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EFFECT OF VARIETY SELECTION, HERBICIDES, AND TILLAGE ON MICHIGAN SUGARBEET (*Beta vulgaris*) PRODUCTION

By

Scott Lee Bollman

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ABSTRACT

EFFECT OF VARIETY SELECTION, HERBICIDES, AND TILLAGE ON MICHIGAN SUGARBEET (*Beta vulgaris*) PRODUCTION

By

Scott Lee Bollman

Michigan sugarbeet growers have two additional options for residual control of late-emerging weeds, with the recent registrations of s-metolachlor and dimethenamid-P. Applications of these herbicides can cause sugarbeet injury. Previous research has shown that sugarbeet varieties differ in their response to herbicides. Reduced sugarbeet growth from herbicide injury can impact sugarbeet's competitiveness with late-emerging weeds and sugarbeet yield. To reduce the potential for sugarbeet injury, *s*-metolachlor should be applied after the first micro-rate application or when sugarbeets are at the 2-leaf stage or larger, with the exception of applying one-fourth of the *s*-metolachlor rate in each of four micro-rate applications. Dimethenamid-P applications should be applied after the second micro-rate application or once sugarbeets are at the 4-leaf stage. The addition of either *s*-metolachlor or dimethenamid-P to micro-rate herbicide applications improved giant foxtail, common lambsquarters, and pigweed (redroot pigweed and Powell amaranth) control compared with the base micro-rate treatment. None of the treatments reduced recoverable white sucrose yield. Results from field and greenhouse experiments indicate that the residual activity of *s*-metolachlor was greater than that of dimethenamid-P. Split-applications of both herbicides provided similar residual control of giant foxtail compared with full-application rates.

Sugarbeet varieties varied in their response to *s*-metolachlor and dimethenamid-P in field and greenhouse experiments. Greenhouse results indicated the greatest sugarbeet

injury from *s*-metolachlor and dimethenamid-P occurred from applications directly to the soil compared with applications to the leaf surface, indicating that herbicide absorption is primarily through the roots and/or hypocotyls of the sugarbeet plant. Under hydroponic conditions, there were no differences in sugarbeet tolerance between *s*-metolachlor and dimethenamid-P, indicating that differences in herbicide solubility and adsorption to the soil contributed to the differences in the magnitude of injury between the herbicides in the field. 'Beta 5833R' was the most tolerant sugarbeet variety and 'Hilleshog 7172RZ' was the most susceptible sugarbeet variety to *s*-metolachlor and dimethenamid-P. Slower metabolism of ^{14}C-herbicides in sugarbeet shoots was likely the most significant factor contributing to differences in sugarbeet variety tolerance to both *s*-metolachlor and dimethenamid-P.

Fields trials were conducted to determine if tillage and soil-applied herbicides had an effect on sugarbeet injury and weed control from micro-rate herbicide applications. Sugarbeets emerged earlier in the moldboard plow system compared with the chisel plowed system. However, under dry conditions sugarbeet emergence was later in the moldboard plowed system. PRE treatments of *s*-metolachlor, ethofumesate, and ethofumesate plus pyrazon followed by four micro-rate applications increased sugarbeet injury compared with the no-PRE treatment. Common lambsquarters, pigweed (redroot pigweed and Powell amaranth), and giant foxtail control in mid-August was consistently higher when a PRE herbicide was applied prior to the micro-rate herbicide treatments. Recoverable white sucrose yield was greater in the moldboard plowed treatments compared with the chisel plowed treatments in three out of four sites tested.

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LITERATURE REVIEW

INTRODUCTION

The two major sources of sucrose in the United States are sugarbeets (*Beta vulgaris* L.) and sugarcane (*Saccharum* spp.). As a member of the *Chenopodiaceae* family, the sugarbeet is grown in the northern parts of the United States where the climate is more temperate. Sugarcane is grown in the tropical and subtropical regions of the southern United States. Sugarbeet is a biennial crop and is harvested for sucrose prior to its reproductive growth stage. In 2004, sugarbeet was grown on 552,793 hectares in the U.S. and contributed over one billion dollars to the U.S. economy (Anonymous 2005b).

Sugarbeet is often the most important cash crop in a grower's rotation. Weed control in sugarbeet continues to be the most serious production problem that these growers face (Luecke and Dexter 2004). The low growth habit of sugarbeet coupled with slow canopy development allows weeds to surpass sugarbeet in growth. Weeds growing above the sugarbeet canopy are able to compete more effectively for light than the sugarbeets that are growing below the canopy. Weeds also compete with sugarbeet for available nutrients and moisture, causing reductions in sugarbeet yield (Schweizer and May 1993). Weeds can also cause problems unrelated to sugarbeet yield. They can cause problems with harvest, reduce sugarbeet quality, produce seed that contributes to future weed problems, and act as hosts for insects and diseases (Dexter 2004).

HISTORY OF SUGARBEET WEED CONTROL

Before modern herbicides and equipment were introduced, primary methods of weed removal was done by hand pulling and hand hoeing. The use of mechanical cultivation began in the mid-nineteenth century with the use of cultivators, rotary hoes and tine weeders (Schweizer and Dexter 1987; Schweizer and May 1993). In the late nineteenth century, about the time when hand labor became difficult to find, the use of chemicals for weed control was introduced. Inorganic compounds such as sulfuric acid and iron sulfate were first used on sugarbeet in the 1890's, however, significant injury occurred to the crop and weed control was not entirely successful (Schweizer and May 1993). Most of these early chemicals on sugarbeet were applied prior to crop and weed emergence.

Many of the first synthetic herbicides for sugarbeet were applied pre-plant incorporated (PPI) or preemergence (PRE) to sugarbeet (Schweizer and May 1993). Pyrazon (5-amino-4-chloro-2-phenyl-3(2*H*)-pyridazinone) and ethofumesate ((±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate) were applied PRE while cycloate (*S*-ethyl cyclohexylethylcarbamothioate) was applied PPI for residual weed control in sugarbeet. Although more effective than previous weed control methods, PRE herbicides had several drawbacks associated with them. PRE herbicide applications often resulted in a reduction in sugarbeet growth (Sadowska 1973; Smith et al. 1982; Smith and Schweizer 1983). Broadcast applications of these herbicides were also very expensive, so PRE herbicides were typically applied in a band application to make them economical. These herbicides also required rainfall to incorporate them into the soil.

Due in part to this moisture requirement, weed control from PRE herbicides was often inconsistent among years (Renner and Powell 1991).

Beginning in the 1960's and into the 1970's, herbicides such as desmedipham (ethyl[3-[[(phenylamino)carbonyl]oxy]phenyl]carbamate}, phenmedipham (3-[(methoxycarbonyl)amino]phenyl (3-methyl-phenyl) carbamate) and ethofumesate were registered for use in sugarbeet. These herbicides were typically applied postemergence (POST) with a surfactant or mineral oil for control of broadleaf weeds. However, due to significant sugarbeet injury, manufacturers developed tank mixtures of these herbicides and reduced the amount of surfactant in order to provide more crop safety. In the 1980's, most the of graminicide herbicides, quizalofop ((*R*)-2-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid), clethodim ((*E*,*E*)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one), and sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohex-en-1-one) were developed for POST control of perennial and annual grass weeds (Schweizer and May 1993; Vencill 2002). In addition, the plant growth regulator herbicide clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) was developed. This herbicide controls several thistle species, common ragweed (*Ambrosia artemisiifolia* L.), and common cocklebur (*Xanthium strumarium* L.) (Vencill 2002). In the early 1990's, the acetolactase synthase (ALS) inhibiting herbicide, triflusulfuron methyl (methyl 2-[[[[[4-((dimethylamino-6-(2,2,2-trifluoroethoxy))-1,3,5-triazin-2-yl]amino]carbonyl]amino] sulfonyl]-3-methylben zoate) was developed. Triflusulfuron methyl controls kochia (*Kochia scoparia* (L.) Schrad.) and velvetleaf (*Abutilon theophrasti* Medik.) (Starke and Renner 1996; Dexter et al. 2001).

Since the registrations of clopyralid and triflusulfuron in the 1980's and 1990's, the use of PRE herbicides for weed control in sugarbeets has decreased dramatically. From 1984 to 2002, PRE herbicide use in sugarbeets decreased from 96 to 4% (Dexter and Luecke 2002). The additional options of several effective POST herbicides like clopyralid and triflusulfuron and the high cost of PRE herbicides lead to the shift in herbicide application timings (Hendrick et al. 1973; Renner and Powell 1991).

In an attempt to reduce sugarbeet injury, research began in 1972 investigating the possibilities of split-applications of phenmedipham. Split-applications consisted of applying 50% of the normal use rate of phenmedipham (0.56-0.84 kg/ha) to 4-leaf sugarbeets and then repeating the application 5 to 7 days later. Sugarbeet injury was less and weed control increased compared with a single full-rate application (Dexter 1994).

By 1980, split-applications of the POST herbicide combination of desmedipham + phenmedipham were widely used for weed control in sugarbeets in order to reduce sugarbeet injury caused by a single herbicide application at the labeled use rates. A typical weed control program would involve a preemergence (PRE) herbicide application followed by 1 or 2 POST standard-split applications and 3 to 4 between-row cultivations (Dexter 1994; Schweizer and May 1993). However, in the late-1990's a new POST herbicide option was developed that changed how sugarbeet growers approached weed control. The micro-rate system included a combination of extremely low rates of desmedipham, or desmedipham + phenmedipham (1:1), or desmedipham + phenmedipham + ethofumesate (1:1:1) plus triflusulfuron (methyl 2-[[[[[4-((dimethylamino-6-(2,2,2-trifluoroethoxy))-1,3,5triazin-2-yl]amino]carbonyl] amino]sulfonyl]-3-methylbenzoate) at 0.004 kg ai/ha plus clopyralid (3,6-dichloro-2-

pyridinecarboxylic acid) at 0.026 kg ai/ha plus methylated seed oil (MSO) at 1.5% v/v. This combination was applied POST three to five times to young actively growing weeds at the cotyledon stage. The MSO adjuvant increased the herbicide activity on weeds, therefore allowing the herbicide rate to be reduced by 75% (Wilson et al. 2001) The advantages of the micro-rate system included the ability to apply herbicides any time of the day, reduced sugarbeet injury, reduced herbicide use and reduced between-row cultivations (Hamill et al. 2001; Wilson et al. 2001). One disadvantage of the micro-rate system was that it may typically require four or more applications to control newly germinating weeds compared with two or three standard-rate applications. According to surveys conducted by Luecke and Dexter (2004) in eastern North Dakota and Minnesota, the number of herbicide applications in sugarbeets increased from 3.2 times in 1990 to 4.3 times in 2004. The increased number of applications can be attributed to the adoption of the micro-rate herbicide system.

