because the math is very simple. This method subtracts the base temperature from the average daily temperature, which provides the GDD accumulated per day.

The use of GDD using air temperature to predict plant development has been used successfully for various crops (Vinocur and Ritchie 2001, Juskiw et al. 2001) and weeds (Nord et al. 1999, Ball et al. 1995). Vinocur and Ritchie (2001) reported that corn (*Zea mays* L.) development was more accurately predicted if surface soil temperatures were used until the apex is above the soil surface, and air temperatures were used after that point. Juskiw et al. (2001) reported that spring barley (*Hordeum vulgare* L.) development could be predicted using GDD based on air temperature, but plant development from emergence to physiological maturity differed between varieties. Nord et al. (1999) compared the growth of spring wheat (*Triticum aestivum* L.), kochia (*Kochia scoparia* L.), and Russian thistle (*Salsola iberica*) under constant temperatures of 15, 23, and 30 C. Spring wheat development in response to GDD was similar at 15 and 23 C but was delayed at 30 C. The optimum temperature for spring wheat development was 25 C, and the base temperature was 4 C. Their data suggested that temperatures at or below the optimum temperature provided better estimates of development by GDD than temperatures above the optimum growth temperature. Roman et al. (1999) reported the optimum temperature for common lambsquarters (*Chenopodium album* L.) development is 25.2 C, and Oryokot et al. (1997) reported the optimum temperature for redroot pigweed is 32.9 C.

Many researchers have tried to predict weed seed germination and emergence based on soil temperature and soil moisture (Roman et al. 2000, Oryokot et al. 1997, Harvey and Forcella 1993, Forcella 1993). In controlled environments, success in determining the temperature and rate of emergence of many weeds has been achieved. However, this usually determines the time of 50% germination or emergence of the weeds (Oryokot et al. 1997, Harvey and Forcella 1993, Alm et al.1993). In field conditions, when weeds have reached 50% emergence the timing is probably too late for POST weed control in sugarbeet, because a certain percentage of weeds would exceed the size controlled by the herbicides. Roman et al. (2000) stated that the use of soil temperature to calculate GDD was a better predictor of common lambsquarters seedling emergence than air temperatures. However, this was only true at one of the two locations in one of the two years, and only under no-till conditions. The difference in predicting emergence was attributed to increased heterogeneity in the soil matrix and vertical distribution of the seedbank caused by the chisel or moldboard plow (Buhler 1992). Most of the sugarbeet grown in the U.S. is planted in fields that have either been chisel plowed or moldboard plowed the previous fall.

DIFFERENTIAL RESPONSE OF SUGARBEET VARIETIES TO HERBICIDES

The crop response and weed control of many POST herbicides is greatly affected by temperature. In fact, most POST herbicide labels provide a range of temperatures in which the particular herbicide should be applied and what weed control or crop response might be expected outside of that range. Often, lower temperatures of 10 to 15.6 C are associated with very little crop response and poor weed control, whereas higher temperatures of 26.7 to 32.3 C are associated with greater weed control and crop response. Temperatures prior to, or after the herbicide application can also affect the response from the herbicide treatment (Mayo and Dexter 1997).

Previous research with sugarbeet varieties indicated a differential response to herbicides among varieties. Dexter and Kern (1977) reported the presence of cultivar by herbicide interactions when higher than recommended rates of EPTC were applied.

There was no clear distinction between varieties; however, data indicated a slight advantage in extractable sugar with diploid compared to triploid varieties. Smith and Schweizer (1983) reported that all characters including plant weight, harvest root weight, and foliar suppression differed among the eight commercial varieties tested when treated with both preemergence herbicides and postemergence herbicides. The two triploid varieties 'Beta 1237' and 'GW D7' had greater leaf area 45 days after treatment, averaged over 1979 and 1980. In 1999, Wilson reported differences in leaf area, root yield, and percent sucrose among the nine varieties treated with herbicide. In all cases, there were no distinctions between the diploid and triploid varieties. These researchers concluded that varietal response to herbicides may vary by year and location. In addition to environmental conditions, the quality of sugarbeet seed varies greatly from year to year depending on the growing conditions of the seed crop and other factors including the seed coating process, and pesticide treatment of seeds (J. M. McGrath, personal communication). Furthermore, sugarbeet varieties respond differently to other early season stresses like temperature extremes, inadequate or excessive moisture, soil pathogens, and herbicide treatments (personal observation). Therefore, it is often very difficult to compare varieties in the field, because of the other stresses involved and the interaction of these stresses and those added by herbicides. Because seed quality varies significantly, the seed used in these experiments should be from the same seed lot to minimize variability.

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CHAPTER 2

TIMING OF POSTEMERGENCE MICRO-RATE APPLICATIONS BASED ON GROWING DEGREE DAYS IN SUGARBEET (*Beta vulgaris*)

Abstract. Postemergence (POST) herbicides must be applied in sugarbeet when weeds are less than 2.5 cm in height for effective weed control. Weeds continue to emerge during the season so multiple POST applications are usually required. This research was conducted to determine if growing degree days (GDD) could be used to effectively time postemergence herbicide applications. GDD were calculated using the average daily temperature with a base temperature of 1.1 C. Common lambsquarters and redroot pigweed were grown in the growth chamber and treated with three micro-rate herbicide applications spaced every 97, 125, and 152 GDD with a base of 1.1 C. Common lambsquarters was controlled with all treatments, but redroot pigweed control in the 152 GDD (C) timing was reduced compared to the 97 GDD and 125 GDD (C) timings. In field research, the sugarbeet varieties Hilleshog E-17 and Beta 5400 were planted April 3, April 17, and May 3 in 2001 and April 5, April 17, and May 1 in 2002. Micro-rate applications (desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha plus methylated seed oil (MSO) at 1.5% v/v) were applied (a) every 7 d, (b) as needed, (c) every leaf pair (2001 only), (d) every 97 GDD, (e) every 125 GDD (2002 only) and (e) every 152 GDD. All herbicide timings controlled common lambsquarters 92% or greater in both 2001 and 2002. In 2001, *Amaranthus* spp. control was 91% with the 152 GDD timing compared to 97% with the 7 d timing, and in 2002 control ranged from 80% with the 152 GDD timing to 86% with the 7 d timing. Although *Amaranthus* spp. control was somewhat less when the micro-rate treatment was applied on a 152 GDD timing, recoverable sucrose in 2001 was significantly greater with the 152 GDD timing at 7,748 kg/ha compared to 6,691 kg/ha with the 7 d timing. In 2002, recoverable sucrose was significantly greater with the

152 GDD timing at 4,935 kg/ha compared to 4,261 kg/ha with the 7 d timing. When the micro-rate herbicide treatment was applied every 152 GDD, the total number of applications was reduced by two in 2001 and three on 2002 compared to the 7 day or labeled timing for the early and mid-April planting dates. For the early May planting dates, the total micro-rate applications were reduced by two in both 2001 and 2002 with the 152 GDD timing compared to the 7 d timing. Sugarbeet growers are continuously trying to reduce production costs in a competitive market and timing micro-rates by GDD may reduce herbicide input costs.

Nomenclature: desmedipham; phenmedipham; ethofumesate; triflusulfuron; clopyralid; common lambsquarters, *Chenopodium album* L. #[1] CHEAL; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; pigweed species, *Amaranthus retroflexus* and *Amaranthus powellii* S. Wats. # AMASS; sugarbeet, *Beta vulgaris* L. Hilleshog E-17 and Beta 5400.

Abbreviations: GDD, growing degree days, POST, postemergence PRE, preemergence.

[1] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

INTRODUCTION

In the last five years, weed control has changed from conventional preemergence (PRE) and POST herbicides to the use of transgenic crops primarily resistant to glyphosate and glufosinate. The use of non-selective herbicides such as glyphosate or glufosinate provides a greater application window with respect to weed size, because these herbicides can be applied to larger weeds than conventional herbicides and still provide excellent weed control. Glyphosate and glufosinate resistant sugarbeet are currently registered for use, but the sugar companies will not accept genetically modified sugarbeet because of the marketing problems associated with sucrose from genetically modified sugar. Sugarcane growers could have a sugar marketing advantage in the world market because of the European markets unwillingness to accept genetically modified crops.

In contrast to the very effective non-selective herbicides glyphosate and glufosinate, POST sugarbeet herbicides seldom control weeds larger than two-true leaves. Application timing is critical for adequate weed control. The micro-rate (a combination of desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha or desmedipham plus phenmedipham plus ethofumesate (1:1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha plus methylated seed oil (MSO) at 1.5% v/v) is usually applied POST three- to- five times to young actively growing weeds at the cotyledon growth stage. The need for additional treatments is affected by the continuing germination of weed seeds and the level of control achieved by the previous treatment. Weeds not controlled by micro-rate treatments may be controlled with higher herbicide rates applied twice and often referred to as a standard-split, or by hand labor. Growers apply standard-split applications in a band and cultivate between the rows to reduce the cost of these POST herbicides. Also hand labor has become more expensive due to increased government regulations and a decrease in the available work force. Schweizer and Dexter (1987) reported a doubling in hand labor costs from $41/ha in 1970 to $82/ha in 1986. A second weeding cost $26/ha in 1970 versus $54/ha in 1986. Both standard-splits and hand-labor are more costly than broadcast applying the micro-rate four times so many growers try to avoid these practices. Scouting fields for weeds less than 2 cm in size is difficult and time consuming. Therefore growers base POST herbicide applications on calendar days to minimize scouting. The ability to predict the proper timing of herbicide treatments to optimize weed control and minimize sugarbeet injury and herbicide cost would be a major benefit to the sugarbeet grower.

The use of growing degree days (GDD) to predict plant development has been used successfully for various crops (Vinocur and Ritchie 2001, Juskiw et al. 2001) and weeds (Nord et al. 1999, Ball et al. 1995). These GDD systems are based on air temperature. Many researchers have tried to predict weed seed germination and emergence based on soil temperature and soil moisture (Roman et al. 2000, Oryokot et al. 1997, Harvey and Forcella 1993, Forcella 1993). In controlled environments, the temperature and rate of emergence of many weeds has been determined. However, this research predicts the time of 50% germination or weed emergence (Oryokot et al. 1997, Harvey and Forcella 1993, Alm et al.1993). In field conditions, when weeds have reached 50% emergence the timing is probably too late for the micro-rate, because a certain percentage of the weeds would exceed the size controlled by the micro-rate. Roman et al. (2000) stated that the use of soil temperature to calculate GDD was a better predictor of common lambsquarters (*Chenopodium album* L.) seedling emergence than air temperatures. However, this was only true at one of the two locations in one of the two years, and only under no-till conditions. Most of the sugarbeets grown in the U.S. are planted in fields that have either been chisel plowed or moldboard plowed the previous fall. Although significant research has been conducted using GDD to time pesticide applications in many crops, particularly insecticide treatments, GDD have not been used to schedule multiple POST herbicide treatments such as those used in sugarbeet.

Currently the herbicide label states that the first micro-rate treatment should be applied when weeds are at the cotyledon growth stage, and follow up treatments should be applied every 5 to 7 d as required. This 5 to 7 d interval is often too short, but can also be too long depending on environmental conditions between treatments. Moisture is required for weed germination and growth. Furthermore, weeds emerge and grow more rapidly under warm conditions. Improper timing with the micro-rate may result in poor weed control, sugarbeet injury, and/or undue cost.

The objectives of this research were to determine if sequential POST herbicide applications in sugarbeet could be based on GDD, and to determine if weed control would be equal to or greater than POST applications based on calendar days. POST herbicide applications based on GDD could increase weed control, reduce herbicide applications, and reduce crop injury. Better timing of POST herbicides in sugarbeet may result in greater sucrose production and increased net returns.