Proper timing of a micro-rate is a delicate balance between managing sugarbeet injury and optimizing weed control. When first adapted, the micro-rate timing was based on scouting fields for weeds less than 2 cm in size and then basing sequential applications on calendar days. The first micro-rate was to be applied when weeds were at the cotyledon growth stage and then further micro-rates were to be applied every 5 to 7 d. However, these recommendations were not always accurate because of varying environmental conditions. If the weather was warm, weeds grew rapidly and were too large at the next application timing. If the weather was cool, a micro-rate was applied too early causing sugarbeet injury. If micro-rates are continually applied too early, additional micro-rates would be required to control newly germinating weeds, thus costing the grower further expense for weed control (Dale and Renner 2004).

To accommodate for varying environment conditions, researchers began working on the use of growing degree days (GDD) to time micro-rate herbicide applications. Since the temperature is considered the primary factor when determining the rate at which plants develop, using a model based on temperature would be one way to quantify plant growth (Holen and Dexter 1996). Growing degree-days are used to predict the development of several other crops (Khurshid and Hutton 2005; Juskiw et al. 2001) and weeds (Webster et al. 1998; Anderson 1997). Growing degree-days are calculated by taking the average daily temperature and subtracting a specific base temperature. This base temperature is selected based the lowest germination temperature of weed species present. In studies comparing several micro-rate intervals in Michigan, research showed that applications based on a 125 GDD interval with base temperature of 1.1 C was a more effective application parameter than a fixed schedule (Dale and Renner 2004). This interval provided good weed control and did not injure sugarbeet. By extending the time between herbicide applications, the sugarbeet was able to metabolize the herbicide and return to its normal photosynthetic rate, thus increasing leaf growth (Hendrick et al. 1974).

SUGARBEET AND WEED INTERACTIONS

Controlling weeds without severely injuring the sugarbeet is the goal of a weed management system in sugarbeets. The time of weed emergence alters the ability of the weeds to compete with the crop. Weeds that emerge within eight weeks of planting are typically more competitive with sugarbeet than weeds that emerge later in the growing season (Dawson 1965; Schweizer and May 1993). Therefore, removal of all weeds early in the season is imperative to maximize yields. In sugarbeet, usually 70% of weeds present are broadleaf weeds and the remaining 30% are grasses (Schweizer and May 1993). Previous research has shown that broadleaf weeds are generally more competitive than grasses. Brimhall et al. (1965) showed that one redroot pigweed (*Amaranthus retroflexus* L.) per sugarbeet plant reduced yield by 70% compared with only 26% yield loss by one green foxtail (*Setaria viridis* (L.) Beauv.). In sugarbeet, a number of studies have investigated the interference of different weeds on sugarbeet root yields. Root yields were decreased when nine to eleven Powell amaranth (*Amaranthus powellii* S. Wats) plants, three to six redroot pigweed, four to six common lambsquarters, one common sunflower (*Helianthus annuus* L.), four kochia, and nine to twelve velvetleaf plants per 30 m of row compete with sugarbeet throughout the season (Schweizer 1973; Schweizer 1981; Schweizer and Bridge 1982; Schweizer 1983; Schweizer and Lauriduson 1985). In other studies, Evans and Dexter (1980) found densities of 0.33, 1, and 3 redroot pigweed plants/m^2 reduced sugarbeet root yield by 17, 15, and 34%, respectively.

Late-emerging weeds can also compete for resources that limit sugarbeet production. Full sugarbeet stands that reach full canopy closure can control late-emerging weeds. In fact, Dawson (1977) reported that annual weeds that emerged after July 1 in a full sugarbeet stand were controlled by shade. However, problems with sugarbeet stand establishment and diseases often result in incomplete stands. Weed growth in these incomplete stands was roughly proportional to the unshaded area left available (Dawson 1973). At the same density, if the sugarbeet stand was 1/2 or 1/3 that of a full stand, competition from barnyardgrass (*Echinochloa crus-galli* L.) and pigweed (mixture of redroot pigweed and *A. powellii* S Wats.) reduced root yield by 5 to 39% and 19 to 49%, respectively. This reduction in yield was due to weed competition. Therefore, controlling weeds between the date of last herbicide application and canopy closure is a very important part of a weed management program.

USE OF *S*-METOLACHLOR AND DIMETHENAMID-P

Before the micro-rate system was widely adopted, PRE herbicides were used on a significant number of the sugarbeet acres. Luecke and Dexter (2004) reported in eastern North Dakota and Minnesota that about 47% percent of sugarbeet acres were treated with a PRE herbicide in 1989. However, as the micro-rate system gained popularity, PRE herbicide use declined to as low as 4% in 2002. Use of PRE herbicides on sugarbeet in Michigan followed a similar trend. From 1998 to 2002, the use of PRE herbicides decreased by 35%[1].

Beginning in 2003, PRE herbicides regained popularity. Preemergence herbicide use increased to 29% in 2003 and 31% in 2004 in eastern North Dakota and Minnesota (Luecke and Dexter 2004). The increased use of PRE herbicides in 2003 and 2004 was related to the registration of *s*-metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide) for use on sugarbeet and difficulty with managing ALS-resistant kochia with POST herbicide applications only.

S-metolachlor is a chloroacetamide herbicide that acts by inhibiting the biosynthesis of fatty acids, lipids, proteins, isoprenoids and flavonoids. Currently, *s*-metolachlor can be applied early preplant (EPP), preplant incorporated (PPI), or PRE in

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

corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr), dry beans (*Phaseolus vulgaris* L.) cotton (*Gossypium hirsutum* L.), potato (*Solanum tuberosum* L.), sorghum (*Sorghum bicolor* L.), and several other crops. Primarily used for annual grass control, *s*-metolachlor also has activity on small seeded broadleaf weeds including pigweed (*Amaranthus*) species. If applied PPI, *s*-metolachlor is effective for yellow nutsedge (*Cyperus esculentus* L.) control. However, because *s*-metolachlor is primarily soil active, it must be applied prior to weed emergence (Anonymous 2005c; Vencill 2002).

Dimethenamid-P is another chloroacetamide herbicide that has been recently registered for use in sugarbeets. Dimethenamid-P and *s*-metolachlor target the same site of action in the plant and are in the same chemical family, thus the weed spectrums that these two herbicides control is very similar (Vasilakoglou and Eleftherohorinos 2003; Vencill 2002). Dimethenamid-P may be applied EPP, PPI, PRE, and POST in corn, soybean, dry bean, sorghum, and several other crops. When applied POST, dimethenamid-P must be applied before weeds have emerged, since it inhibits shoot development in germinating plants and does not have POST activity (Anonymous 2005a).

There is the risk of sugarbeet injury as a result of *s*-metolachlor applications. Dexter and Luecke (2003) reported that in 2003, PPI applications of *s*-metolachlor resulted in an average of 44% injury. When they compared crop injury data in 2003 to data from the previous six years, sugarbeet injury was 38% higher in 2003. They speculated that the increased injury observed was due to cold, wet conditions that slowed sugarbeet emergence and increased herbicide uptake. They also reported that farmers who applied *s*-metolachlor PRE or lay-by (POST) had significantly less injury compared with those who made PPI applications. Additionally, Renner (2003) and Dale et al. (2006) observed a loss of sugarbeet stand and plant stunting due to PRE applications of *s*-metolachlor. Loss of sugarbeet stand can not only reduce yield, but it can slow canopy closure allowing weeds to germinate, emerge, and capture light for competition with sugarbeets later in the growing season.

Like *s*-metolachlor, there is a potential for crop injury from applications of dimethenamid-P. Rice et al. (2002) reported significant injury from POST applications of dimethenamid-P when applied to four- to six-leaf sugarbeets. The injury that was observed from these applications was general plant stunting and slight yellowing. Although, both herbicides have been reported to cause some sugarbeet injury, there have been few reports comparing sugarbeet response the two herbicides in the same trial.

Both *s*-metolachlor and dimethenamid-P have shown the potential to increase weed control in sugarbeet. Dexter et al. (2002) reported that pigweed control was similar when dimethenamid-P was applied in the second of three micro-rate applications compared with four micro-rate applications. Rice et al. (2002) and Guza et al. (2002) both observed an increase in weed control when dimethenamid-P was added to other sugarbeet herbicide treatments. Guza et al. (2002) reported an increase in control of redroot pigweed, barnyardgrass, and hairy nightshade (*Solanum physalifolium* Rusby) when dimethenamid-P was added to glyphosate (*N*-(phosphonomethyl)glycine) in glyphosate-resistant sugarbeets. Similar results have been reported in other glyphosate-resistant crops. For example, the addition of dimethenamid-P to glyphosate extended barnyardgrass control eight weeks after treatment because of the residual activity of dimethenamid-P (Scott et al. 1998). Rice et al. (2002) showed that dimethenamid-P added to a desmedipham-phenmedipham application resulted in an 85 and 22% increase in barnyardgrass control in 1998 and 1999, respectively. The increase in control was attributed to the residual activity of dimethenamid-P controlling barnyardgrass that emerged later in the growing season. The authors pointed out that the increase in control probably would have been much higher in 1999 if sufficient rainfall had occurred shortly after the application to incorporate the herbicide.

The addition of *s*-metolachlor to micro-rate herbicide applications has also been reported to improve weed control in sugarbeets. Applying *s*-metolachlor PRE or in one of the micro-rate applications resulted in similar or greater control of common lambsquarters and redroot pigweed when compared with the standard micro-rate program (Dexter and Luecke 2004). By including *s*-metolachlor or dimethenamid-P in sugarbeet weed control programs, growers have more options for residual control of certain late emerging weed species like annual grasses and pigweeds. This addition may also allow growers to reduce or eliminate between-row cultivation, thus reducing time and expenses invested in their weed control programs in sugarbeet.

ABSORPTION, TRANSLOCATION, METABOLISM, AND DEGRADATION OF CHLOROACETAMIDE HERBICIDES

Absorption and metabolism have been the proposed basis for tolerance to chloroacetamide herbicides (Cottingham and Hatzios 1992). Dixon and Stoller (1982) showed that control of yellow nutsedge was due to its ability to more rapidly absorb metolachlor and absorb a larger quantity compared with corn. Even though both yellow nutsedge and corn absorbed the metolachlor and converted it to metabolites, corn was able to metabolize metolachlor at a much greater rate. Other researchers have reported similar results. Le Baron et al. (1988) showed that tolerant plants like corn and soybeans were able to metabolize metolachlor at sufficient rates to prevent accumulation and persistence at phototoxic levels. In corn, metabolism is further mediated by glutathione-*S*-transferase (GST) which catalyzes a conjugation of metolachlor with glutathione or homoglutathione. Glutathione-*S*-transferases are present in soybeans, but the level of activation is not as efficient as corn (Scarponi et al. 1992).