MATERIALS AND METHODS

Growth Chamber Studies. Common lambsquarters and redroot pigweed (*Amaranthus retroflexus* L.) (Source: Michigan State University Agronomy Farm, East Lansing) were planted in plastic pots (10-cm by 15-cm depth) filled with a mixture of sphagnum peat and perlite. Pots were placed in a growth chamber at 27:11 C (day:night temperature) for 5 d and were transferred to growth chambers set at 23:7, 27:11, and 31:15 C 2 d prior to the first micro-rate treatment. The 23:7 C chamber provided 97 GDD every 7 d, the 27:11 C chamber provided 125 GDD every 7 d, and the 31:15 C chamber provided 152 GDD every 7 d. GDD were calculated using the average daily temperature and the base temperature was 1.1 C (max + min/2 -1.1 C = GDD in C for 1 day). Holen and Dexter (1996) reported that 1.1 C was the optimum base temperature for sugarbeet. All chambers had a photoperiod of 16:8 h (light:dark). Pots were watered daily as needed and fertilized once each week with 50 ml of N, P_2O_5, K_2O (20:20:20) at 20 ppm concentration. The experimental design was a RCB with four replicates and was repeated. The whole-plot was the three growth chamber temperatures, and the sub-plot was herbicide treatment. Treatments included (a) no treatment, (b) herbicide treatments applied two times starting two wk after planting, and (c) herbicide treatments applied three times starting one wk after planting within each growth chamber. Data were subjected to ANOVA using the PROC MIXED procedure in SAS and means were separated using Fishers Protected LSD at (P 0.05). The herbicides applied in the micro-rate each application were desmedipham plus phenmedipham at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha plus MSO[2] at 1.5% v/v. Herbicides were applied two (herbicide applications 14 and 21 days after planting) or three times (herbicide applications 7, 14, and 21 days after planting) on weekly intervals which resulted in spray schedules of 97, 125, and 152 GDD. Herbicide treatments were applied with a single tip track-sprayer equipped with an 8003E[3] spray tip calibrated to deliver 187 L - ha^{-1} at 207 kPa. Visual observations were recorded 1 wk after the last treatment.

Field Studies. Field experiments were conducted in 2001 and 2002 near East Lansing, MI. The experiments were located in different fields each year on a Colwood-Brookston loam (fine-loamy, mixed, mesic Typic Haplaquolls, and fine-loamy, mixed, mesic Typic Argiaqoulls), 53% sand, 27% silt, and 21% clay, with pH 6.9 and 2.4% organic matter. Fields were fall plowed followed by a field cultivator in the spring for seedbed preparation. Prior to planting sugarbeet, the fields were fertilized with granular urea (46-0-0) at 125 kg/ha using a broadcast applicator and incorporated to a 10-cm depth with a field cultivator. In addition, granular fertilizer N, P_2O_5, K_2O (19-19-19) at 110 kg/ha was applied in-furrow at planting. Both Hilleshog E-17[4] and Beta 5400[5] were seeded at a depth of 2.5 cm at 118,000 seeds/ha in 76 cm rows with a John Deere 7200 Max-Emerge® 2[6] planter. Sugarbeets were planted to stand with a seed spacing of 250 sugarbeet per 30 m of row. Planting dates in 2001 were April 5, April 17, and May 3; in 2002 the planting dates were April 7, April 17, and May 1. Micro-rate treatments in 2001 and 2002 were applied (a) every 7 d, (b) as needed, (c) every leaf pair (2001 only), (d) every 97 GDD, (e) every 152 GDD (2002 only), and (f) every 152 GDD. The leaf pair treatment was dropped in 2002 because of the difficulty in determining "leaf pair" in a sugarbeet population and the fact that the 2001 field research and growth chamber research indicated that 125 GDD would be a proper substitution. GDD were calculated using the average daily temperature with a base of 1.1 C. Herbicide treatments were applied using a tractor mounted compressed air sprayer in water at 187 L ha^{-1} 207 kPa

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[2] Loveland industries Inc., PO Box 1289, Greeley, CO 80632.
[3] Teejet even fan tips. Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.
[4] Hilleshog seeds, 1350 Kansas Ave., Longmount, CO 80501.
[5] Beta seeds, 1788 Maschall Road, Shakopee, MN 55379.

through XR 8003[7] spray tips. All herbicide treatments were initiated when average weed height was 1.5 cm, and repeated according to treatment. In 2002, clethodim ((E,E)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) was applied over the entire plot area to control giant foxtail, but was not needed in 2001.

Sugarbeet injury and weed control were estimated visually 14 days after the final herbicide treatment for each planting date using the rating scale of 0 (no injury) to 100 (completely killed). Sugarbeet was topped with a two-row topper, and harvested October 30, 2001 and October 21, 2002 with a mechanical two-row lifter. A sample from each plot was analyzed for recoverable sucrose by the method outlined by the Association of Official Agriculture Chemists (1955) by Michigan Sugar Company., Carollton, MI.

The experimental design was a factorial in a split-split-plot arrangement with four replicates. The whole-plot was planting date, sub-plot was sugarbeet variety, and sub-sub-plot was the various herbicide treatments. Data were subjected to ANOVA using the PROC MIXED procedure in SAS and means were separated using Fishers Protected LSD at (P 0.05). Planting date by variety and treatment by variety by planting date interactions were not significant; therefore, the data were combined over varieties and planting dates for the analyses.

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[6] Deere and Co., 501 River Drive, Moline, IL 61265-1100.
[7] Teejet flat fan tips. Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.

RESULTS AND DISCUSSION

Growth chamber studies. Common lambsquarters and redroot pigweed control was 90% or more when the micro-rate herbicide treatment was applied three times spaced every 97 or 125 GDD (Table 2). However, when the micro-rate treatment was applied three times spaced every 152 GDD, common lambsquarters and redroot pigweed control decreased to 84 and 63%, respectively. When the first application was skipped, common lambsquarters and redroot pigweed control was reduced for both the 125 and 152 GDD timings. Waiting until GDD totaled 250 resulted in larger weeds that could not be controlled by the micro-rate of these herbicides, even when a second application was made 7 d later. This research showed that micro-rates of herbicides applied three times starting one wk after planting using the 97 and 125 GDD timing effectively controlled common lambsquarters and redroot pigweed. Furthermore, the timeliness of the first application is apparent. If weeds "escape" the first treatment and exceed 3 cm, control decreases to 87% or less. The development of common lambsquarters was likely reduced in the 31:15 C growth chamber because optimum growth occurs at 25 C, and growth decreases at higher temperatures. This would explain the complete control observed with the 152 GDD spacing in the growth chamber, but reduced control observed in the field in 2002 (Table 7).

POST micro-rate applications in the field in 2001 and 2002. When the micro-rate was applied every 152 GDD, the total number of applications was reduced by two in 2001 and three in 2002 compared to the 7 d or labeled timing for the early and mid-April planting dates (Table 3 and Table 4). For the early May planting dates, total micro-rate applications were reduced by two with the 152 GDD timing compared to the 7 d timing in both 2001 and 2002 (Table 5). The mean number of days between herbicide applications was 4.5 d greater for the 152 GDD timing for all planting dates in 2001 and 2002, and was 4 d greater for the 125 GDD timing in the early and late planting dates in

2002 compared to the 7 d timing (Tables 3, 4,and 5). This lengthening of the time interval between applications reduces costs and is an advantage to the sugarbeet grower if weeds are controlled.

Sugarbeet response in the field in 2001 and 2002. The sugarbeet variety Beta 5400 tended to incur greater injury than Hilleshog E-17 (personal observation), but the varietal differences were not significant and the data were combined. Sugarbeet injury ranged from 18% in the 152 GDD timing to 27% in the 7 d timing in 2001, and from 19% to 29% in 2002, respectively (Table 6). Sugarbeet injury was evaluated as an overall reduction in leaf area and stunted sugarbeet growth. In 2001, sugarbeet injury was less in the 152 GDD timing compared to the 7 d timing, and in 2002 injury in the 7 d timing was greater than all other timings. Sucrose yield was greater in sugarbeets that were treated with a micro-rate every 152 GDD and every new leaf pair compared to the every 7 d and 'as needed' timings in 2001 (Table 6). In 2002, sucrose yield was significantly less in sugarbeets in the 7 d timing than in all other timings. Extending the time between micro-rate herbicide applications from 7.4 to 10.6 d or longer (Table 3) allowed sugarbeet to metabolize the herbicides and increase leaf expansion (Hendrick et al. 1974).

Weed response. Both common lambsquarters and *Amaranthus* spp. populations were high in all plots (550 per m^2). Other weeds that were present sporadically were common ragweed (*Ambrosia artemisiifolia* L.), eastern black nightshade (*Solanum ptycanthum* Dunn.), and giant foxtail (*Setaria faberi* Herrm.). Common lambsquarters control was excellent with all timings in both years; with the exception of minor differences in 2002 (Table 7). In 2002, common lambsquarters control was less in the 152 GDD timing compared to the 7 d, as needed, and 97 GDD timings, but similar to the 125 GDD timing. Control of *Amaranthus* spp. (mixture of redroot pigweed and powell amaranth) was greater in the 7 d, leaf pair, and 97 GDD timings than in the as needed and 152 GDD timing in 2001; however, control was greater than 90% in all timings. *Amaranthus* spp.

control in 2002 did not differ by herbicide timing. In 2002, *Amaranthus* spp. control was generally less than in 2001. The reduced *Amaranthus* spp. control may have been caused by the moisture deficit experienced at East Lansing, Michigan in 2002 (Table 1). Horak and Wax (1991) reported that reduced soil moisture delays redroot pigweed germination. This also explains why more herbicide treatments had to be applied in 2002 than 2001. Redroot pigweed generally germinates when temperatures exceed 25 C, whereas common lambsquarters generally emerges when temperatures exceed 10 C. Orykot et al. (1997) reported that redroot pigweed emerges from 19 to 33 C. Harvey and Forcella (1993) reported that common lambsquarters emerges from 9 to 33 C; however, the optimum temperature was 24 C.

Weed control was reduced when the time between micro-rate applications was extended, or as total applications decreased. However, weed control was acceptable with the 152 GDD timing in both 2001 and 2002, and sucrose yield was similar or greater in the 152 GDD timing compared to other timings. The cost of one micro-rate application was approximately $50/ha, not including application cost in 2002. By applying the micro-rate using GDD, two or three micro-rate applications could be eliminated while maintaining sucrose yields similar to, or greater, than the 7 d timing. Sugarbeet growers would save up to $150/ha in herbicide expense when using GDD to time micro-rate applications compared to the 7 d timing. This cost is even greater when considering other factors such as sugarbeet injury, compaction, equipment depreciation, and labor costs.

A model based on soil temperature and moisture that would provide consistent results from field to field may not be feasible because of differences in tillage practices, soil texture, soil type, moisture, burial depth, and the high genetic diversity of weed seeds influencing weed seed emergence. In addition, soil temperature data are often not as readily accessible as air temperature, and growers use GDD based on air temperature for other pest management decisions for crops including corn, soybeans, and sugarbeet. The time spent in calculating GDD is minimal. Weather stations and the sugar companies provide maximum and minimum temperatures each day. Extensive scouting is not required because redroot pigweed and common lambsquarters are currently the two important weed species in sugarbeet production. Other weeds such as common ragweed are easily controlled with clopyralid regardless of size and annual grasses are controlled with acetyl-CoA carboxylase (ACCase) inhibiting herbicides such as Sethoxydim, clethodim, and quizalofop (Vencill 2002). Velvetleaf is controlled by the micro-rate since triflusulfuron requires a MSO for effective control (Starke and Renner 1991). Therefore, timing POST herbicide applications by GDD in sugarbeet will control a broadspectrum of weeds and increase growers/applicators confidence in the timeliness of POST herbicide applications.

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Table 1. Deviations from the normal monthly precipitation and mean temperature in 2001 and 2002 at Michigan State University Horticulture Teaching and Research Center, East Lansing, MI.

Month	Precipitation (cm)		Temperature (C)	
	2001	2002	2001	2002
April	0.4	1.3	0.6	-1.4
May	13.2	5.2	1.7	-2.9
June	-0.5	-3.6	0.1	1.0
July	-5.3	1.8	-0.3	1.2
August	-3.8	-3.9	1.1	0.5
September	3.8	-5.8	-1.5	1.9

Table 2. Common lambsquarters and redroot pigweed control 28 days after planting with two or three POST herbicide treatments applied every 97, 125, and 152 growing degree days (in C) in growth chambers.

Temperature regimes[a]	GDD	Herbicide applications[b]	Common lambsquarters	Redroot pigweed
Day:night (C)	(C)	DAP[c]	% control[d]	
23:7	97	14 and 21	100a	100a
23:7	97	7, 14, and 21	100a	100a
27:11	125	14 and 21	87c	77c
27:11	125	7, 14, and 21	95b	90b
31:15	152	14 and 21	52d	34e
31:15	152	7, 14, and 21	84c	63d

[a]Common lambsquarters and redroot pigweed were grown in growth chambers set at 23:7 C, 27:11 C, and 31:15 C. Growing degree days were calculated by subtracting 1.1 C from the average daily temperature (C).
[b]Herbicide treatments were applied 14 and 21 d after planting or 7, 14, and 21 d after planting. Herbicides applied were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha and methylated seed oil at 1.5% v/v.
[c]Abbreviations: GDD, growing degree days, DAP, days after planting.
[d]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.

Table 3. The number of days after planting that micro-rate herbicide treatments were applied for the April 5, 2001 and April 7, 2002 planting dates[ab].

	Timings									
	2001					2002				
	7 day	Scout	Leaf pair	97 GDD	152 GDD	7 day	Scout	97 GDD	125 GDD	152 GDD
	21	21	21	21	21	9	9	9	9	9
	27	27	29	29	33	16	24	24	24	29
	38	45	38	38	45	24	37	37	37	44
	45	55	45	45	59	29	51	51	55	55
	51		55	55	69	37	61	57	61	61
	60		67	64		43	68	69	73	73
	67			70		51	73	73	79	
						61				
						68				
Mean[c]	7.3	11.3	9.2	8.2	12	7.4	10.6	10.6	11.6	12.8
Total[d]	7	4	6	7	5	9	7	7	7	6

[a] Growing degree days were calculated by subtracting 1.1 C from the average daily temperature (C).
[b]Timings included: every 7 d (labeled treatment), as needed (scouting for weeds at cotyledon growth stage), every leaf pair (application every new leaf pair in sugarbeet), every 97 GDD, every 125 GDD, and every 152 GDD.
[c]Mean is the average number of days between herbicide applications.
[d]Total is the total number of applications for each herbicide timing.

Table 4. The number of days after planting that micro-rate herbicide treatments were applied for the April 19, 2001 and April 17, 2002 planting dates[ab].

	Timings									
	2001					2002				
	7 day	Scout	Leaf pair	97 GDD	152 GDD	7 day	Scout	97 GDD	125 GDD	152 GDD
	15	15	15	15	15	19	19	19	19	19
	21	26	26	21	27	27	27	33	34	37
	26	39	33	27	39	33	41	45	45	51
	33	57	43	33	55	41	51	54	54	63
	39	66	52	43	67	51	58	63	63	66
	48	72	67	52		58	63	66	69	
	55		73	58		66	69	72		
				67		72				
Mean[c]	6.7	11.4	9.7	7.4	13	7.6	8.3	8.8	10	14.3
Total[d]	7	6	7	8	5	8	7	7	6	5

[a] Growing degree days were calculated by subtracting 1.1 C from the average daily temperature (C).
[b]Timings included: every 7 d (labeled treatment), as needed (scouting for weeds at cotyledon growth stage), every leaf pair (application every new leaf pair in sugarbeet), every 97 GDD, every 125 GDD, and every 152 GDD.
[c]Mean is the average number of days between herbicide applications.
[d]Total is the total number of applications for each herbicide timing.

Table 5. The number of days after planting that micro-rate herbicide treatments were applied for the May 2, 2001 and May 3, 2002 planting dates[ab].

	Timings									
	2001					2002				
	7 day	Scout	Leaf pair	97 GDD	152 GDD	7 day	Scout	97 GDD	125 GDD	152 GDD
	11	11	11	11	11	13	13	13	13	13
	17	23	17	17	21	19	27	27	31	31
	23	36	32	27	38	27	44	40	40	44
	32	51	39	36	51	37	49	49	49	52
	39	57	51	42	60	43	55	55	58	61
	51		57	49		51				
	57			55		57				
Mean[c]	7.7	11.5	9.2	7.7	12.3	7.5	10.5	10.5	11.3	12
Total[d]	7	5	6	7	5	7	5	5	5	5

[a] Growing degree days were calculated by subtracting 1.1 C from the average daily temperature (C).
[b]Timings included: every 7 d (labeled treatment), as needed (scouting for weeds at cotyledon growth stage), every leaf pair (application every new leaf pair in sugarbeet), every 97 GDD, every 125 GDD, and every 152 GDD.
[c]Mean is the average number of days between herbicide applications.
[d]Total is the total number of applications for each herbicide timing.

Table 6. Sugarbeet injury and yield as affected by herbicide application timings in 2001 and 2002, averaged over varieties and planting dates[a-d].

	Sugarbeet injury		Sucrose yield	
Timing[e]	2001	2002	2001	2002
	%		RWSH	
7 d	27a	29a	6,691b	4,261b
As needed	23ab	18b	6,612b	4,700a
Leaf pair	24ab	-	7,493a	-
97 GDD	23ab	18b	7,131ab	4,890a
125 GDD	-	20b	-	4,710a
152 GDD	18b	19b	7,748a	4,935a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]The leaf pair treatment was replaced with the 125 growing degree day treatment in 2002.
[c]Abbreviations: RWSH, recoverable white sucrose per ha.
[d]Sugarbeet injury was recorded 14 days after the last herbicide application for each planting date.
[e]Herbicides applied were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha and methylated seed oil at 1.5% v/v.

Table 7. Common lambsquarters and *Amaranthus* species control by herbicide applications timings in 2001 and 2002, averaged over varieties and planting dates[a,b].

	Common lambsquarters		*Amaranthus* species[d]	
Timing[c]	2001	2002	2001	2002
	%			
7 d	97a	96ab	97a	86a
As needed	99a	96ab	86c	83a
Leaf pair	99a	-	96a	-
97 GDD	100a	96ab	99a	84a
125 GDD	-	93bc	-	83a
152 GDD	97a	92c	91b	80a

[a] Sugarbeet injury was recorded 14 days after the last herbicide application for each planting date.
[b]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[c]Herbicides applied were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha and methylated seed oil at 1.5% v/v.
[d]*Amaranthus* species was a combination of redroot pigweed and powell amaranth.

CHAPTER 3

EFFECT OF PREEMERGENCE AND POSTEMERGENCE HERBICIDES ON WEED CONTROL AND SUGARBEET (*Beta vulgaris*) YIELD AND QUALITY.

Abstract. Weed control in sugarbeet is very expensive, and often includes peemergence (PRE) and postemergence (POST) herbicides, cultivation, and hand labor. In 2000 the "micro-rate", a combination of desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha or desmedipham plus phenmedipham plus ethofumesate (1:1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha plus 1.5% methylated seed oil (MSO), received registration in Michigan. The micro-rate herbicide treatment is applied three to five times on a 7 d interval. Some growers have reported more injury from micro-rate applications than standard applications. This research evaluated weed control, sugarbeet injury and yield in sugarbeet treated with various herbicide programs including PRE only, POST only, and combinations of PRE and POST herbicides. Common lambsquarters control was 91 to 95% with all POST treatments in 2001, and 97% or greater with all POST treatments when combined over PRE treatments. In 2002, desmedipham plus phenmedipham at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha plus 1.5% MSO and desmedipham plus phenmedipham plus ethofumesate at 0.27 kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 kg/ha provided 90 and 100% control, respectively. *Amaranthus* spp. control was 86 to 92% in 2001, and 96 to 100% in 2002 with all POST treatments. In 2001, *Amaranthus* spp. control was 93 to 96%, and 97 to 100% with all POST treatments when combined over PRE treatments. Sugarbeet injury was similar among all herbicide treatments in 2001. In 2002, sugarbeet injury ranged from 29 to 38% when both desmedipham plus phenmedipham or desmedipham plus phenmedipham plus ethofumesate were applied at 0.09 kg/ha compared to 43% when desmedipham plus phenmedipham or desmedipham plus phenmedipham plus

ethofumesate were applied at 0.56 and 0.27 kg/ha, respectively. Recoverable sucrose yields did not differ among all herbicide treatments in the small plot and in the strip plots in sugarbeet growers' fields in 2001 and 2002.

Nomenclature: desmedipham; phenmedipham; ethofumesate; triflusulfuron; clopyralid; common lambsquarters, *Chenopodium album* L. #[1] CHEAL; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; pigweed species, *Amaranthus retroflexus* and *Amaranthus powellii* S. Wats. # AMASS; sugarbeet, *Beta vulgaris* L.

Additional index words: Micro-rate, standard-split.

Abbreviations: PRE, preemergence, POST, postemergence, PPI, preplant incorporated, MSO, methylated seed oil.

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[1] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

INTRODUCTION

Weed control in sugarbeets has relied on both PRE and POST herbicide applications. Cycloate can be pre-plant incorporated (PPI) or pyrazon and ethofumesate applied PRE to provide residual weed control. Two major limiting factors affecting the use of PRE herbicides are the excessive cost which restricts their overall use and requires that they be applied in a band application, and the requirement of moisture to provide adequate activation of the PRE herbicides. Renner and Powell (1991) reported inconsistent weed control from PRE herbicides among years. In addition, previous research has reported that sugarbeet treated with soil applied herbicides were more susceptible to POST herbicide treatments (Dexter and Luecke 1988, Smith et al. 1982). However, Starke and Renner (1996) reported that sugarbeet response to POST herbicides was not affected by PPI or PRE herbicide treatments. POST herbicides such as desmedipham plus phenmedipham (1:1 ratio) plus triflusulfuron plus clopyralid are almost always applied to control weeds not controlled by the PRE herbicides.

Since the early 1970s, research on reduced rates of POST herbicides applied twice as a split application has resulted in better weed control. Desmedipham applied at 0.28 kg/ha followed by (fb) 0.28 kg/ha 7 to 14 d later, controlled weeds more effectively and tended to injure sugarbeet (*Beta vulgaris* L.) less than desmedipham at 1.12 kg/ha or split applications of 0.56 kg/ha fb 0.56 kg/ha (Dexter 1994). Split applications of desmedipham at 0.28 fb 0.28 kg/ha were widely used by 1980. From 1984 to 1998, 96% of the sugarbeet ha no longer received a PRE herbicide, and growers switched to a POST only program relying on two to three standard-split treatments and one to two cultivations in North Dakota and Minnesota (Luecke and Dexter 2003). In 1998 the micro-rate (desmedipham at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.03 kg/ha plus MSO at 1.5% v/v) was registered in North Dakota and Minnesota, and was registered in Michigan in 2000.

The switch to a total POST program in Michigan has occurred at a slower rate than North Dakota and Minnesota. A typical weed control program in Michigan prior to 2000, included the use of a PRE herbicide such as pyrazon at 3.36 kg/ha plus ethofumesate at 1.68 kg/ha fb two POST standard split herbicide treatments and three to four cultivations because the herbicides were applied in a band. Michigan sugarbeet growers applied PRE herbicides on 75% of the sugarbeet ha in 2001 and 60% in 2002 (Renner 2002[2]). A contributing factor to the reduction in PRE herbicide use has been the registration of the micro-rate in 2000. While no survey was conducted in 2000, it is estimated that PRE herbicides were applied to more than 90% of the sugarbeet ha in Michigan. In 2002, the micro-rate and PRE herbicides were applied to 60% of the sugarbeet ha in Michigan indicating that some of the sugarbeet growers using the micro-rate POST were also using a PRE herbicide. The reduced cost of the micro-rate enables sugarbeet growers to broadcast apply the micro-rate compared to the standard-split that had to be applied in a band; however, the micro-rate requires several timely applications. Although both the micro-rate and standard-split can be applied in a band, cultivation is required in either case.