Translocation of these herbicides appears to be only from root to shoot. In an experiment conducted on corn and grain sorghum, no basipetal transport of metolachlor was observed from herbicide applied to the leaf surface. However, some acropetal movement was observed (Dixon and Stoller 1982, Zama and Hatzios 1986). There was no movement of foliar applied metolachlor in soybean or cotton. When the metolachlor was applied to the roots of the soybean plant, the herbicide was transported to the leaves.

Previous research has shown that corn injury from applications of metolachlor occur more frequently under cool, wet conditions (Boldt and Barrett 1989; Rowe et al. 1991; Viger et al. 1991). Viger et al. (1991) reported that corn seedlings grown under cool temperatures (21 C) absorbed more metolachlor compared with seedlings grown under warm temperatures (30 C). Furthermore, under these cool conditions corn seedlings metabolized the metolachlor more slowly than under warm temperatures. As with many other herbicides, metolachlor and dimethenamid-P becomes more available as soil moisture increases, thus plant absorption increases (Wehtje et al. 1987; Osborne et al. 1995). Osborne et al. (1995) showed that under conditions of excessive moisture, metolachlor and dimethenamid both caused more crop injury compared with normal soil moisture conditions. Therefore, lower crop tolerance to metolachlor and dimethenamid applications under cool, wet condition can be attributed to increased uptake of the herbicide and a reduction in metabolism of the phototoxic compound.

The primary factors affecting the dissipation of chloroacetamide herbicides in soil are adsorption and microbial decomposition. Adsorption rates typically increase with increasing organic matter and clay content; therefore the soil type may affect the availability of the herbicide (Zimdahl and Clark 1982). Although adsorption plays a role in inactivation of acetanilide herbicides, microbial decomposition accounts for nearly 90% of the total inactivation (Mullison 1979; Zimdahl and Clark 1982; Vencill 2002). Beestman and Deming (1974) showed that propachlor and alachlor were 50 times more persistence in soils that were sterilized compared with non-sterile soil. As with adsorption rates, the rate of microbial degradation of chloroacetamide herbicides can vary according to environmental conditions. Microbial degradation typically increases with under warm, moist soil conditions. Zimdahl and Clark (1982) showed the half-lives of these herbicides were inversely proportional to moisture and temperature, with more degradation occurring in soils with a higher clay contents. Therefore, predicting the length of residual activity of *s*-metolachlor and dimethenamid-P can be difficult. Mueller et al. (1999) observed that the metolachlor had a greater half-life (13.6 days) compared with dimethenamid (7.3 days) in three southern states. In other research, the half-lives of *s*-metolachlor and dimethenamid-P have been estimated at 30-50 d and 35-42 d in the northern United States, respectively (Vencill 2002). Even though these values are relatively close to each other, it should be noted they can vary greatly depending upon soil temperature, moisture, and soil textural composition (Zimdahl and Clark 1982).

Currently, there is no known method of absorption, translocation, and metabolism of metolachlor or dimethenamid-P in the sugarbeet plant, however there have been several studies investigating other herbicides. Duncan et al. (1981) reported tolerant sugarbeet seedlings and moderately susceptible common ragweed plants absorbed less ethofumesate compared with two highly susceptible species, common lambsquarters and redroot pigweed. Furthermore, the sugarbeet plants translocated much less ethofumesate than the weed species tested. Much of the ethofumesate that was applied to the plant was found in the water-soluble portion of the sugarbeet, indicating that the chemical was inactivated. The authors pointed out that the number of metabolites found in the sugarbeet plant was related to the age of the plant. Therefore, the stage of the plant at herbicide application would be the key factor in determining the response.

Similar to ethofumesate, the sugarbeet plant foliage absorbs very little lenacil (3-cyclohexyl-6,7-dihydro-1*H*-cyclopentapyrimidine-2,4 (3*H*, 5*H*)-dione) when applied to the leaves (Zhang et al. 1999). Of the lenacil that was absorbed, most was converted to polar metabolites. These polar metabolites are formed primarily by a conjugation reaction with a glucose molecule.

HISTORY OF SUGARBEET VARIETAL RESPONSE TO HERBICIDES

Previous research has shown that sugarbeet varieties respond differently to herbicide applications. Dexter and Kern (1977) showed that 19 sugarbeet varieties responded differently to applications of EPTC (*S*-ethyl dipropyl carbamothioate). Recoverable white sugar loss ranged from 7 to 27% across all varieties. These varieties tended to fall into two groups, varieties that could tolerate EPTC applications and varieties that were susceptible. Smith et al. (1982) reported significant Year by Genotype and Herbicide by Genotype interactions for juice purity and a significant Year by Herbicide interaction for root yield when evaluating the response of 15 sugarbeet varieties to cycloate and PPI applications of ethofumesate followed by an application of desmedipham + phenmedipham. Of the 15 varieties, 5 were inbred lines, 5 were F_1 hybrids, and the last five were commercial varieties. Because interactions changed by year, it is difficult for sugarbeet breeders to develop commercial varieties that may be tolerant to commercial herbicides. Further research by Smith and Schweizer (1983) observed severe reductions in sugarbeet growth in spring and early summer following herbicide applications. However, injury was overcome and no reduction in yield was observed. As advances in sugarbeet production occurred, the reliance on herbicides applied at planting has switched to applying tank-mix combinations POST (Dexter et al. 1997). Wilson (1999) investigated the response of sugarbeet varieties to different POST treatments that included desmedipham + phenmedipham with triflusulfuron, clopyralid, ethofumesate, or sethoxydim. Wilson documented that varieties responded differently to herbicides and the response varied between years. Furthermore, the sugarbeet plants recovered from early season injury and only suffered minor yield loss. Although previous research has shown that applications of *s*-metolachlor and dimethenamid-P can cause sugarbeet injury, currently there is no information on whether application timing or differences in sugarbeet varietal tolerance may reduce the risk of injury from *s*-metolachlor and dimethenamid-P applications.

TILLAGE PRACTICES

In order to save time, reduce the use of fossil fuels, and retain valuable soil organic matter, minimum tillage has become more widespread in agriculture (Glenn and Dotzenko 1978; Derksen et al. 1996). Previous research conducted in corn has shown that yields are similar in reduced tillage systems and conventional moldboard plowed systems (Griffith et al. 1973; Al-Darby and Lowery 1987). However, other researchers have reported low early-season soil temperatures and increased soil moisture in reduced tillage systems resulted in reduced early-season growth and loss in yield (Vyn and Raimbault 1993). Beyaert et al. (2002) demonstrated that as tillage density decreased, soil temperature decreased. The primary factor that was responsible for the low soil temperature and high soil moisture was increased residue cover.

Glenn and Dotzenko (1978) found that there was no difference in sugarbeet emergence, stand, or recoverable white sugar yield between minimum and conventional tillage systems in Colorado. However, in Michigan weather conditions are generally cooler and wetter in April and May than in northern Colorado (Anonymous 2006), and therefore results may differ. If PRE or PPI herbicides are applied, the risk for sugarbeet injury is increased. Pyrazon has been reported to reduce sugarbeet emergence if applied during a wet spring (Sadowska 1973) and as previously mentioned, metolachlor may result in more injury if applied during a cool, wet spring.

Tillage has a profound effect on the weed population dynamics. In no-tillage or minimum tillage systems, the majority of the weed seeds are at or near the soil surface compared with conventional tillage systems (Yenish et al. 1992). Small seeded weeds tend to survive, germinate, and emerge better when they are at or near the soil surface and therefore adapt better to a no-tillage or minimum tillage system (Buhler 1995). Redroot pigweed seeds will only germinate if located within 2.5-cm of the soil surface (Oryokot et al. 1997). Therefore, by changing from conventional tillage to minimum tillage system, small seeded weeds like redroot pigweed may become more problematic. Other seeds that need to be buried in the soil profile to break dormancy would more likely thrive in a conventional tillage system (Buhler 1995).

Tillage systems can also alter emergence patterns of certain weed species making them more or less competitive with the crop. Conventional tillage promotes the germination of common lambsquarters, field pennycress (*Thlaspi arvense* L.), green foxtail, wild buckwheat (*Polygonum convolvulus* L.), and wild oat (*Avena fatua* L.) in the spring (Bullied et al. 2003). If certain tillage practices alter the emergence patterns of weeds, then herbicide programs may need to change as well.

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CHAPTER 2

OPTIMIZING *S*-METOLACHLOR AND DIMETHENAMID-P APPLICATIONS IN SUGARBEET (*Beta Vulgaris*) MICRO-RATE HERBICIDE PROGRAMS

Abstract. Field trials were conducted in East Lansing, MI in 2004 and 2005 and in St. Charles, MI in 2004, 2005, and 2006 to compare weed control and sugarbeet tolerance from sugarbeet micro-rate herbicide applications that included *s*-metolachlor and dimethenamid-P. All herbicide treatments consisted of the base micro-rate treatment of desmedipham plus phenmedipham at 45/45 g/ha plus triflusulfuron-methyl at 4.4 g/ha plus clopyralid at 26 g/ha plus methylated seed oil (MSO) at 1.5% v/v applied four times at approximately 125 growing degree days (base 1.1 C) intervals. Treatments included the base micro-rate treatment alone and with full- and split-application rates of *s*-metolachlor at 1.4 kg/ha or dimethenamid-P at 0.84 kg/ha at the various micro-rate application timings. All treatments resulted in sugarbeet injury. In 2004 and 2006, full-rates of both *s*-metolachlor and dimethenamid-P applied PRE or in the first micro-rate had greater injury than the base micro-rate. When the *s*-metolachlor or dimethenamid-P applications were split between PRE and the third micro-rate or between the first and the third micro-rates injury was still greater than the base micro-rate treatment. Furthermore, applying dimethenamid-P at one-fourth the rate in all four micro-rates also caused significant sugarbeet injury compared with the base micro-rate treatment. Applying a full-rate of *s*-metolachlor or dimethenamid-P in either the third or fourth micro-rate timings or splitting the applications between the second and fourth micro-rates did not increase sugarbeet injury compared with the base micro-rate treatment. Control of common lambsquarters and giant foxtail from all treatments containing *s*-metolachlor or dimethenamid-P, regardless of the time of application, was greater than the base micro-

rate treatment at all locations. *Amaranthus* spp. control was 94% or greater from all treatments. In 2004, control of giant foxtail late in the season was greater in all treatments that included *s*-metolachlor or dimethenamid-P compared with the base micro-rate treatment. In 2005, the only treatments that did not improve giant foxtail control late in the season compared with the base micro-rate treatment were the treatments that included a full-rate of *s*-metolachlor or dimethenamid-P applied in the fourth micro-rate. Even though some herbicide treatments that included *s*-metolachlor or dimethenamid-P caused greater sugarbeet injury compared with the base micro-rate treatment, there were no differences in recoverable white sucrose yield between treatments.