The micro-rate provided sugarbeet growers with a new weed control program that has several advantages over the previous weed control program. The micro-rate is typically applied three- to- five times to very small weeds (1.5 cm or less) and provides good to excellent annual weed control and allows the grower to apply POST herbicides throughout the day and not just in the evening, which can be a limiting factor with standard rates. Broadcast applications limit the number of cultivations required for weed control.

The objectives of these studies were to evaluate weed control and sugarbeet yield following PRE and POST herbicide applications. We wanted to determine if PRE

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[2] Renner, K. A. Annual sugarbeet grower survey 2002.

herbicides increased weed control when followed by (fb) POST herbicides applied as the micro-rate or standard-split, and if the PRE herbicide applied influenced POST weed control from the micro-rate or standard-split. Furthermore, we investigated if herbicides applied at the micro-rate were more injurious to sugarbeets than herbicides applied at the standard-split. Research trials in sugarbeet growers' fields were conducted to compare the results observed in small-plot trials with those in larger scale strip trials. Sugarbeet growers using the micro-rate were very interested in knowing if a PRE herbicide improved weed control or affected sucrose yield. The cost of PRE herbicides in a 25-cm band ranges from $27 to $107/ha and this cost could be eliminated if micro-rate applications or standard-split applications alone controlled the weeds.

MATERIALS AND METHODS

Small plot field research. Experiments were conducted at three sites in Michigan in 2001 and two sites in 2002 in cooperation with Michigan and Monitor Sugar Companies (Table 1). Hilleshog E-17 was planted at all sites each year. Research at Michigan State University was conducted at the Saginaw Valley Bean and Beet Research Farm in Saginaw County. The Michigan Sugar Company sites were located in a grower's fields in Saginaw County, and The Monitor Sugar Company site was located in Bay County. The dominant weeds at each site were redroot pigweed (*Amaranthus retroflexus* L.) and powell amaranth (*Amaranthus powellii* S. Wats.), and common lambsquarters (*Chenopodium album* L.). In 2001 and 2002, sugarbeet were planted in 71- or 76-cm wide rows between the dates of April 23 and May 5 (Table 2). Plots were 9.1-m long and four-rows wide. Herbicide treatments were applied using a tractor mounted compressed air sprayer in water at 187 L ha^{-1} at 207 kPa using XR 8003 spray tips. Herbicide(s), rate, application timing, number of applications, and herbicide programs used in small plot research trials in 2001 and 2002 are given in Table 3.

For simplicity, the "&" symbol will designate a pre-mix formulation of herbicide and "plus" will signify a tank mix of two or more products. From this point forward, desmedipham & phenmedipham at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha plus methylated seed oil (MSO[3]) at 1.5% will be referred to as the Betamix micro-rate, and desmedipham & phenmedipham & ethofumesate at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha plus MSO at 1.5% will be referred to as the Progress micro-rate. Desmedipham & phenmedipham at 0.56 kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 kg/ha will be referred to as the Betamix standard-split, and desmedipham & phenmedipham & ethofumesate at 0.28

[3] Loveland industries Inc., PO Box 1289, Greeley, CO 80632.

kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 kg/ha will be referred to as the Progress standard-split.

Cycloate was applied and incorporated prior to planting (PPI), and ethofumesate, pyrazon, and s-metolachlor were applied immediately after planting (PRE) at all locations. When the first emerging weeds reached the cotyledon growth stage the micro-rate was applied, and the treatment repeated every 5 to 10 d when newly emerging weeds reached the cotyledon growth stage. The standard-split applications were applied when the second and fourth micro-rate treatments were applied. The micro-rate was applied four times and the standard-split was applied twice. The PRE only treatments were hand weeded so that the effect of herbicide treatment only on sucrose yield could be determined. Sugarbeet injury and weed control were estimated visually 14 days after the fourth micro-rate and second standard-split applications using the rating scale of 0 (no injury) to 100 (completely killed). After the 14 DAT rating, all treatments were hand weeded throughout the season. Sugarbeets were topped with a four-row topper, and harvested in October at all sites in 2001 and 2002. The center two-rows were harvested, weighed, and a sample from each plot was analyzed for recoverable sucrose by the method outlined by the Association of Official Agriculture Chemists (1955) by Michigan Sugar Company, Carrollton, MI.

The experimental design was a RCB arranged in a 5 X 5 factorial with four replicates at each location. Locations were considered as separate environments. Environments were random, and herbicides were considered fixed effects. Data were subjected to ANOVA using the PROC MIXED procedure in SAS and means were compared using Fishers protected LSD test at the 0.05 probability level. Homogeneity of variance was tested by comparing error mean squares. The error mean squares were obtained from the ANOVA table from the individual environmental analyses. By dividing the smaller error mean square value into the larger error mean square value, a ratio was obtained. If this ratio was less than 5, environments were considered homogeneous, and the data were combined (personal communication, Alexandra Kravchenko).

Strip trials in production fields. Large strip trials were conducted in three grower fields in 2001 and four fields in 2002 within the sugarbeet production area in Michigan. These fields were chosen because the growers applied only POST herbicides at the micro-rate, and were interested if PRE herbicides reduced sugarbeet populations, injured sugarbeets or improved weed control compared to the micro-rate alone. Farm plots were located at Dave Tromble Farms in 2001 and 2002, LaRaCha Farms in 2001 and 2002, Maxwell Farms in 2001, Wackerle Farms in 2002, and Helmrich Farms in 2002. All farm locations were in Bay and Saginaw Counties. Pyrazon at 4.48 kg/ha, ethofumesate at 1.68 kg/ha, and pyrazon plus ethofumesate at 3.36 and 1.68 kg/ha, respectively, were applied PRE in each growers field. These were the only PRE herbicides registered in sugarbeet in 2001 and 2002, and are common PRE herbicides applied by sugarbeet growers in Michigan. Strips were 4, 6, or 8 rows wide and were 30 to 240 m long depending on equipment and field size. The growers applied their micro-rate treatments over their fields, including the areas of PRE herbicides. Sugarbeet populations were counted when sugarbeets had four to six leaves. Sugarbeet injury and weed control were also evaluated every 7 to 14 d at each production field throughout the growing season.

Experiments were arranged in a RCBD with three replicates at each location. Locations were considered as separate environments. Environments were random, and herbicides were considered fixed effects. Data were subjected to ANOVA using the PROC MIXED procedure in SAS, and means were compared using Fishers protected LSD test at the 0.05 probability level. Homogeneity of variance was tested by comparing error mean squares. The error mean squares were obtained from the ANOVA table from the individual environmental analyses. By dividing the smaller error mean square value into the larger error mean square value, a ratio was obtained. If this ratio was less than 5, environments were considered homogeneous, and the data were combined (personal communication, Alexandra Kravchenko). Each large plot was harvested and weighed when the rest of the field was harvested with a commercial sugarbeet lifter. Samples from each plot were analyzed for recoverable sucrose by the method outlined by the Association of Official Agriculture Chemists (1955) by Michigan Sugar Company., Carollton, MI.

RESULTS AND DISCUSSION

Small plot field research. Sugarbeet injury was 5% or less from all POST treatments in 2001 (Table 4). There were no significant differences in sugarbeet injury from Betamix and Progress, applied in the micro-rate or standard-split. Sugarbeet populations were similar, ranging from 141 to 147 plants/30 m in 2001 (Table 4). *Amaranthus* spp. control was 83% with the Betamix standard-split and 92% with the Progress standard-split. The micro-rate provided 86 and 89% *Amaranthus* spp. control with Progress and Betamix, respectively. Common lambsquarters control was 91% with the Betamix micro-rate and 95% with the Betamix standard-split in 2001 (Table 4). All POST treatments provided similar weed control, but no treatments provided 100% control. Sucrose yields were similar among all POST treatments.

When PRE herbicides were applied prior to POST herbicides, there were no significant differences in sugarbeet injury and populations between POST treatments in 2001 (Table 5). *Amaranthus* spp. control was greater with the Betamix micro-rate than the Progress micro-rate, but was similar to the standard-split application of Betamix or Progress and to the PRE only/hand-weeded treatments. Common lambsquarters control was 97% with all POST herbicide treatments combined over PRE treatments (Table 5). Sucrose yields were similar among all POST treatments combined over PRE treatments. In 2001, PRE herbicides increased common lambsquarters control and some PRE herbicides increased *Amaranthus* spp. control, but applying PRE herbicides did not increase sucrose yield compared to sugarbeets treated with only POST herbicides (Tables 4 and 5).

Cycloate reduced sugarbeet populations in 2001 with and without POST herbicides (Tables 6 and 7), but this did not result in a significant reduction in sucrose. This was similar to the results observed by Wilson et al. (1990), who reported a reduction in sugarbeet populations by cycloate. PRE herbicides fb POST herbicides, resulted in 6% or less sugarbeet injury in 2001 (Table 7). All PRE herbicide applications increased weed control in PRE/POST combinations compared to no PRE, but there was no significant difference in sucrose yield. Therefore, in 2001 weed control was greater with PRE/POST combinations but there were no significant differences in sucrose yield. All PRE herbicide applications provided similar control of *Amaranthus* spp. and common lambsquarters.

In 2002, sugarbeet injury from the Betamix standard-split application was 29% compared to 38% from the Betamix micro-rate and 43% from the Progress micro-rate and standard-split (Table 8). Sugarbeet populations were not significantly influenced by POST herbicides, ranging from 172 to 193 plants/30 m in 2002 (Table 8). *Amaranthus* spp. control was 96% with the Betamix standard-split and 100% with the Progress micro-rate; however, differences were not significant. Common lambsquarters control was 90% from the Betamix micro-rate and 100% from the Progress standard-split in 2002 (Table 8). Although there were some differences in weed control among POST herbicide treatments, sucrose yields were similar among all POST herbicide treatments.

In 2002, sugarbeet injury increased significantly where PRE herbicides were fb the Progress micro-rate and standard-split, and the Betamix standard-split compared to the Betamix micro-rate (Table 9). PRE herbicides caused 28% sugarbeet injury, and the Progress micro-rate when combined over PRE herbicide applications resulted in 44% sugarbeet injury. However, sugarbeet populations were not significantly reduced by these treatments. *Amaranthus* spp. control was excellent with all POST herbicide treatments combined over PRE herbicide treatments (Table 9). Common lambsquarters control was 92 to 97% in all POST herbicide treatments combined over PRE herbicides. The Progress micro-rate provided significantly greater *Amaranthus* spp. control than the Betamix micro-rate and standard-split (Table 9). Although there were some differences in weed control among POST herbicide treatments, sucrose yields were similar among all POST herbicide treatments combined over PRE herbicide treatments.

S-metolachlor reduced sugarbeet populations compared to ethofumesate in 2002 with and without POST herbicides (Tables 10 and 11), and sucrose yields were reduced significantly compared to cycloate, ethofumesate, and no PRE herbicide. However, we would expect the no PRE herbicide treatment to have the highest stand. *Amaranthus* spp., common lambsquarters control, and sucrose yields were similar among all PRE herbicide treatments including the no PRE treatment. Therefore, in 2002 weed control was similar with PRE/POST herbicide combinations and there were no significant differences in sucrose yield.

These data show that PRE herbicides can increase *Amaranthus* spp. and common lambsquarters control depending on environmental conditions. These data also show that sugarbeet injury increases when rainfall is greater than normal and temperatures are lower than normal as experienced in 2002 (Table 2). Under cool wet conditions, sugarbeets are more susceptible to herbicide injury compared to the warm and dry conditions experienced in 2001; however, under these dry conditions many PRE herbicides are ineffective. Smith and Schweizer (1987) reported that favorable spring temperatures and soil moisture conditions favored plant uptake of herbicides. Weed control was often increased by PRE herbicides, but sucrose yields were not. Morishita and Downard (1995) reported greater common lambsquarters control from ethofumesate compared to the no PRE herbicide treatment when fb desmedipham plus phenmedipham plus ethofumesate. However, Dexter et al. (1988) reported increased sugarbeet injury and weed control when POST herbicide treatments were applied over PPI herbicides, but not PRE herbicides. They hypothesized that the inadequate rainfall in 1988 contributed to the poor control from Antor PRE. Renner and Powell (1991) reported inconsistent weed control with PRE herbicides and attributed it to inadequate rainfall in 1998. While our PRE herbicides were applied broadcast, sugarbeet growers would apply these herbicides in a band and cultivate to reduce expenses. We also found that there were little differences between the micro-rate and the stand-split with Betamix or with Progress. POST herbicide applications in sugarbeet need to be applied timely to achieve satisfactory control. Particularly the first POST application may be more important than the choice of herbicide or the number of applications. Herbicides must be applied to weeds with less than two- true leaves and should be applied when the weeds are in the cotyledon growth stage. These data indicated some advantage with Progress compared to Betamix which was not expected based on previous observations.