Nomenclature: dimethenamid-P; *s*-metolachlor; common lambsquarters, *Chenopodium album* L. CHEAL; pigweed species, *Amaranthus retroflexus* L. and *Amaranthus powellii* S. Wats. AMASS; velvetleaf, *Abutilon theophrasti* Medik. ABUTH; giant foxtail, *Setaria faberi* Herrm. SETFA.

Key words: application timing, reduced rate, residual control

INTRODUCTION

Weed management can be challenging in sugarbeet (*Beta vulgaris* L.) due to limited herbicide options, slow crop canopy development, and a lengthy growing season. In the late 1990's a POST herbicide program was developed that changed how sugarbeet growers approached weed management. The micro-rate system which included a combination of desmedipham plus phenmedipham (45/45), or desmedipham plus phenmedipham plus ethofumesate (30/30/30) at 90 g ai/ha plus triflusulfuron at 4.4 g ai/ha plus clopyralid at 26 g ai/ha plus methylated seed oil (MSO) at 1.5% v/v was applied several times postemergence (POST) to young actively growing weeds at the cotyledon stage (Dexter and Lueke 1998). The inclusion of MSO increased the herbicide activity on cotyledon weeds, therefore allowing the typical herbicide rate to be reduced by 75% (Wilson et al. 2001). When introduced, the first micro-rate application was applied when weeds were at the cotyledon growth stage, and follow up treatments were applied every 5 to 7 d as required. However, in cooler conditions when weeds and sugarbeets were not actively growing some of these applications were not needed. Research conducted by Dale and Renner (2005) showed that applications based on a 125 growing degree day (GDD) interval with base temperature of 1.1 C were more effective than a fixed schedule in terms of weed control and economics.

The micro-rate herbicide program was applied to 50% of the Minnesota and North Dakota (Luecke and Dexter 2004) and 60% of the Michigan sugarbeet hectares in 2003.[2] Almost 50% of the sugarbeet growers in Michigan were basing application timings on GDD. The low herbicide rates used in the micro-rate system reduced the weed control costs per hectare, allowing growers to broadcast-apply the micro-rate and reduce cultivations. Furthermore, herbicide injury from micro-rates was generally less than other POST herbicide programs, and growers could apply the POST micro-rates throughout the day instead of applications only in the late afternoon or evening to avoid injury (Hamill et al. 2001; Wilson et al. 2001). However, for micro-rates to be effective, application timing must be precise. Increased time between micro-rate applications can result in reduced weed control (Dale and Renner 2005). Additionally, due to the lack of residual activity from the micro-rate, four or more applications are often required to

[2] Sprague Survey of the Michigan and Monitor Sugar Company Agriculturalists in 2003.

control weeds throughout the season. In years that are favorable for late-emerging weeds, additional micro-rate applications will add to the expense of the overall weed control program.

Weeds that escape control in sugarbeet can reduce yield. Brimhall et al. (1965) reported that one redroot pigweed and one green foxtail per sugarbeet plant reduced sugarbeet yield 70% and 26%, respectively. Even at low weed densities sugarbeet yield can be affected. Schweizer and May (1993) reported that weed densities as low as 1 plant/m^2 reduced sugarbeet root yield by as much as 11%. Competition from late-emerging weeds in sugarbeet is dependent on the completeness of the sugarbeet stand. Dawson (1977) reported that weeds that emerged after July 1 were suppressed and died in a full stand of sugarbeets of normal vigor. However, when the sugarbeet stand was reduced, late-emerging pigweed (*Amaranthus* spp.) and barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) reduced sugarbeet root yield from 5 to 49% depending on the sugarbeet stand. Additionally, late-emerging weeds can cause harvest issues, reduce quality of the harvested product, act as a host for insects and diseases, increase the need for tillage, and produce seed that will cause future weed problems (Dexter 2004).

Ethofumesate can be applied preemergence (PRE) or can be tank-mixed with micro-rates and applied POST to improve control of common lambsquarters, pigweed (*Amaranthus* spp.), kochia (*Kochia scoparia* (L.) Schrad.), and hairy nightshade (*Solanum physalifolium* Rusby) (Dale et al. 2006; Guza et al. 2002; Wilson 1994). PRE applications can provide some residual control of late-emerging weeds, however POST applications of ethofumesate are at rates much lower than PRE applications. Therefore, POST applications of ethofumesate provide little to no residual weed control

(Anonymous 2006). Inclusion of ethofumesate in weed control programs has also been shown to increase sugarbeet injury (Dale et al. 2006; Guza et al. 2002).

The recent registrations of *s*-metolachlor and dimethenamid-P for use in sugarbeet provide growers with additional options for weed control. *S*-metolachlor and dimethenamid-P are both chloroacetamide herbicides that are primarily absorbed by emerging shoots of grass and broadleaf weeds (Vencill 2002). Because of their mechanism of action, these herbicides are only phytotoxic to emerging seedlings and only control weeds prior to emergence. Thus, typical application timings for *s*-metolachlor and dimethenamid-P are early preplant (EPP), preplant incorporated (PPI), and preemergence (PRE) in crops for which they are registered. However, due to the potential for sugarbeet injury from PRE and PPI applications, *s*-metolachlor and dimethenamid-P are currently registered for POST applications after sugarbeets have reached the 2-true-leaf stage (Anonymous 2005a; Anonymous 2005b). Additionally, *s*-metolachlor has a 24(C) registration for PRE applications.

Since the primary factors affecting the dissipation of chloroacetamide herbicides in soil are adsorption and microbial decomposition, predicting the length of residual activity of *s*-metolachlor and dimethenamid-P can be difficult (Vencill 2002). Furthermore, soil parameters, such as organic matter and clay content, will affect the amount of *s*-metolachlor and dimethenamid-P adsorbed to the soil. Greater amounts of soil organic matter and clay will increase the adsorption of these herbicides and warm, moist soil conditions will increase microbial degradation (Mullison 1979; Zimdahl and Clark 1982; Chesters et al. 1989). The half-lives of *s*-metolachlor and dimethenamid-P have been estimated at 30 to 50 d and 35 to 42 d in the northern United States, respectively (Vencill 2002). Even though these values are relatively close to each other, differences in soil temperature, soil moisture, and soil texture will affect degradation of these herbicides (Zimdahl and Clark 1982).

Additionally, *s*-metolachlor and dimethenamid-P are not effective on all weeds that are problematic in sugarbeets. In order to control weeds that emerge prior to 2-leaf sugarbeets and to broaden the spectrum of weeds controlled, tank-mixtures with herbicides that have postemergence activity are needed.

The addition of *s*-metolachlor or dimethenamid-P to POST micro-rate herbicide programs provides growers with additional options for control of late-emerging weeds. This addition may allow growers to reduce or eliminate cultivation or additional micro-rate applications, thus reducing the time and expense invested in weed control. Because sugarbeet injury concerns have been reported from both PRE and POST applications of *s*-metolachlor and dimethenamid-P (Dexter and Luecke 2003; Renner 2003; Rice et al. 2002), we wanted to determine if *s*-metolachlor or dimethenamid-P could be added to the micro-rate program without injuring the sugarbeet and if splitting the rates of these herbicides in the micro-rate application would reduce the risk of crop injury. Therefore, the objectives of this research were to: 1) compare weed control and sugarbeet tolerance from the addition of *s*-metolachlor and dimethenamid-P to micro-rate herbicide programs, and 2) evaluate the length of residual weed control from *s*-metolachlor and dimethenamid-P applications.

MATERIALS AND METHODS

Field Experiments. Experiments were conducted in Michigan at St. Charles (2004, 2005, and 2006) and E. Lansing (2004 and 2005) to evaluate weed control and sugarbeet tolerance from the addition of *s*-metolachlor and dimethenamid-P to micro-rate herbicide programs. The soil at St. Charles was a Misteguay silty clay loam (fine-loamy, mixed, mestic Aeric Endoaquepts) with a soil pH of 8.1, and 3.0% organic matter. The soil at East Lansing was a Capac sandy clay loam (fine-loamy, mixed, mestic Aeric Ochraqualfs) with a soil pH of 6.8, and 2.6% organic matter. Experiments followed soybean and corn in the rotation at St. Charles and East Lansing, respectively. Fields were fall plowed followed by field cultivation in the spring. 'Crystal 963'[3] PAT, one of the predominant varieties in Michigan, was planted 2.5-cm deep at 118,560 seeds/ha in 76-cm rows. In St. Charles, sugarbeets were planted on April 7, 2004, April 6, 2005, and April 11, 2006. In East Lansing, sugarbeets were planted on April 9, 2004 and April 6, 2005. Plots were four rows wide by 9.1 to 10.7 m long.

All herbicide treatments consisted of the base micro-rate treatment of desmedipham plus phenmedipham at 45/45 g/ha plus triflusulfuron-methyl at 4.4 g/ha plus clopyralid at 26 g/ha plus methylated seed oil (MSO) at 1.5% v/v applied four times at approximately 125 growing degree days (base 1.1 C) intervals (Dale and Renner 2005). Treatments included: (a) the base micro-rate treatment, (b) *s*-metolachlor at 1.4 kg/ha applied PRE prior to the four micro-rate treatments, (c) *s*-metolachlor at 1.4 kg/ha applied in the first micro-rate, (d) *s*-metolachlor at 1.4 kg/ha applied in the second micro-rate, (e) *s*-metolachlor at 1.4 kg/ha applied in the third micro-rate, (f) *s*-metolachlor at 1.4 kg/ha applied in the fourth micro-rate, (g) *s*-metolachlor at 0.7 kg/ha applied PRE and in

[3] American Crystal Sugar Company, 101 North 3rd Street, Moorhead, MN 56560

the third micro-rate, (h) *s*-metolachlor at 0.7 kg/ha applied in the first and third micro-rates, (i) *s*-metolachlor at 0.7 kg/ha applied in the second and fourth micro-rates, and (j) *s*-metolachlor at 0.35 kg/ha applied in all four micro-rates. Dimethenamid-P at 0.84 kg/ha was applied at same timings as *s*-metolachlor. These use rates represent the typical herbicide dose used during one field season in Michigan (Anonymous 2005a, Anonymous 2005b). All experiments also included an untreated control. Table 1 shows application dates, sugarbeet growth stages, and accumulated GDDs for each application. Temperature and precipitation data were collected from the Michigan Automated Weather Network stations[4] located at the Saginaw Valley Bean and Beet Research Farm (St. Charles) and the MSU Horticulture Teaching and Research Center (East Lansing) (Table 2). Because of weather conditions, micro-rates were not always applied at exactly 125 GDD intervals. Herbicide treatments were applied in water using a tractor-mounted compressed-air sprayer calibrated to deliver 178 L/ha at 207 kPa, through AirMix 11003[5] spray nozzles.

Common lambsquarters was the predominant weed species present at St. Charles in all years. Average densities were 111, 152, and 54 plants/m^2 in 2004, 2005, and 2006, respectively. Also present at St. Charles was a mixture of redroot pigweed (*Amaranthus retroflexus* L.) and Powell amaranth (*Amaranthus powellii* S.) with a combined density of 55 plants/m^2 in 2004 and 23 plants/m^2 in 2005. At East Lansing, giant foxtail was the dominant weed in 2004 and 2005 with densities of 56 and 211 plants/m^2, respectively. Velvetleaf was present in both years at East Lansing with densities of 18 plants/m^2 in

[4] Website: http://www.agweather.geo.msu.edu/mawn/.

[5] Greenleaf Technologies, P.O. Box 1767, Covington, LA, 70434.

2004 and 33 plants/m^2 in 2005. In addition, common lambsquarters was present at East Lansing in 2005 with a density of 267 plants/m^2.

Sugarbeet injury and weed control were evaluated using a rating scale of 0 (no injury) to 100 (plant death). Sugarbeet injury was rated prior to the fourth micro-rate application timing and again 14 days after this treatment (DAT). Weed control was evaluated 14 DAT. In addition, late-season giant foxtail control was evaluated 100 DAT. Sugarbeet was only harvested at St. Charles, because of the lack of harvesting equipment in East Lansing. Sugarbeet was flailed and topped with a four-row topper, and harvested October 11, 2004, September 19, 2005, and September 18, 2006 with a two-row mechanical lifter. Sugarbeets were weighed and a sample of roots from each plot was analyzed for recoverable white sucrose by Michigan Sugar Company, Bay City, MI.

Greenhouse Research. At St. Charles in 2004 and 2005 and East Lansing in 2005, eight to ten soil cores (79 cm^2 in area and 2.5-cm deep) were collected between the center rows of selected treated plots 30 days after the 4th micro-rate application for use in greenhouse bioassays. The soil was stored in 4 L sealed plastic freezer bags at 4 C until planting. Samples were mixed thoroughly and placed in 10 x 10-cm plastic pots. Approximately 30 giant foxtail seeds were planted in each pot at a 0.5-cm depth. Pots were placed in the greenhouse and sunlight was supplemented with sodium vapor lighting to provide a total midday light intensity of 1000 μmol/m/s photosynthetic photon flux at plant height in a 16 h day. Greenhouse temperature was maintained at 25 ± 2 C. Pots were sub-irrigated as needed to maintain field capacity. At 7 and 14 d after planting, 50 ml of a fertilizer solution containing 70 mg/L of 20% nitrogen, 20% P_2O_5, and 20% K_2O were applied to each pot. At 21 d after planting, giant foxtail germination was determined and visual injury was evaluated. Weed injury was rated from 0 (no effect) to 100 (plant death). All aboveground plant tissue was harvested, dried, and weighed to determine reduction of plant biomass. Pots were then remixed and previous steps were repeated two more times or until no further reduction in giant foxtail growth was observed.

Statistical Analysis. For the field research, the experimental design was a randomized complete block design with either three or four replications depending upon site. Data were subjected to ANOVA using the PROC MIXED procedure in SAS to test for treatment effects and possible interactions. Data were pooled across site and year when no treatment by site interactions occurred. If these interactions were significant, then data were analyzed separately by year, site, or both site and year. Means were then compared using Fisher's protected LSD at the $P \leq 0.05$.

All greenhouse experiments were conducted twice and were designed as a randomized complete block with three or four replications. Data were subjected to ANOVA using the PROC MIXED procedure in SAS to test interactions. Since no interactions between repeated experiments were observed, data were combined. Means of treatments were separated using Fisher's protected LSD at the $P \leq 0.05$.

RESULTS AND DISCUSSION

Field Experiment. Due to planting problems that caused poor sugarbeet emergence and stand, sugarbeet injury data from East Lansing in 2004 will not be presented. Differences in precipitation and temperature at each site influenced sugarbeet injury. In April of 2004 and 2006, precipitation was lower than the 30-year average and temperatures were slightly higher (Table 2). However, in May when most of the herbicide applications were made (Table 1), precipitation was greater than the 30-year average. Because of the increased precipitation the overall injury in both of these years was greater and data were combined because there was not a significant interaction between the 2004 and 2006 sugarbeet injury data at St. Charles. Sugarbeet injury was similar between the East Lansing and St. Charles sites in 2005. Overall sugarbeet injury was plant stunting and sugarbeet stand was not reduced from any of the herbicide treatments (data not shown).

In 2004 and 2006, sugarbeet injury was 18% from the base micro-rate treatment when evaluated at the last micro-rate application (Table 3). The addition of *s*-metolachlor in the first micro-rate application at the full-rate of 1.4 kg/ha or at the half-rate of 0.7 kg/ha increased sugarbeet injury compared with the base micro-rate treatment. Injury was also greater than the base micro-rate when *s*-metolachlor applications at 1.4 kg/ha was split between PRE and the third micro-rate application. When dimethenamid-P was applied PRE or in the first micro-rate, regardless of application rate, sugarbeet injury was greater than the base micro-rate treatment. When either applications of *s*-metolachlor or dimethenamid-P increased injury compared with the base micro-rate, injury was greater from dimethenamid-P application, except when either herbicide was split between PRE and the third micro-rate application or split between the first and third micro-rate application (Table 3). Trends in sugarbeet injury 14 d after the last micro-rate application were similar (Table 4). Applications of *s*-metolachlor in the first micro-rate at the full- or half-rate or split between PRE and the third micro-rate and applications of dimethenamid-P PRE or in the first micro-rate injured sugarbeet greater than the base micro-rate treatment. PRE applications of *s*-metolachlor have been reported to cause significant sugarbeet injury (Dexter and Luecke 2003; Dexter and Luecke 2004; Renner 2003). However, at this evaluation timing, dimethenamid-P applied in the second micro-rate at 0.84 kg/ha or when split between the second and fourth micro-rate application caused more sugarbeet injury than the base micro-rate treatment. The smaller sugarbeet size at the first evaluation timing may have masked the effects that the applications of dimethenamid-P in the second micro-rate had on sugarbeet growth.

The addition of *s*-metolachlor or dimethenamid-P to the micro-rate program did not have as much of an effect on sugarbeet injury at East Lansing and St. Charles in 2005, compared with 2004 and 2006. As mentioned previously, precipitation in 2005 was below the 30-yr average in May (Table 2). Sugarbeet injury from the base micro-rate treatment was 15% at the last micro-rate application (Table 3). At this evaluation, only PRE applications of *s*-metolachlor at 1.4 kg/ha and dimethenamid-P at 0.84 kg/ha, and *s*-metolachlor applied in the first micro-rate had sugarbeet injury greater than the base micro-rate. By 14 d after the last micro-rate application, sugarbeets recovered from most of the injury from the micro-rate treatments and only *s*-metolachlor applied PRE and in the first micro-rate had greater injury than the base micro-rate treatment (Table 4).

Across the four sites, applying s-metolachlor in the second micro-rate or later did not increase sugarbeet injury compared with the base micro-rate treatment. The second micro-rate application was made when sugarbeets were at the two-leaf stage (Table 1). These applications are consistent with current labeling for *s*-metolachlor for POST applications when sugarbeets have reached the two-true-leaf stage (Anonymous 2005b). Additionally, applications of s-metolachlor at one-fourth of the full rate in each of the micro-rate applications also did not increase sugarbeet injury compared with the base micro-rate treatment. If there are weed control benefits from these applications, there may be the potential for changes in the current label. Similar to s-metolachlor, dimethenamid-P is registered for POST applications when sugarbeets have reached the two-true-leaf stage (Anonymous 2005b). However, at two out of the four sites, applying dimethenamid-P in the second micro-rate, when sugarbeets were at the two-leaf-stage (Table 1), resulted in injury greater than the base micro-rate treatment (Tables 3 and 4). Applications of dimethenamid-P were less injurious when they were made at the third micro-rate timing or later.

Control of common lambsquarters from all treatments containing *s*-metolachlor or dimethenamid-P, regardless of time of application, was greater than the base micro-rate treatment at all locations in 2004, 2005, and 2006 (Table 5). At St. Charles in 2004, a full-rate of dimethenamid-P PRE or in any micro-rate resulted in greater common lambsquarters control compared with *s*-metolachlor. At the combined locations, a full-rate of dimethenamid-P PRE or in the first or second micro-rates provided greater control of common lambsquarters compared with *s*-metolachlor. In other research, Guza et al. (2002) found that the addition of dimethenamid-P to glyphosate increased control of common lambsquarters in glyphosate-tolerant sugarbeets. This treatment also resulted in greater common lambsquarters control than the glyphosate treatment that included ethofumesate. In contrast, Dale et al. (2006) reported no difference in control of common lambsquarters between PRE treatments of *s*-metolachlor and ethofumesate.

Amaranthus spp. control was 94% or greater from all treatments (Table 5). All treatments containing a full- or a split-rate of *s*-metolachlor or dimethenamid-P controlled

Amaranthus spp. greater than the base micro-rate treatment, except for a full-rate of *s*-metolachlor in the third or the fourth micro-rate and a full-rate of dimethenamid-P in the fourth micro-rate. Similar increases in control of common lambsquarters and redroot pigweed were observed by Dexter and Luecke (2004) and Guza et al. (2002). Velvetleaf control did not increase when *s*-metolachlor or dimethenamid-P were included in the micro-rate treatments (Table 6).