Strip trials in production fields. Based on the comparisons of error mean squares, Dave Tromble Farms in 2001, LaRaCha Farms in 2001 and 2002, Wackerle Farms in 2002, and Helmrich Farms in 2002 were combined: and sugarbeet injury and recoverable sucrose are reported in Table 12. Maxwell Farms in 2001 is reported in Table 13 and Dave Tromble Farms in 2002 is reported in Table 14. When combined over five locations in 2001 and 2002, PRE herbicides did not affect sugarbeet populations or recoverable sucrose per ha (Table 12). Also at Maxwell Farms in 2001 (Table 13) and at Dave Tromble Farms in 2002 (Table 14) PRE herbicides did not significantly affect sugarbeet populations or recoverable sucrose per ha. Sucrose yields increased in plots treated with PRE herbicides at Maxwell Farms in 2001, but only 30 m of each plot at this location was harvested because half of some plots were destroyed by cultivation. At all other locations, at least 150 m of each plot was harvested. This may have contributed to the larger differences in sucrose yield among treatments. Weed control was excellent in all treatments at all locations except at the Maxwell Farm in 2001 and the Wackerle Farm in 2002, weed control was poor in general and there was no observable effect of the PRE herbicides (data not presented).

Sugarbeet growers were disappointed with the efficacy of the PRE herbicides under these conditions, and felt there was no benefit from the PRE herbicides (personal communication). At Maxwell Farms in 2001 and Wackerle Farms in 2002, excessive early season moisture prevented the timely application of POST herbicides, and a poor sugarbeet population contributed to the poor weed control. These data suggest that PRE herbicides were not required in production fields as weed control and sucrose yields were not significantly increased. These results are somewhat different than the small plot research, where there was some advantage to PRE herbicides with respect to *Amaranthus* spp. anc common lambsquarters control; however, sucrose yields were similar with or without PRE herbicides at all locations.

We observed a reduction in sugarbeet population from cycloate in 2001 and *s*-metolachlor in 2002. Schweizer (1979) reported a reduction in sugarbeet population and top growth from cycloate and ethofumesate. Wilson et al. (1990) also reported a decrease in sugarbeet population and size from cycloate and ethofumesate; however, by the end of the growing season sugarbeets had recovered from early season injury and none of the herbicides reduced root yield. Sugarbeet growers must decide if the risk of stand loss under cool, wet conditions is outweighed by the benefit of six to eight weeks of weed control. Starke and Renner (1996) reported that sugarbeet response to POST herbicides was not affected by PPI or PRE herbicides. We observed similar results in 2001 but not in 2002. Rainfall in 2002 may have increased sugarbeet uptake of PRE herbicides and cool, wet conditions slow metabolism of herbicide in sugarbeet. Therefore growers must decide if there is a greater risk applying POST herbicides following PRE herbicides under cool, wet conditions.

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Table 1. Soil series, type, organic matter, and planting dates for small plot research trials at each location in 2001 and 2002.

Site		Soil			Planting		
Location	Year	Series	Type	OM[a]	Variety	Date	Row Width
				(%)			(cm)
Michigan State Univ.	2001	Zilwaukee	Silty Clay	3.3	HM E-17	4/27	71
Michigan Sugar Co.	2001	Sloan-Ceresco	Clay	9.7	HM E-17	5/3	76
Monitor Sugar Co.	2001	Londo	Clay Loam	2.3	HM E-17	4/26	76
Michigan State Univ.	2002	Zilwaukee	Silty Clay	3.6	HM E-17	5/5	71
Michigan Sugar Co.	2002	Sloan-Ceresco	Clay	10.2	HM E-17	4/23	76

[a]Abbreviations: OM, organic matter.

Table 2. Deviations from the normal monthly precipitation and mean temperature in 2001 and 2002 at Michigan State University Saginaw Valley Beet & Bean Research Farm, Saginaw, MI.

	Precipitation (cm)		Temperature (C)	
Month	2001	2002	2001	2002
April	-1.0	1.3	0.8	-0.4
May	0.5	3.8	-1.4	-3.3
June	-2.6	-0.6	-0.1	-0.1
July	-2.3	0.4	-0.2	0.7
August	-3.4	1.4	1.4	-0.7
September	2.9	-6.0	-1.4	1.2

Table 3. Herbicide, rate, application timing, number of applications, and herbicide programs used in small plot research trials in 2001 and 2002.

Herbicide(s)[a,b]	Rate	Application timing[a]	Number of Applications	Herbicide program
	kg/ha			
Desm. plus phen. plus tfsu. plus clpy. plus MSO	0.045, 0.045, 0.004, and 0.023	POST	4	Betamix[b] micro-rate
Desm. plus phen plus etho. plus tfsu. plus clpy. plus MSO	0.03, 0.03, 0.03, 0.004, and 0.023	POST	4	Progress[b] micro-rate
Desm. plus phen. plus tfsu. plus clpy.[c]	0.28, 0.28, 0.017, and 0.1	POST	2	Betamix standard-split
Desm. plus phen plus etho. plus tfsu. plus clpy.[c]	0.09, 0.09, 0.09, 0.017, and 0.1	POST	2	Progress standard-split
S-metolachlor	1.42	PRE	1	Preemergence
Pyrazon	4.48	PRE	1	Preemergence
Ethofumesate	1.68	PRE	1	Preemergence
Cycloate	3.36	PPI	1	Preemergence

[a]Abbreviations: desm., desmedipham; phen., phenmedipham; etho., ethofumesate; tfsu., triflusulfuron; clpy., clopyralid; MSO, methylated seed oil.
[b]MSO was used at 1.5 % v/v.
[c]Clopyralid was only applied in the second split of the standard-split application.

Table 4. Sugarbeet injury and population, *Amaranthus* species and common lambsquarters control, and recoverable sucrose per hectare from POST herbicides only combined at three locations in 2001[abc].

POST treatment	Herbicide rate	Sugarbeet injury	Sugarbeet population	AMASS	CHEAL	RWSH
	kg/ha	— % —	Plants/30 m	— % control	—	kg/ha
No POST plus handweeded	-	0a	142a	100a	100a	6,726a
Desm. plus phen. plus tfsu. plus clpy. plus MSO[d]	0.045, 0.045, 0.004, and 0.023	5b	143a	89b	91c	6,590a
Desm. plus phen. plus etho. plus tfsu. plus clpy. plus MSO[d]	0.03, 0.03, 0.03, 0.004, and 0.023	3ab	147a	86b	93c	6,079a
Desm. plus phen. plus tfsu. plus clpy.[e]	0.28, 0.28, 0.017, and 0.1	5b	141a	83b	95bc	6,646a
Desm. plus phen. plus etho. plus tfsu. plus clpy.[e]	0.09, 0.09, 0.09, 0.017, and 0.1	4b	136a	92ab	94c	6,333a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]Abbreviations: desm., desmedipham; phen., phenmedipham; etho., ethofumesate; tfsu., triflusulfuron; clpy., clopyralid; MSO, methylated seed oil; AMASS (*Amaranthus* species), redroot pigweed and powell amaranth; CHEAL, common lambsquarters; RWSH, recoverable white sucrose per hectare.
[c]Sugarbeet populations were measured at harvest, and AMASS and CHEAL control were rated 14 days after the last POST application.
[d]MSO was used at 1.5 % v/v and treatments containing MSO were applied four times and treatments not containing MSO were applied twice.
[e]Clopyralid was only applied in the second split of the standard-split application.

Table 5. Sugarbeet injury and population, *Amaranthus* species and common lambsquarters control, and recoverable sucrose per hectare from POST herbicides combined over PRE herbicides at three locations in 2001[a-d].

POST treatment	Herbicide rate	Sugarbeet injury	Sugarbeet population	AMASS	CHEAL	RWSH
	kg/ha	— % —	Plants/30 m	— % control —		kg/ha
PRE only plus handweeded	-	4a	140a	100a	100a	6,464a
Desm. plus phen. plus tfsu. plus clpy. plus MSO[e]	0.045, 0.045, 0.004, and 0.023	6a	141a	96ab	97a	6,639a
Desm. plus phen. plus etho. plus tfsu. plus clpy. plus MSO[e]	0.03, 0.03, 0.03, 0.004, and 0.023	6a	140a	93c	97a	6,375a
Desm. plus phen. plus tfsu. plus clpy.[f]	0.28, 0.28, 0.017, and 0.1	4a	142a	94bc	97a	6,758a
Desm. plus phen. plus etho. plus tfsu. plus clpy.[f]	0.09, 0.09, 0.09, 0.017, and 0.1	5a	141a	96ab	97a	6,439a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P   0.05.
[b]POST treatments are combined over all PRE treatments including No PRE, pyrazon at 4.48, *s*-metolachlor at 1.42, ethofumesate at 1.68, and cycloate at 3.36 kg ai/ha.
[c]Abbreviations: desm., desmedipham; phen., phenmedipham; etho., ethofumesate; tfsu., triflusulfuron; clpy., clopyralid; MSO, methylated seed oil; AMASS (*Amaranthus* species), redroot pigweed and powell amaranth; CHEAL, common lambsquarters; RWSH, recoverable sucrose per hectare.
[d]Sugarbeet populations were measured at harvest, and AMASS and CHEAL control were rated 14 days after the last POST application.
[e]MSO was used at 1.5 % v/v and treatments containing MSO were applied four times and treatments not containing MSO were applied twice.
[f]Clopyralid was only applied in the second split of the standard-split application.

Table 6. Sugarbeet injury and population, *Amaranthus* species and common lambsquarters control, and recoverable sucrose per hectare from PRE herbicides at three locations in 2001[a-d].

PRE treatment	Herbicide rate	Sugarbeet population	AMASS	CHEAL	RWSH
	kg/ha	Plants/30 m	—— % control ——		kg/ha
No PRE plus handweeded	-	148a	100	100	6,503a
S-metolachlor	1.42	147a	100	100	6,503a
Ethofumesate	1.68	149a	100	100	6,780a
Pyrazon	4.48	148a	100	100	6,585a
Cycloate	3.36	139b	100	100	6,395a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]All treatments were hand weeded.
[c]Abbreviations: AMASS (*Amaranthus* species), redroot pigweed and powell amaranth; CHEAL, common lambsquarters; RWSH, recoverable sucrose per hectare.
[d]Sugarbeet populations were measured at harvest, and AMASS and CHEAL control were rated 14 days after the last POST application.

Table 7. Sugarbeet injury and population, *Amaranthus* species and common lambsquarters control, and recoverable sucrose per hectare from PRE herbicides combined over POST herbicides at three locations in 2001[a-d].

PRE treatment	Herbicide rate	Sugarbeet injury	Sugarbeet population	AMASS	CHEAL	RWSH
	kg/ha	— % —	Plants/30 m	— % control —		kg/ha
No PRE	-	4a	141a	90b	95b	6,461a
S-metolachlor	1.42	6a	141a	96a	98a	6,493a
Ethofumesate	1.68	5a	143a	98a	99a	6,790a
Pyrazon	4.48	4a	142a	97a	99a	6,543a
Cycloate	3.36	6a	134b	96a	98a	6,390a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]Abbreviations: AMASS (*Amaranthus* species), redroot pigweed and powell amaranth; CHEAL, common lambsquarters; RWSH, recoverable white sucrose per hectare.
[c]PRE treatments are combined over all POST treatments including desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha, plus MSO at 1.5% v/v applied four times; desmedipham plus phenmedipham plus ethofumesate (1:1:1 ratio) at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha, plus MSO at 1.5% v/v applied four times; desmedipham plus phenmedipham at 0.56 kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 kg/ha applied two times; and desmedipham plus phenmedipham plus ethofumesate at 0.56 kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 applied two times.
[d]Sugarbeet populations were measured at harvest, and AMASS and CHEAL control were rated 14 days after the last POST application.