All treatments that included *s*-metolachlor or dimethenamid-P resulted in greater control of giant foxtail compared with the base micro-rate treatment (Table 6). In 2004, the only treatments containing *s*-metolachlor or dimethenamid-P that did not provide greater than 98% control of giant foxtail were the treatments in which the chloroacetamide herbicide was added to the fourth micro-rate treatment only. In 2005, the addition of a full-rate of s-metolachlor or dimethenamid-P to the fourth micro-rate was the only treatments that did not result in at least 75% control of giant foxtail. Since giant foxtail has already emerged by the time of the fourth micro-rate and *s*-metolachlor and dimethenamid-P only control emerging grass species (Vencill 2002), the micro-rate treatments containing these herbicides could not control the emerged grasses.

Control of giant foxtail in 2004 was greater in all treatments that included *s*-metolachlor or dimethenamid-P compared with the base micro-rate treatment when evaluated later in the growing season (Table 7). These results are similar to Rice et al. (2002) who reported more consistent late-season control of barnyardgrass in treatments containing either dimethenamid or dimethenamid-P, regardless if sethoxydim was applied POST to control emerged grasses. However, the control from *s*-metolachlor and dimethenamid-P differed. When the full-rates of the two herbicides are compared, control from *s*-metolachlor was greater than dimethenamid-P. Since the control of giant foxtail from these treatments at 14 DA the fourth micro-rate is nearly identical (Table 7), this difference in control can be attributed to an increase in the residual control of *s*-metolachlor compared to dimethenamid-P. These results would agree with those of Mueller et al. (1999) who observed that metolachlor had a greater half-life than dimethenamid. In 2005, late-season grass control was similar to the data from the 14 DA the fourth micro-rate evaluation. The only treatments that did not increase the control of giant foxtail compared with the base micro-rate were the treatments that included a full-rate of *s*-metolachlor or dimethenamid-P to the fourth micro-rate or the split-rate application of *s*-metolachlor between the second and fourth micro-rates. No differences in control were present between *s*-metolachlor and dimethenamid-P.

Although significant differences in sugarbeet injury and weed control were observed, no differences were observed in recoverable white sucrose yield between herbicide treatments (Table 8). Sucrose yield was greater in all herbicide treatments compared with the untreated control plot. Smith and Schweizer (1983) showed that the sugarbeet can overcome injury from herbicide applications in the spring and early summer and yield similar to untreated control plots. However, if a reduction in stand were to occur, yield loss would be much more pronounced (Winter and Wiese 1978). If rainfall occurs shortly after PRE applications of *s*-metolachlor or dimethenamid-P and stand loss occurs, potential for yield loss would be much greater.

Greenhouse Research. Since soil type was uniform at each site, no interaction was observed. Therefore the data was combined within each site across years. Soil bioassay of the base micro-rate treatment resulted in no residual control of giant foxtail at St. Charles (Table 9). At the first planting, dimethenamid-P split between all four micro-rates and all treatments of *s*-metolachlor, except when applied at a full-rate in the first micro-rate resulted in at least a 76% reduction in giant foxtail growth. Treatments that provided the least amount of weed control at the first planting were both herbicides at the full-rate in the second micro-rate and dimethenamid-P at a full-rate in the third micro-rate and spilt between all four micro-rates. Although not always statistically significant, *s*-metolachlor reduced giant foxtail growth more than dimethenamid-P when compared across all treatments at the first planting. *S*-metolachlor applied at a full-rate in the third or fourth micro-rate or split between the second and fourth micro-rates reduced giant foxtail growth the greatest at the second planting. Similar to the first planting, *s*-metolachlor reduced growth of giant foxtail more than dimethenamid-P at each application timing except for a full-rate applied in the second micro-rate at the second planting. At the third planting, *s*-metolachlor applied at a full-rate in the fourth micro-rate, split between the second and fourth micro-rates, and spilt between all four micro-rates provided the greatest growth reduction of giant foxtail. However, growth reduction from these treatments only ranged from 13 to 17%.

At East Lansing, reduction in giant foxtail growth ranged from 52 to 88% from applications of *s*-metolachlor at the first planting (Table 10). The treatments that resulted in the greatest growth reduction included *s*-metolachlor applied at the full-rate in the fourth micro-rate or split between all four micro-rates. All timings containing *s*-metolachlor reduced giant foxtail growth more than similar timings containing dimethenamid-P. No treatment containing dimethenamid-P reduced giant foxtail growth greater than 38% at the first planting. At both the second and third plantings, the *s*-metolachlor application split between all four micro-rates was more effective in reducing giant foxtail growth than dimethenamid-P at the same application timings.

Our research indicates that full- and split-rate applications of *s*-metolachlor or dimethenamid-P PRE and in the first micro-rate can significantly injure sugarbeet. No reduction in sugarbeet population was observed in this research due to dry conditions in April each year. In wet springs there is potential for loss of stand and increased sugarbeet injury from *s*-metolachlor or dimethenamid-P that could possibly affect yield. Application of either herbicide in the third or fourth micro-rate generally caused the least amount of crop injury. In addition, dimethenamid-P usually caused greater sugarbeet injury than *s*-metolachlor at the same timing. Control of common lambsquarters, *Amaranthus* spp., and giant foxtail control was improved with the addition of either herbicide compared with the base micro-rate alone. Applications of *s*-metolachlor or dimethenamid-P made prior to the fourth micro-rate provided the greatest control, regardless of rate. Although applying *s*-metolachlor or dimethenamid-P in one of the last two micro-rates resulted in the greatest crop safety, applications must be made prior to weed emergence to provide the best control. Results from field and greenhouse experiments indicate that the residual activity of *s*-metolachlor was greater compared with dimethenamid-P. These results agree with Mueller et al. (1999) who observed metolachlor has a greater half life than dimethenamid-P. This difference in residual activity may be attributed to the leaching potential of these two herbicides, especially under the coarse-textured soil conditions found in East Lansing. Skipper et al. (1976) reported that under sandy loam soils, leaching was the major means of dissipation of chloroacetamide herbicides. The difference in the rate of dissipation of these two herbicides is probably due to the difference of the water solubility and the adsorption coefficients of the two herbicides. Most annual grasses and small-seed broadleaf weeds that germinate are within 10-cm of the soil surface (Anderson 1996). Therefore, an adequate amount of herbicide must in this zone to control weeds. For *s*-metolachlor and dimethenamid-P the average K_{oc} is 200 and 155 ml/g, respectively, and the water solubility is 488 and 1174 mg/L, respectively (Vencill 2002). Thus, *s*-metolachlor would not be as likely leach out of the root zone compared with dimethenamid-P since it is less soluble in water and more of the herbicide will adsorb to the soil and organic particles. As a result, *s*-metolachlor would provide greater residual weed control later into the growing season based on its chemical properties. Therefore, *s*-metolachlor may be a better choice than dimethenamid-P for use in sugarbeet micro-rate herbicide programs because of greater crop safety, residual activity, and weed control.

Table 1. Application date, sugarbeet growth stage, and accumulated growing degree-days for each herbicide application at E. Lansing and St. Charles, MI[a].

	East Lansing						St. Charles								
	2004			2005			2004			2005			2006		
Application timing[b]	Date	Leaf stage[c]	GDD[d]	Date	Leaf stage	GDD	Date	Leaf stage	GDD	Date	Leaf stage	GDD	Date	Leaf stage	GDD
PRE	APR 9	–	–	APR 6	--	--	APR 7	--	--	APR 6	--		APR 11	--	–
Micro 1	APR 23	cot	144	APR 19	cot	137	APR 22	cot	141	APR 29	cot	182	APR 29	cot	186
Micro 2	MAY 6	2	270	MAY 6	cot to 2	325	MAY 5	2	251	MAY 12	cot to 2	308	MAY 9	2	335
Micro 3	MAY 16	2 to 4	422	MAY 17	2 to 4	414	MAY 17	4 to 6	432	MAY 25	2 to 6	453	MAY 22	2 to 4	466
Micro 4	MAY 30	4 to 6	627	MAY 27	2 to 6	536	MAY 27	6 to 8	569	JUN 6	4 to 8	590	MAY 30	4 to 8	620

[a] Abbreviations: APR, April; cot, cotyledon; GDD, growing degree-days; JUN, June; Micro, micro-rate; PRE, preemergence.
[b] PRE herbicide applications were applied immediately after planting.
[c] Sugar beet leaf stage.
[d] Accumulated growing degree-days with base temperature of 1.1 C. Growing degree-days were calculated by averaging the daily high and low temperatures and subtracting the base temperature of 1.1 C.

Table 2. Deviations from the 30-yr average monthly precipitation and mean temperature in 2004 and 2005 and at E. Lansing in 2004, 2005, and 2006 at St. Charles, MI[a].

	East Lansing				St. Charles					
	Precipitation		Temperature		Precipitation			Temperature		
Month	2004	2005	2004	2005	2004	2005	2006	2004	2005	2006
	cm		C		cm			C		
April	-5.7	-5.1	2.3	2.4	-4.1	-4.0	-2.6	1.1	0.9	1.7
May	13.6	-3.6	0.9	-2.0	9.7	-2.5	3.4	0.2	-2.1	1.1
June	0.3	2.3	-0.9	3.2	-0.5	5.2	-2.2	-0.7	3.0	0.2
July	3.3	4.7	-1.4	0.4	-0.5	2.5	8.9	-1.4	0.2	0.4
August	0.6	-6.5	-1.7	1.9	-2.2	-6.0	-1.5	-2.3	0.6	-0.4
September	-5.9	-0.9	1.8	2.5	-8.2	-8.1	2.5	1.8	2.1	-1.3

[a] Precipitation and temperature data were collected from the Michigan Automated Weather Network.

Table 3. Sugarbeet injury from micro-rate herbicide applications with and without the addition of *s*-metolachlor and dimethenamid-P at E. Lansing in 2005 and at St. Charles in 2004, 2005, and 2006, at the last micro-rate application.

Timings and rates of *s*-meto.[a] & dimeth.-P with the 4 micro-rates					St. Charles 2004 & 2006[b]		E. Lansing & St. Charles 2005	
PRE	M1	M2	M3	M4	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P
					% injury		% injury	
Micro-rate treatment alone[c]					18		15	
1X[d]					21	28	26	30
	1X				24	34	26	17
		1X			15	23	17	21
			1X		18	18	16	14
				1X	12	14	16	19
0.5X			0.5X		24	23	21	21
	0.5X		0.5X		31	28	20	15
		0.5X		0.5X	13	17	11	20
	0.25X	0.25X	0.25X	0.25X	18	23	15	19
$LSD_{0.05}$					5		8	

[a] Abbreviations: *s*-meto., *s*-metolachlor; dimeth.-P, dimethenamid-P; PRE, preemergence; M1, micro-rate 1; M2, micro-rate 2; M3, micro-rate 3; M4, micro-rate 4.