Table 8. Sugarbeet injury and population, *Amaranthus* species and common lambsquarters control, and recoverable sucrose per hectare from POST herbicides only at two locations in 2002[a,b,c].

POST treatment	Herbicide rate	Sugarbeet injury	Sugarbeet population	AMASS	CHEAL	RWSH
	kg/ha	— % —	Plants/30 m	— % control	—	kg/ha
No POST plus handweded	-	0a	177a	100a	100a	6,723a
Desm. plus phen. plus tfsu. plus clpy. plus MSO [d]	0.045, 0.045, 0.004, and 0.023	38bc	172a	99a	90c	7,084a
Desm. plus phen plus etho. plus tfsu. plus clpy. plus MSO [d]	0.03, 0.03, 0.03, 0.004, and 0.023	43c	188a	100a	98ab	7,027a
Desm. plus phen. plus tfsu. plus clpy.[e]	0.28, 0.28 0.017, and 0.1	29b	193a	96a	93bc	7,220a
Desm. plus phen plus etho. plus tfsu. plus clpy.[e]	0.09, 0.09, 0.09, 0.017, and 0.1	43c	191a	98a	100a	6,883a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]Abbreviations: desm., desmedipham; phen., phenmedipham; etho., ethofumesate; MSO, methylated seed oil; AMASS (*Amaranthus* species), redroot pigweed and powell amaranth; CHEAL, common lambsquarters; RWSH, recoverable white sucrose per hectare.
[c]Sugarbeet populations were measured at harvest, and AMASS and CHEAL control were rated 14 days after the last POST application.
[d]MSO was used at 1.5 % v/v and treatments containing MSO were applied four times and treatments not containing MSO were applied twice.
[e]Clopyralid was only applied in the second split of the standard-split application.

Table 9. Sugarbeet injury and population, *Amaranthus* species and common lambsquarters control, and recoverable sucrose per hectare from POST herbicides combined over PRE herbicides at two locations in 2002[a,b,c].

POST treatment	Herbicide rate	Sugarbeet injury	Sugarbeet population	AMASS	CHEAL	RWSH
	kg/ha	— % —	Plants/30 m	— % control	—	kg/ha
PRE only plus handweeded	-	28a	181a	100a	100a	6,706a
Desm. plus phen. plus tfsu. plus clpy. plus MSO [d]	0.045, 0.045, 0.004, and 0.023	34ab	187a	99a	94c	7,170a
Desm. plus phen plus etho. plus tfsu. plus clpy. plus MSO [d]	0.03, 0.03, 0.03, 0.004, and 0.023	44c	187a	100a	97ab	6,812a
Desm. plus phen. plus tfsu. plus clpy.[e]	0.28, 0.28, 0.017, and 0.1	39bc	178a	98a	92c	7,034a
Desm. plus phen plus etho. plus tfsu. plus clpy.[e]	0.09, 0.09, 0.09, 0.017, and 0.1	37b	189a	97a	96abc	6,866a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]POST treatments are combined over all PRE treatments including pyrazon at 4.48, *s*-metolachlor at 1.42, ethofumesate at 1.68, and cycloate at 3.36 kg ai/ha.
[c]Abbreviations: desm., desmedipham; phen., phenmedipham; etho., ethofumesate; tfsu., triflusulfuron; clpy., clopyralid; MSO, methylated seed oil; AMASS (*Amaranthus* species), redroot pigweed and powell amaranth; CHEAL, common lambsquarters; RWSH, recoverable white sucrose per hectare.
[c]Sugarbeet populations were measured at harvest, and AMASS and CHEAL control were rated 14 days after the last POST application.
[d]MSO was used at 1.5 % v/v and treatments containing MSO were applied four times and treatments not containing MSO were applied twice.
[e]Clopyralid was applied in the second split of the standard-split application.

Table 10. Sugarbeet injury and population, *Amaranthus* species and common lambsquarters control, and recoverable sucrose per hectare from POST herbicides at two locations in 2002[a-d].

PRE treatment	Herbicide rate	Sugarbeet population	AMASS	CHEAL	RWSH
	kg/ha	Plants/30 m	—— % control ——		kg/ha
No PRE	-	177bc	100	100	6,799ab
S-metolachlor	1.42	163c	100	100	5,777c
Ethofumesate	1.68	191ab	100	100	6,721ab
Pyrazon	4.48	179bc	100	100	6,563bc
Cycloate	3.36	186bc	100	100	7,671a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]All treatments were hand weeded.
[c]Abbreviations: AMASS (*Amaranthus* species), redroot pigweed and powell amaranth; CHEAL, common lambsquarters; RWSH, recoverable white sucrose per hectare.
[d]Sugarbeet populations were measured at harvest, and AMASS and CHEAL control were rated 14 days after the last POST application.

Table 11. Sugarbeet injury and population, *Amaranthus* species and common lambsquarters control, and recoverable sucrose per hectare from PRE herbicides combined over POST herbicides at two locations in 2002[a-d].

PRE treatment	Herbicide rate	Sugarbeet injury	Sugarbeet population	AMASS	CHEAL	RWSH
	kg/ha	— % —	Plants/30 m	—— % control	——	kg/ha
No PRE	-	37a	184ab	98a	96a	6,977a
S-metolachlor	1.42	40a	178b	99a	95a	6,775a
Ethofumesate	1.68	37a	189a	99a	97a	6,911a
Pyrazon	4.48	38a	184ab	98a	95a	6,733a
Cycloate	3.36	36a	187ab	99a	96a	7,190a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]Abbreviations: AMASS (*Amaranthus* species), redroot pigweed and powell amaranth; CHEAL, common lambsquarters; RWSH, recoverable white sucrose per hectare.
[c]PRE treatments are combined over all POST treatments including desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha, plus MSO at 1.5% applied four times; desmedipham plus phenmedipham plus ethofumesate (1:1:1 ratio) at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha, plus MSO at 1.5% v/v applied four times; desmedipham & phenmedipham at 0.56 kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 kg/ha applied two times; and desmedipham & phenmedipham & ethofumesate at 0.56 kg/ha plus triflusulfuron at 0.017 kg/ha plus clopyralid at 0.1 applied two times.
[d]Sugarbeet populations were measured at harvest, and AMASS and CHEAL control were rated 14 days after the last POST application.

Table 12. Sugarbeet stand and recoverable white sucrose per hectare combined over Tromble Farms 2001, LaRaCha Farms 2001 and 2002, Wackerle Farms 2002, and Helmrich Farms 2002[a-d].

Preemergence treatments	Herbicide rate	Sugarbeet population	RWSH
	kg/ha	plants/30 m	kg/ha
No PRE	-	141a	5,789a
Pyrazon	4.48	139a	5,962a
Pyrazon plus ethofumesate	3.36 plus 1.68	138a	5,827a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]POST micro-rate herbicide treatments were applied three to five times at each location by the sugarbeet grower.
[c]Abbreviations: RWSH, recoverable white sucrose per hectare.
[d]Sugarbeet populations were measured at harvest.

Table 13. Sugarbeet stand and recoverable white sucrose per hectare at Maxwell Farms in 2001[a-d].

Preemergence treatments	Herbicide rate	Sugarbeet population	RWSH
	kg/ha	plants/30 m	kg/ha
No PRE	-	84a	8,627a
Pyrazon	4.48	103a	9,508a
Pyrazon plus ethofumesate	3.36 plus 1.68	85a	9,978a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P   0.05.
[b]POST micro-rate herbicide treatments were applied three to five times at each location by the sugarbeet grower.
[c]Abbreviations: RWSH, recoverable white sucrose per hectare.
[d]Sugarbeet populations were measured at harvest.

Table 14. Sugarbeet stand and recoverable white sucrose per hectare at Dave Tromble Farms in 2002[a-d].

Preemergence treatments	Herbicide rate	Sugarbeet population	RWSH
	kg/ha	plants/30 m	kg/ha
No PRE	-	146a	5,493a
Pyrazon	4.48	122a	5,889a
Pyrazon plus ethofumesate	3.36 plus 1.68	123a	5,839a

[a]Means within a column followed by the same letter are not different, according to Fisher's protected LSD at P 0.05.
[b]POST micro-rate herbicide treatments were applied three to five times at each location by the sugarbeet grower.
[c]Abbreviations: RWSH, recoverable white sucrose per hectare.
[d]Sugarbeet populations were measured at harvest.

CHAPTER 4

RESPONSE OF SUGARBEET (*Beta vulgaris*) VARIETIES AND LINES TO POSTEMERGENCE HERBICIDE TREATMENTS.

Abstract. Previous research has shown a differential response of sugarbeet varieties to herbicides. Injury may reduce sugarbeet leaf area, yield, or sucrose content. This research evaluated the response of fourteen sugarbeet varieties and four USDA sugarbeet lines to postemergence (POST) herbicides applied three times at reduced rates, termed the "micro-rate". A tank mixture of desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha plus methylated seed oil (MSO) at 1.5% v/v was applied three times at weekly intervals beginning at the cotyledon growth stage. These experiments were conducted in the growth chamber and in the field. Leaf area, fresh weights, and dry weights were recorded 1 wk after the third micro-rate applciation and compared to the respective control. Sugarbeet varieties differed in their response to micro-rate treatments. Micro-rate treatments reduced leaf area of the fourteen sugarbeet varieties by 3 to 35% and dry weights by 11 to 59%. Micro-rate treatments reduced leaf area of the USDA lines by 20 to 29% and dry weights by 47 to 53%. The commercial variety Hilleshog E-17 and USDA line WC 93404 were the most tolerant to micro-rate treatments in both studies with a 3 and 20% reduction in leaf area, and 19 and 47% reduction in dry weight, respectively. Hilleshog E-17, a diploid, did not have a significant reduction in leaf area, fresh weight, or dry weight in growth chamber of field studies. Beta 5736, a triploid, had significant reductions in leaf area, fresh weight, and dry weight in both growth chamber studies and dry weight in the field study. Other varieties and lines varied in response dependent on experimental conditions. Therefore reductions in sugarbeet leaf area and biomass will occur following POST herbicide applications, and the degree of response will be dependent on both variety and environment.

Nomenclature: desmedipham; phenmedipham; ethofumesate; triflusulfuron; clopyralid; common lambsquarters, *Chenopodium album* L. #[1] CHEAL; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; pigweed species, *Amaranthus retroflexus* and *Amaranthus powellii* S. Wats. # AMASS; sugarbeet, *Beta vulgaris* L. Hillshog E-17 and Beta 5400.

Additional index words: micro-rate.

Abbreviations: GDD, growing degree days, POST, postemergence.

[1] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

INTRODUCTION

Sugarbeet (*Beta vulgaris* L.) growers face many production challenges, and one of the most critical choices is variety selection. Sugarbeet varieties are chosen based on their yield potential, cost, disease resistance, herbicide tolerance, and emergence potential. Without a uniform plant population adapted to the production problems within the field or region, the grower will have difficulty achieving economical sucrose yields (Smith et al. 2001). Establishing an optimum sugarbeet population is critical to achieve the greatest sucrose yields. A uniform sugarbeet population minimizes variability among individual sugarbeets, and limits the area where weeds may emerge in the row. There are great differences in variety emergence. Sugarbeet often are overseeded because sugarbeet seedlings are weak and from 20 to 60% of the seedlings can be lost to unfavorable soil moisture, soil crusting, wind damage, insects, and seedling diseases (Schweizer and Dexter 1987). Sugarbeet seed is very expensive relative to other major agronomic crops so varieties with the greatest field emergence are preferred by sugarbeet growers.

Sugarbeet varieties differ in their susceptibility to herbicide treatments (Dexter and Luecke 1997, Wilson 1999, Wilson et al. 1990, and Smith and Schweizer 1983). Dexter and Kern (1978) reported that sugarbeet varieties varied in response to EPTC, and there was a significant herbicide by variety by year interaction. In 2 of 3 years, varieties responded differently to EPTC, but in one year there was no herbicide response to any of the varieties. In other research, herbicides including cycloate applied pre-plant incorporated (PPI), ethofumesate applied preemergence (PRE), and desmedipham plus phenmedipham applied POST reduced plant weight of eight sugarbeet varieties by 39 to 55% 45 days after planting and there were significant herbicide by variety interactions (Smith and Schweizer 1983). However, by harvest root yield reductions from herbicide treatments averaged 5% and herbicide by variety interactions were no longer significant. Wilson (1999) reported a significant reduction in the sugarbeet root yield, percent sucrose, and sucrose yield of nine sugarbeet varieties when treated with desmedipham plus phenmedipham at 0.36 kg/ha with either triflusulfuron at 0.018 kg/ha or ethofumesate at 0.016 kg/ha.

Since these studies were conducted, herbicide programs in sugarbeet have changed significantly. In recent years the use of PRE and PPI applied herbicides have declined and the use of POST applied herbicides have increased (Wilson 1999). Data from eastern North Dakota and Minnesota indicated that on average each ha of sugarbeet received 4.2 POST herbicide applications (Dexter et al. 1997). Combinations of desmedipham plus phenmedipham or desmedipham plus phenmedipham plus ethofumesate with triflusulfuron and clopyralid were applied POST in tank mixtures for broadleaf weed control and annual grass suppression. The most common POST program is referred to as the micro-rate (desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha plus MSO at 1.5% v/v). Furthermore, new sugarbeet varieties are released in each growing region of the U.S. each year, and susceptibility to POST herbicides is not known. Our objective was to determine if sugarbeet varieties differed in their susceptibility to POST micro-rate herbicides. Furthermore, we were interested if variety response to POST herbicides could be correlated to ploidy level. This information would be useful to sugarbeet growers in designing POST weed management systems that were not injurious to sugarbeet. Lastly, if a particular sugarbeet population was highly susceptible or tolerant to POST herbicides these lines could be exploited in future sugarbeet breeding research.

MATERIALS AND METHODS

Growth chamber research. Commercial sugarbeet varieties and USDA lines were grown in growth chambers with a photoperiod of 16:8 h (light:dark) and thermoperiod of 24:14 C (day:night). Eight to ten sugarbeet seeds of each variety or line were seeded in plastic pots (10-cm square by 15-cm depth) containing a mixture of sphagnum peat and perlite. Each pot was thinned to four plants per pot three days after emergence. Pots were watered daily as needed and fertilized once each week with 50 ml of N, P_2O_5, K_2O (20-20-20) at 20 ppm. The herbicides applied in the micro-rate were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha plus MSO[2] at 1.5% v/v. Herbicides were applied three times on weekly intervals with a single tip track-sprayer equipped with an 8003E[3] spray tip calibrated to deliver 187 L ha^{-1} at 207 kPa. Fresh and dry weights and leaf area of three sugarbeet plants from each pot were recorded one wk after the last treatment. The experimental design was a CRD with four replications and was repeated. Data were subjected to ANOVA using the PROC MIXED procedure in SAS and means were separated using Fishers Protected LSD at (P 0.05).

In the first experiment, two triploids Beta 5736 and Beta 5400 and two diploids Hilleshog E-17 and ACH 555 were screened for sensitivity to the micro-rate. In the second experiment, there were four triploids Spartan, Beta 5451, Beta 5172, and Beta 5736, and eight diploids Prompt, Hilleshog E-17, Hilleshog E-33, Hilleshog E-38, Hilleshog RH-5, ACH 963, ACH 913, and ACH 1353. These varieties were the twelve sugarbeet varieties in the Michigan State University Sugarbeet Advancement variety trials in 2002. In addition, two former commercial varieties ACH 185 a triploid, and USH 20 a diploid, and four USDA lines including WC 93404 (sp85576cms X 92HS25), WC

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[2] Loveland industries Inc., PO Box 1289, Greeley, CO 80632.
[3] Teejet even fan tips. Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.

93406 (sp85657cms X 92HS25), WC 93407 (FC607cms X 92HS25), and WC 93409 (C40 X 92HS26) were included with the 12 commercial varieties.

Field research. Fourteen sugarbeet varieties and four USDA lines were planted with a small-plot planter on April 30, 2002 (Table 6). Plots were four rows wide by 7.6 m, and the center 3 m of each plot were treated with herbicide. The first micro-rate treatment was applied when sugarbeet were at the cotyledon growth stage and was repeated 7 and 14 d later. The herbicides applied in the micro-rate were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg/ha plus triflusulfuron at 0.004 kg/ha plus clopyralid at 0.023 kg/ha plus MSO[2] at 1.5% v/v. Herbicide treatments were applied with a back-pack compressed air sprayer equipped with an 8003E spray tip calibrated to deliver 187 L ha^{-1} at 207 kPa. The experimental design was a RCBD in a split-plot arrangement with three replications. The whole-plot was variety and sub-plot was herbicide treatment. Treatments consisted of either treated or untreated sugarbeet. Three plants from each of the center two rows of the treated area, and three plants from each of the center two rows of the untreated area were harvested one wk after the third micro-rate treatment. Leaf area and leaf fresh weights were measured at harvest and dry weights were recorded 1 wk later.

RESULTS AND DISSCUSSION

Growth chamber research. In the first experiment, herbicide treatments reduced leaf fresh weight, dry weight, and leaf area of Beta 5400[4] and Beta 5736; however, there was no significant reduction in the measured variables for the varieties ACH 555[5] and HM E-17[6] (Table 1). The major difference between the Beta varieties and the other two varieties was that the two Beta varieties were triploids and the other two varieties were diploids. In experiment two, leaf area, fresh weight, and dry weight of Beta 5736 were reduced by micro-rate treatments and Hilleshog E-17 again did not have a significant reduction in leaf area or biomass, confirming the results from the first experiment. However, the fresh weight, dry weight, and leaf area of two triploids Spartan and Beta 5451 were not significantly reduced by micro-rate treatments (Table 2). Two diploids, Hilleshog E-38 and Hilleshog RH-5, had significant reductions in all measured variables. Six diploids including Prompt, Hilleshog E-33, Hilleshog E-38, Hilleshog RH-5 ACH 913, ACH 1353, and USH 20 had dry weight reductions compared to their respective controls. The USDA lines WC 93406, WC 93407, and WC 93409 showed significant reductions in leaf area and dry weight compared to the untreated control in the growth chamber (Table 4). The only variable reduced with the USDA line WC 93404 was dry weight. Therefore sugarbeet response to POST applied herbicides did not segregate by ploidy level or by seed company.

Field research. In the field, the leaf area of five triploids; Beta 5736, Beta 5451, Beta 5172, ACH 185, and Spartan were reduced by 30, 38, 32, and 30%, respectively. However, this was not statistically significant. The leaf dry weights of Beta 5736, Beta 5451, Beta 5172, and ACH 185 were reduced by the micro-rate applications (Table 3). The leaf area of diploids was reduced by up to 40% but this was not statistically

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[4] Beta seeds, 1788 Maschall Road, Shakopee, MN 55379.
[5] American Crystal Sugar Company, 101 N. 3[rd] St. Moorhead, MN 56560.
[6] Hilleshog seeds, 1350 Kansas Ave., Longmount, CO 80501.

significant. Dry weights of the diploids Hilleshog E-33, Hilleshog E-38, ACH 963, and USH 20 were reduced by herbicide treatments (Table 5). The only diploids without significant reductions in dry weights were Hilleshog E-17, Hilleshog RH-5, Prompt, ACH 913, and ACH 1353. These results are similar to the growth chamber results for Hillshog E-17, but not for Prompt, ACH 1353, and ACH 913. The only significant reductions in the four USDA lines were the leaf dry weights of WC 93407 and WC 93409.

Although some of the results differed between the growth chamber and the field, the leaf fresh and dry weight of Hilleshog E-17 were not significantly reduced by the micro-rate herbicide applications in the growth chamber or the field (Table 5). Furthermore the leaf fresh and dry weights of Beta 5736 were reduced in the growth chamber and in the field. The Beta Seed Co. is presently replacing Beta 5400 and Beta 5736 with Beta 5451 and 5172. These data indicate that the newer varieties appear to be less sensitive to micro-rate herbicide applications. Furthermore, the Hilleshog Seed Co. is replacing E-17, with E-33 and E-38. These data indicate that their newer varieties appear to be more sensitive to micro-rate treatments. However, it is difficult to draw conclusions from one seed lot of each of these varieties. Further work should compare seed lots and seed processing to determine how these factors affect emergence, stress and herbicide response, and yield. Perhaps the seed lots of E-33 and E-38 tested were more sensitive than seed produced in 2002 for the 2003 growing season. Since sugarbeet seed harvest, handling, and processing are such critical components of seed emergence, the influence of these factors versus the genetics of the variety on herbicide response is difficult to assess. Varieties vary in emergence from year to year suggesting that some varieties are affected by environmental conditions more than others. Seed processing affects emergence, and some sugarbeet growers purchase raw seed and some purchase pelleted seed. Seed quality is something that may not be adequately controlled, but it would be beneficial to know how varieties are affected by seed harvest and processing, as well as by field conditions including herbicide applications. Clearly differences in Hilleshog E-17 and Beta 5736 response to POST applied herbicides may occur in future varieties.

Furthermore, it is difficult to determine how each variety metabolizes the four herbicides applied in the micro-rate. The micro-rate applied to each variety contained desmedipham, phenmedipham, triflusulfuron, and clopyralid. Desmedipham and phenmedipham inhibit photosynthesis by binding to the Q_B-binding niche on the D1 protein of the photosystem II complex in chloroplast thylakoid membranes (Vencill 2002); triflusulfuron inhibits acetolactate synthase (ALS), a key enzyme in the biosynthesis of the branched-chain amino acids isoleucine, leucine, and valine (Vencill 2002); and the mechanism of action of clopyralid is not completely understood, but is similar to that of endogenous auxin and other auxin-type herbicides (Vencill 2002). Each variety may respond differently to each of the applied modes of action, and thus respond to a micro-rate application may be confounded by applying herbicides with multiple modes of action.

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Table 1. Fresh weight, dry weight, and leaf area of four commercial sugarbeet varieties following three micro-rate herbicide treatments in the growth chamber[ab].

Variety	Ploidy level	Herbicide	Leaf fresh weight		Leaf dry weight		Leaf area	
			g	reduction — % —	g	reduction — % —	cm^2	reduction — % —
Beta 5400	Triploid	Treated	117*	26	0.51*	35	61*	24
		Untreated	148		0.78		80	
Beta 5736	Triploid	Treated	98*	30	0.39*	43	49*	35
		Untreated	140		0.69		75	
ACH 555	Diploid	Treated	133	2	0.67	11	72	14
		Untreated	136		0.75		84	
HM E-17	Diploid	Treated	130	7	0.69	17	69	14
		Untreated	140		0.83		80	

[a]*Indicates significant differences between means within varieties and columns according to Tukey's test for honestly significant differences ($HSD_{0.05}$) from an ANOVA.
[b]Herbicides applied were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha and MSO at 1.5% v/v.

Table 2. Fresh weight, dry weight, and leaf area of fourteen commercial sugarbeet varieties following three micro-rate herbicide treatments in the growth chamber[ab].