[b] Data were combined across locations.

[c] The micro-rate treatment was desmedipham and phenmedipham at 90 g/ha + triflusulfuron-methyl at 4.4 g/ha + clopyralid at 26 g/ha + methylated seed oil at 1.5% v/v. This treatment was applied four times at approximately 125 GDD intervals (Table 1).

[d] The 1X rate of *s*-metolachlor was 1.4 kg/ha and the 1X rate of dimethenamid-P was 0.84 kg/ha.

Table 4. Sugarbeet injury from micro-rate herbicide applications with and without the addition of *s*-metolachlor and dimethenamid-P at E. Lansing in 2005 and at St. Charles in 2004, 2005, and 2006, 14 days after the last micro-rate application.

Timings and rates of *s*-meto.[a] & dimeth.-P with the 4 micro-rates					St. Charles 2004 & 2006[b]		E. Lansing & St. Charles 2005	
PRE	M1	M2	M3	M4	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P
					% injury		% injury	
Micro-rate treatment alone[c]					8		4	
1X[d]					14	21	11	6
	1X				16	30	11	4
		1X			8	25	7	6
			1X		14	13	2	7
				1X	11	6	3	5
0.5X			0.5X		18	16	5	7
	0.5X		0.5X		24	30	3	1
		0.5X		0.5X	8	16	2	5
	0.25X	0.25X	0.25X	0.25X	13	21	1	7
$LSD_{0.05}$					8		6	

[a] Abbreviations: *s*-meto., *s*-metolachlor; dimeth.-P, dimethenamid-P; PRE, preemergence; M1, micro-rate 1; M2, micro-rate 2; M3, micro-rate 3; M4, micro-rate 4.

[b] Data were combined across locations.

[c] The micro-rate treatment was desmedipham and phenmedipham at 90 g/ha + triflusulfuron-methyl at 4.4 g/ha + clopyralid at 26 g/ha + methylated seed oil at 1.5% v/v. This treatment was applied four times at approximately 125 GDD intervals (Table 1).

[d] The 1X rate of *s*-metolachlor was 1.4 kg/ha and the 1X rate of dimethenamid-P was 0.84 kg/ha.

Table 5. Common lambsquarters and pigweed control from micro-rate herbicide applications with and without the addition of *s*-metolachlor and dimethenamid-P at E. Lansing in 2005 and at St. Charles in 2004, 2005, and 2006, 14 days after the last micro-rate application.

Timings and rates of *s*-meto.[b] & dimeth.-P with the 4 micro-rates					Common lambsquarters				Pigweed species[a]	
					St. Charles 2004		E. Lansing 2005, St. Charles 2005 & 2006[c]		St. Charles 2004 & 2005	
PRE	M1	M2	M3	M4	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P
					% control		% control		% control	
Micro-rate treatment alone[d]					83		73		94	
1X[e]					95	83	84	91	98	99
	1X				95	99	82	92	99	99
		1X			95	99	84	91	99	99
			1X		94	99	84	87	96	98
				1X	90	99	81	84	96	95
0.5X			0.5X		92	99	87	93	98	99
	0.5X		0.5X		99	98	90	91	99	99
		0.5X		0.5X	99	99	87	89	99	99
	0.25X	0.25X	0.25X	0.25X	99	99	90	88	99	99
$LSD_{0.05}$					3		6		2	

[a] Pigweed species were a mixture of redroot pigweed and Powell amaranth.

[b] Abbreviations: *s*-meto., *s*-metolachlor; dimeth.-P, dimethenamid-P; PRE, preemergence; M1, micro-rate 1; M2, micro-rate 2; M3, micro-rate 3; M4, micro-rate 4.

[c] Data were combined across locations.

[d] The micro-rate treatment was desmedipham and phenmedipham at 90 g/ha + triflusulfuron-methyl at 4.4 g/ha + clopyralid at 26 g/ha + methylated seed oil at 1.5% v/v. This treatment was applied four times at approximately 125 GDD intervals (Table 1).

[e] The 1X rate of *s*-metolachlor was 1.4 kg/ha and the 1X rate of dimethenamid-P was 0.84 kg/ha.

Table 6. Giant foxtail and velvetleaf control from micro-rate herbicide applications with and without the addition of *s*-metolachlor and dimethenamid-P at E. Lansing in 2004 and 2005 and at St. Charles in 2004, 14 days after the last micro-rate application.

Timings and rates of *s*-meto.[a] & dimeth.-P with the 4 micro-rates					Giant foxtail				Velvetleaf	
					E. Lansing 2004		E. Lansing 2005		E. Lansing 2004 & 2005[b]	
PRE	M1	M2	M3	M4	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P
					% control		% control		% control	
Micro-rate treatment alone[c]					90		43		78	
1X[d]					99	99	82	83	77	81
	1X				98	99	87	91	79	82
		1X			99	99	85	93	78	84
			1X		98	98	75	81	83	81
				1X	95	95	52	58	76	82
0.5X			0.5X		98	99	79	84	81	81
	0.5X		0.5X		99	99	88	88	84	85
		0.5X		0.5X	99	99	78	83	82	82
	0.25X	0.25X	0.25X	0.25X	99	99	91	87	82	82
$LSD_{0.05}$					2		6		NS	

[a] Abbreviations: *s*-meto., *s*-metolachlor; dimeth.-P, dimethenamid-P; PRE, preemergence; M1, micro-rate 1; M2, micro-rate 2; M3, micro-rate 3; M4, micro-rate 4.

[b] Data were combined across locations.

[c] The micro-rate treatment was desmedipham and phenmedipham at 90 g/ha + triflusulfuron-methyl at 4.4 g/ha + clopyralid at 26 g/ha + methylated seed oil at 1.5% v/v. This treatment was applied four times at approximately 125 GDD intervals (Table 1).

[d] The 1X rate of *s*-metolachlor was 1.4 kg/ha and the 1X rate of dimethenamid-P was 0.84 kg/ha.

Table 7. Late-season giant foxtail control (100 days after the last application) from micro-rate herbicide applications with and without the addition of *s*-metolachlor and dimethenamid-P at E. Lansing in 2004 and 2005.

Timings and rates of *s*-meto.[a] & dimeth.-P with the 4 micro-rates					Giant foxtail			
					E. Lansing 2004		E. Lansing 2005	
PRE	M1	M2	M3	M4	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P
					——— % control ———		——— % control ———	
Micro-rate treatment alone[b]					44		50	
1X[c]					94	65	82	68
	1X				95	70	92	93
		1X			88	69	87	92
			1X		81	61	73	87
				1X	73	75	53	55
0.5X			0.5X		85	71	78	80
	0.5X		0.5X		89	75	83	87
		0.5X		0.5X	99	97	79	87
	0.25X	0.25X	0.25X	0.25X	99	93	92	90
$LSD_{0.05}$					12		19	

[a] Abbreviations: *s*-meto., *s*-metolachlor; dimeth.-P, dimethenamid-P; PRE, preemergence; M1, micro-rate 1; M2, micro-rate 2; M3, micro-rate 3; M4, micro-rate 4.

[b] The micro-rate treatment was desmedipham and phenmedipham at 90 g/ha + triflusulfuron-methyl at 4.4 g/ha + clopyralid at 26 g/ha + methylated seed oil at 1.5% v/v. This treatment was applied four times at approximately 125 GDD intervals (Table 1).

[c] The 1X rate of *s*-metolachlor was 1.4 kg/ha and the 1X rate of dimethenamid-P was 0.84 kg/ha.

Table 8. Recoverable white sucrose from micro-rate herbicide applications with and without the addition of *s*-metolachlor and dimethenamid-P at St. Charles in 2004, 2005, and 2006.

Timings and rates of *s*-meto.[a] & dimeth.-P with the 4 micro-rates					St. Charles 2004 & 2006[b]		St. Charles 2005	
PRE	M1	M2	M3	M4	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P
					——— kg/ha ———		——— kg/ha ———	
Micro-rate treatment alone[c]					6610		3331	
1X[d]					6964	6692	3755	3435
	1X				6875	6494	3248	3431
		1X			6907	6354	3795	3118
			1X		6425	6801	3554	3566
				1X	6664	6802	3153	4034
0.5X			0.5X		7002	6951	3627	3305
	0.5X		0.5X		6263	6848	3399	3564
		0.5X		0.5X	6884	6968	3538	3678
	0.25X	0.25X	0.25X	0.25X	6804	6727	3791	3573
Untreated					4852		791	
$LSD_{0.05}$					833		847	

[a] Abbreviations: *s*-meto., *s*-metolachlor; dimeth.-P, dimethenamid-P; PRE, preemergence; M1, micro-rate 1; M2, micro-rate 2; M3, micro-rate 3; M4, micro-rate 4.

[b] Data were combined across locations.

[c] The micro-rate treatment was desmedipham and phenmedipham at 90 g/ha + triflusulfuron-methyl at 4.4 g/ha + clopyralid at 26 g/ha + methylated seed oil at 1.5% v/v. This treatment was applied four times at approximately 125 GDD intervals (Table 1).

[d] The 1X rate of *s*-metolachlor was 1.4 kg/ha and the 1X rate of dimethenamid-P was 0.84 kg/ha

Table 9. Giant foxtail growth reduction from soil sampled in field plots treated with micro-rate herbicide programs with and without the addition of *s*-metolachlor and dimethenamid-P at St. Charles in 2004 and 2005. Soil samples were taken 30 days after the fourth micro-rate application. Giant foxtail was planted in the soil three times at three week intervals.

Timings and rates of *s*-meto.[a] & dimeth.-P with the 4 micro-rates					Planting 1		Planting 2		Planting 3	
PRE	M1	M2	M3	M4	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P
					— % growth reduction —		— % growth reduction —		— % growth reduction —	
Micro-rate treatment alone[b]					0		0		0	
		1X[c]			49	37	20	16	3	4
			1X		77	39	34	14	9	6
				1X	81	80	38	15	13	5
		0.5X		0.5X	76	57	43	12	14	6
	0.25X	0.25X	0.25X	0.25X	88	38	23	12	17	4
Untreated					0		0		0	
$LSD_{0.05}$					13		10		7	

[a] Abbreviations: *s*-meto., *s*-metolachlor; dimeth.-P, dimethenamid-P; PRE, preemergence; M1, micro-rate 1; M2, micro-rate 2; M3, micro-rate 3; M4, micro-rate 4.