Variety	Ploidy level	Herbicide	Leaf fresh weight		Leaf dry weight		Leaf area	
			g	reduction — % —	g	reduction — % —	cm^2	reduction — % —
Spartan	Triploid	Treated	16.0	18	1.1	31	350	13
		Untreated	19.5		1.6		401	
Beta	Triploid	Treated	17.3	10	1.1	27	367	8
5451		Untreated	19.3		1.5		399	
Beta	Triploid	Treated	13.3	32	0.8*	43	311	10
5172		Untreated	19.7		1.4		347	
Beta	Triploid	Treated	12.1*	38	0.8*	43	263*	24
5736		Untreated	19.7		1.4		347	
ACH	Triploid	Treated	16.2	28	1.0*	44	358*	17
185		Untreated	22.4		1.8		432	
HM	Diploid	Treated	16.3	13	1.3	19	378	3
E-17		Untreated	18.8		1.6		389	
HM	Diploid	Treated	15.0	20	0.9*	47	322	16
E-33		Untreated	18.8		1.7		382	
HM	Diploid	Treated	13.3*	43	0.8*	55	292*	27
E-38		Untreated	22.3		1.8		399	
HM	Diploid	Treated	10.9*	45	0.7*	59	253*	27
RH-5		Untreated	20.0		1.7		348	
Prompt	Diploid	Treated	15.3	22	1.1*	39	326	16
		Untreated	19.5		1.8		386	
ACH	Diploid	Treated	16.9	13	1.0	33	320	16
963		Untreated	19.5		1.5		382	
ACH	Diploid	Treated	14.0	31	0.9*	44	297*	21
913		Untreated	20.4		1.6		377	
ACH	Diploid	Treated	14.1*	26	0.9*	44	314	18
1353		Untreated	19.0		1.6		381	
USH 20	Diploid	Treated	15.0	12	1.0*	37	331	9
		Untreated	17.1		1.6		365	

[a]*Indicates significant differences between means within varieties and columns according to Tukey's test for honestly significant differences ($HSD_{0.05}$) from an ANOVA.
[b]Herbicides applied were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha and methylated seed oil at 1.5% v/v.

Table 3. Fresh weight, dry weight, and leaf area of fourteen commercial sugarbeet varieties following three micro-rate herbicide treatments in the field[ab].

Variety	Ploidy level	Herbicide	Leaf fresh weight		Leaf dry weight		Leaf area	
			g	reduction — % —	g	reduction — % —	cm^2	reduction — % —
Spartan	Triploid	Treated	50	43	5.6	44	925	38
		Untreated	88		10		1497	
Beta	Triploid	Treated	51	44	5.4*	43	967	38
5451		Untreated	91		9.5		1572	
Beta	Triploid	Treated	43	34	4.8*	32	812	32
5172		Untreated	65		7.1		1186	
Beta	Triploid	Treated	54	29	5.9*	29	900	30
5736		Untreated	76		8.3		1282	
ACH	Triploid	Treated	47	34	5.5*	30	883	30
185		Untreated	71		7.9		1262	
HM	Diploid	Treated	33	42	3.8	43	628	40
E-17		Untreated	57		6.7		1042	
HM	Diploid	Treated	40	38	4.2*	42	742	35
E-33		Untreated	65		7.3		1148	
HM	Diploid	Treated	36	35	4.2*	33	715	29
E-38		Untreated	55		6.3		1014	
HM	Diploid	Treated	46	22	5.1	20	780	23
RH-5		Untreated	59		6.4		1017	
Prompt	Diploid	Treated	42	32	4.9	32	783	27
		Untreated	62		7.2		1080	
ACH	Diploid	Treated	45	32	5.1*	32	833	19
963		Untreated	66		7.5		1029	
ACH	Diploid	Treated	63	15	6.8	11	1205	11
913		Untreated	74		7.6		1352	
ACH	Diploid	Treated	56	8	6.3	2	1082	3
1353		Untreated	61		6.4		1111	
USH 20	Diploid	Treated	53	35	5.9*	37	945	29
		Untreated	82		9.3		1335	

[a]*Indicates significant differences between means within varieties and columns according to Tukey's test for honestly significant differences ($HSD_{0.05}$) from an ANOVA.
[b]Herbicides applied were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha and methylated seed oil at 1.5% v/v.

Table 4. Fresh weight, dry weight, and leaf area of four USDA sugarbeet lines following three micro-rate herbicide treatments in the growth chamber and in the field[ab].

Line[c]	Ploidy level	Herbicide	Leaf fresh Weight		Leaf dry weight		Leaf area	
				reduction		reduction		reduction
			g	— % —	g	— % —	cm^2	— % —
Growth chamber studies								
WC 93404	Diploid	Treated	12.7	27	0.9*	47	290	20
		Untreated	17.5		1.7		362	
WC 93406	Diploid	Treated	11*	41	0.8*	50	255*	27
		Untreated	18.7		1.6		348	
WC 93407	Diploid	Treated	11.5*	44	0.8*	53	274*	29
		Untreated	20.7		1.7		384	
WC 93409	Diploid	Treated	10	43	0.7*	50	225*	28
		Untreated	17.6		1.4		314	
Field studies								
WC 93404	Diploid	Treated	40	38	6.5	16	785	31
		Untreated	65		7.7		1137	
WC 93406	Diploid	Treated	39	15	5.1	12	873	1
		Untreated	46		5.8		879	
WC 93407	Diploid	Treated	39	46	4.5*	48	742	46
		Untreated	72		8.6		1377	
WC 93409	Diploid	Treated	35	48	4.2*	47	683	44
		Untreated	67		7.9		1220	

[a]*Indicates significant differences between means within varieties and columns according to Tukey's test for honestly significant differences ($HSD_{0.05}$) from an ANOVA.
[b]Herbicides applied were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha and methylated seed oil at 1.5% v/v.
[c]WC 93404 (SP85576 cmc X 9sH525), WC 93406 (SP85657 cms X 92H525), WC 93407 (FC607 cms X 92H525), WC 93409 (C40 X 92H526).

Table 5. Leaf area and dry weight reductions following three herbicide applications of 16 sugarbeet varieties in the growth chamber and in the field[ab].

		Leaf area reduction			Leaf dry weight reduction		
Variety	Ploidy level	Exp. 1	Exp. 2	Field	Exp. 1	Exp. 2	Field
Beta 5400	Triploid	*	-	-	*	-	-
Beta 5736	Triploid	*	*	NS	*	*	*
Beta 5451	Triploid	-	NS	NS	-	NS	*
Beta 5172	Triploid	-	*	NS	-	*	*
ACH 185	Triploid	-	*	NS	-	*	*
Spartan	Triploid	-	NS	NS	-	NS	NS
Hilleshog E-17	Diploid	NS	NS	NS	NS	NS	NS
Ach 555	Diploid	NS	-	-	NS	-	-
Prompt	Diploid	-	NS	NS	-	*	NS
Hilleshog E-33	Diploid	-	NS	NS	-	*	*
Hilleshog E-38	Diploid	-	*	NS	-	*	*
Hilleshog RH-5	Diploid	-	*	NS	-	*	NS
ACH 963	Diploid	-	NS	NS	-	NS	*
ACH 913	Diploid	-	*	NS	-	*	NS
ACH 1353	Diploid	-	NS	NS	-	*	NS
USH 20	Diploid	-	NS	NS	-	*	*

[a]*Indicates significant differences between means within varieties and columns according to Tukey's test for honestly significant differences ($HSD_{0.05}$) from an ANOVA, - indicates that the specific variety was not included in that specific experiment, and NS indicates no significant differences between means within varieties and columns.
[b]Herbicides applied were desmedipham plus phenmedipham (1:1 ratio) at 0.09 kg ai/ha plus triflusulfuron at 0.004 kg ai/ha plus clopyralid at 0.023 kg ae/ha and methylated seed oil at 1.5% v/v.

EXTENSION SUMMARY OF WEED MANAGEMENT SYSTEMS IN SUGARBEET

Applying herbicides at a micro-rate every 97 GDD (max + min temperature/2 – 1.1 C = GDD/day C) controlled common lambsquarters and redroot pigweed in the growth chamber and the field. Applying a micro-rate herbicide treatment every 97 GDD (175 GDD F) increased the time between applications by one to three days compared to micro-rate herbicide applications every 7 d in 2001 and 2002. Applying micro-rate herbicide treatments every 125 GDD (225 GDD F) resulted in weed control similar to the 7 d timing and caused less sugarbeet injury than the 7 d or 97 GDD application timings. When the micro-rate herbicide treatment was applied every 152 GDD (275 GDD F), common lambsquarters control was acceptable; however, *Amaranthus* spp. control was reduced compared to more frequent application timings. We would recommend applying a micro-rate herbicide treatment every 152 GDD (C) early in the season (April to mid May) when early season weeds such as common lambsquarters, common ragweed (*Ambrosia artemisiifolia* L.), and velvetleaf (*Abutilon theophrasti* Medicus) are emerging, and then switching to 125 or 97 GDD timings when *Amaranthus* spp. starts to emerge. Annual grasses can be controlled by adding clethodim or quizalofop to all or one of the micro-rate herbicide treatments.

Preemergence (PRE) herbicides increased common lambsquarters and *Amaranthus* spp. control by 2 to 11% in 2001 and 2002. In 2002, PRE herbicides increased sugarbeet injury by 10 to 15% when combined over postemergence (POST) herbicides. This probably occurred because of cool-wet conditions early in the season in 2002. PRE herbicides such as cycloate or *s*-metolachlor will control yellow nutsedge (*Cyperus esculentus* L.) Cycloate also provides good control of velvetleaf. If a field is infested with yellow nutsedge and velvetleaf, PRE herbicides should be applied because POST herbicides do not control yellow nutsedge and velvetleaf is difficult to control with only triflusulfuron. Depending on which PRE herbicide is selected, the cost is similar to or greater than the cost of one or more POST micro-rate herbicide applications. With pyrazon, ethofumesate, or the combination of pyrazon and ethofumesate, the cost is similar to two or more micro-rate herbicide applications. The registration of *s*-metolachlor in 2003 and the expected registration of dimethenamid in 2004, along with the registration of generic forms of ethofumesate may reduce the cost of PRE herbicides in sugarbeet. So each sugarbeet grower will have to weigh the cost of a PRE herbicide with the cost of an application of a micro-rate or standard-split POST herbicide treatment.

In this research, desmedipham plus phenmedipham or desmedipham plus phenmedipham plus ethofumesate applied in the micro-rate or standard-split in combination with triflusulfuron and clopyralid provided similar weed control and sugarbeet injury. In other research, micro-rate applications of desmedipham plus phenmedipham plus ethofumesate have provided less sugarbeet injury and *Amaranthus* spp. control. Micro-rate herbicide applications provide greater control of velvetleaf than standard-split applications, because the methylated seed oil used in the micro-rate increases the effectiveness of triflusulfuron. For both micro-rate and standard-split applications, the timing of the first herbicide application is very important. Herbicides need to be applied when weeds, particularly common lambsquarters, *Amaranthus* species, and velvetleaf are in the cotyledon to- two- leaf growth stage.

This research indicated that sugarbeet varieties respond differently to herbicide treatments. Hilleshog E-17 has been the leading variety in Michigan for several years because of its' early season vigor. However, E-17 lacks disease resistance so some sugarbeet growers plant other varieties such as Beta 5736. In this research, the leaf dry weight of E-17 was not significantly reduced by three micro-rate herbicide applications, when measured 1 week after the last application. However, the leaf dry weight of Beta 5736 was significantly reduced in all three experiments. Beta 5736 is one of the leading sucrose-producing varieties in Michigan. Therefore, early season leaf injury may not result in sucrose yield loss. Breeding for resistance or tolerance to POST herbicides would be difficult, because POST herbicide applications usually are combinations of three or more herbicides with multiple modes of action. The response of each sugarbeet variety to any stress including herbicides may depend on the growing conditions of the seed plants, how the seed was handled, conditioned, and stored, and the environmental conditions at planting, through the time of sugarbeet emergence, and at the times of herbicide applications.

Since the phenotype expressed each year is a function of the genotype and the environment, it may be that the environment is playing a key role in sugarbeet variety response to POST herbicides and other stresses each year. Growers will continue to choose varieties based on sucrose yield and disease resistance. How varieties respond to early season stress, including herbicide applications is an area of future research. Sucrose synthesis may not be delayed by early season stress and reductions in leaf area or dry weight.