[b] The micro-rate treatment was desmedipham and phenmedipham at 90 g/ha + triflusulfuron-methyl at 4.4 g/ha + clopyralid at 26 g/ha + methylated seed oil at 1.5% v/v. This treatment was applied four times at approximately 125 GDD intervals (Table 1).

[c] The 1X rate of *s*-metolachlor was 1.4 kg/ha and the 1X rate of dimethenamid-P was 0.84 kg/ha.

Table 10. Giant foxtail growth reduction from soil sampled in field plots treated with micro-rate herbicide programs with and without the addition of *s*-metolachlor and dimethenamid-P at East Lansing in 2004 and 2005. Soil samples were taken 30 days after the fourth micro-rate application. Giant foxtail was planted in the soil three times at three week intervals.

Timings and rates of *s*-meto.[a] & dimeth.-P with the 4 micro-rates					Planting 1		Planting 2		Planting 3	
PRE	M1	M2	M3	M4	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P	*s*-meto.	dimeth.-P
					— % growth reduction —		— % growth reduction —		— % growth reduction —	
Micro-rate treatment alone[b]					0		0		0	
		1X[c]			60	33	15	10	7	1
			1X		52	37	10	8	6	4
				1X	81	35	20	11	5	6
		0.5X		0.5X	61	38	21	17	10	9
	0.25X	0.25X	0.25X	0.25X	88	38	23	12	13	5
Untreated					0		0		0	
$LSD_{0.05}$					14		10		7	

[a] Abbreviations: *s*-meto., *s*-metolachlor; dimeth.-P, dimethenamid-P; PRE, preemergence; M1, micro-rate 1; M2, micro-rate 2; M3, micro-rate 3; M4, micro-rate 4.

[b] The micro-rate treatment was desmedipham and phenmedipham at 90 g/ha + triflusulfuron-methyl at 4.4 g/ha + clopyralid at 26 g/ha + methylated seed oil at 1.5% v/v. This treatment was applied four times at approximately 125 GDD intervals (Table 1).

[c] The 1X rate of *s*-metolachlor was 1.4 kg/ha and the 1X rate of dimethenamid-P was 0.84 kg/ha.

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CHAPTER 3

TOLERANCE OF 12 SUGARBEET (*Beta vulgaris*) VARIETIES TO APPLICATIONS OF *S*-METOLACHLOR AND DIMETHENAMID-P

Abstract. Sugarbeet varieties vary in their response to herbicides. *S*-metolachlor and dimethenamid-P were recently registered for use in sugarbeets. Field trials were conducted in four environments in Michigan in 2004, 2005, and 2006 to evaluate the response of twelve sugarbeet varieties to *s*-metolachlor and dimethenamid-P applied PRE and POST to 2-leaf and 4-leaf sugarbeets. *S*-metolachlor and dimethenamid-P reduced sugarbeet populations when rainfall occurred within 7 d of the PRE applications. Dimethenamid-P PRE caused the most injury across all varieties followed by *s*-metolachlor PRE. Dimethenamid-P POST to 2-leaf sugarbeets injured sugarbeets more than *s*-metolachlor POST to 2- and 4-leaf sugarbeets. The least of sugarbeet injury from dimethenamid-P was POST applications to 4-leaf sugarbeets. Sugarbeet varietal differences were most pronounced from PRE applications of both herbicides and from the POST 2-leaf application of dimethenamid-P. Of the twelve sugarbeet varieties evaluated, Hilleshog 2771RZ and Beta 5833R were the most tolerant and Hilleshog 7172RZ typically the most sensitive to these herbicides. Growers will probably not choose varieties based on herbicide tolerance, but instead base variety selection on sugar yield and disease resistance. However, if a grower has chosen to plant a particular variety for his farm this information may assist him in deciding if there are risks associated with using *s*-metolachlor or dimethenamid-P for weed control.

Nomenclature: *s*-metolachlor; dimethenamid-P; sugarbeet, *Beta vulgaris* L.

Key words: application timing, varietal tolerance

INTRODUCTION

The recent registrations of *s*-metolachlor and dimethenamid-P for use in sugarbeet provide growers with additional options for weed control. *S*-metolachlor and dimethenamid-P are both chloroacetamide herbicides that are primarily absorbed by emerging shoots of grass and broadleaf weeds (Vencill 2002). Because of their mechanism of action, these herbicides are only phytotoxic to emerging seedlings, and therefore will only control weeds prior to emergence. Thus, typical application timings for *s*-metolachlor and dimethenamid-P are early preplant (EPP), preplant incorporated (PPI), and preemergence (PRE) in crops for which they are registered.

Differential tolerance of crop cultivars, including sugarbeet, to herbicides has been previously studied (Dale et al. 2005; Dexter and Luecke 1997; Smith and Schweizer 1983; Wilson 1999). Dexter and Kern (1977) reported that sugarbeet varieties responded differently to EPTC. Recoverable white sugar yield for the 19 varieties evaluated separated into two groups, a tolerant group (7 to 16% yield loss) and a susceptible group (24 to 27% yield loss). Herbicide by variety interactions have also been reported from cycloate PPI and ethofumesate PRE (Smith et al. 1982). Smith and Schweizer (1983) reported that sugarbeet plant weight was reduced 39 to 55% with significant herbicide by variety interactions 45 d after planting. However by harvest, sugarbeet had recovered from early season injury and root yield was not different between the eight commercial varieties evaluated.

Corn and soybean are generally tolerant to *s*-metolachlor and dimethenamid-P. However, differential tolerance of soybean varieties (Osborne et al. 1995a; Osborne et el. 1995b) and corn inbreds and hybrids (Bernards et al. 2006; Cottingham et al. 1993; Rowe and Penner 1990) to metolachlor and dimethenamid have been demonstrated. Root length was reduced in 7 of 32 soybean cultivars and lateral root length was reduced in 12 cultivars from dimethenamid and metolachlor applications, respectively (Osborne et al. 1995a). Rowe and Penner (1990) reported that corn hybrid, herbicide rate, and soil moisture at the time of planting all affected corn hybrid tolerance to metolachlor.

Sugarbeet injury from *s*-metolachlor and dimethenamid-P applications has been reported by growers and researchers. In two out of three years, postemergence applications of dimethenamid-P resulted in significant sugarbeet injury, 12 and 28 d after treatment (Rice et al. 2002). PPI and PRE applications of *s*-metolachlor resulted in significant sugarbeet stand reductions and over 40% visible injury, in years when moisture was not limited (Dexter and Luecke 2003; Renner 2003). Instances of injury from *s*-metolachlor and dimethenamid-P have been inconsistent. Currently *s*-metolachlor and dimethenamid-P are labeled for POST applications after sugarbeet has reached 2-fully developed true leaves. Additionally, *s*-metolachlor has a 24(C) registration for preemergence applications. Herbicide application timing and/or differences in tolerance of sugarbeet varieties to *s*-metolachlor and dimethenamid-P may explain some of the variability observed in sugarbeet response. Investigating the response of current sugarbeet varieties to applications of *s*-metolachlor and dimethenamid-P will provide information to growers on the potential risk of applying these herbicides to certain varieties. Therefore, the objectives of this research were to: 1) examine how application timing influences sugarbeet tolerance to *s*-metolachlor and dimethenamid-P, and 2) evaluate the response of twelve commercially grown sugarbeet varieties to *s*-metolachlor and dimethenamid-P.

MATERIALS AND METHODS

Field Experiments. Twelve commercial sugarbeet varieties were planted at St. Charles, MI in 2004, 2005, and 2006 and at E. Lansing, MI in 2005. All varieties were monogerm hybrids. 'Crystal 271,'[6] 'Crystal 963,'[1] 'Beta 5451,'[7] and 'Beta 5310'[2] were triploid varieties (2N=3X=27). 'Beta 5833R,'[2] 'Beta 4381R,'[2] 'Hilleshog E-17,'[8] 'Hilleshog 2761RZ,'[3] 'Hilleshog 2763RZ,'[3] 'Hilleshog 2771RZ,'[3] 'Hilleshog 7172RZ,'[3] and '*SX* Prompt,'[9] were diploid varieties (2N=2X=18). Sugarbeet varieties selected for this experiment were Michigan Sugar Company approved varieties and were included in the Sugarbeet Advancement official variety trials.

The soil at St. Charles was a Misteguay silty clay loam (fine-loamy, mixed, mestic Aeric Endoaquepts) with a soil pH of 8.1, and 2.9% organic matter. The soil at E. Lansing was a sandy clay loam (fine-loamy, mixed, mestic Aeric Ochraqualfs) with a soil pH of 6.6, and 3.4% organic matter. Experiments followed wheat and corn in the rotation at St. Charles and E. Lansing, respectively. Fields were fall plowed followed by field cultivation in the spring.

The experimental design was a split-split plot with herbicide as the main plot, application timing as the sub-plot, and sugarbeet variety as the sub-sub plot. All treatments were replicated four times at St. Charles in 2004 and 2005, and three times at E. Lansing 2005 and St. Charles 2006. The herbicide treatments were *s*-metolachlor at 1.4 kg/ha and dimethenamid-P at 0.84 kg/ha. Each herbicide was applied at three applications timings: 1) immediately after planting (PRE), 2) when sugarbeets were at the

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[6] American Crystal Sugar Company, 101 North 3rd Street, Moorhead, MN 56560.

[7] Betaseed, Inc., 1788 Marschall Road, P.O. Box 195, Shakopee, MN 55379.

[8] Syngenta Seeds Inc., 1020 Sugarmill Road, Longmont, CO 80501.

[9] Seedex, 1350 Kansas Avenue, Longmont, CO 80501

two-true-leaf growth stage (2-leaf), or 3) when sugarbeets were at the four-true-leaf growth stage (4-leaf). Herbicides were applied using a tractor-mounted compressed-air sprayer calibrated to deliver 178 L/ha at 207 kPa through AirMix 11003[10] nozzles. A non-treated control for each variety was also included for comparison. Sugarbeets were planted 2.5-cm deep at 118,560 seeds/ha in 76-cm rows. At St. Charles, sugarbeets were planted on April 7, 2004, April 4, 2005, and April 6, 2006, and at E. Lansing, sugarbeets were planted on April 6, 2005. Plot length was 9.1 m, and width was two rows at St. Charles and one row at E. Lansing. Daily precipitation was recorded at each site (Table 11). All plots were kept weed-free by mechanical cultivation and hand-weeding.

Sugarbeet injury was visually evaluated 14 d after the 4-leaf application timing by comparing the treated varieties to their respective non-treated varieties. Visual estimations of injury were based on a rating scale of 0 (no injury) to 100 (plant death). Sugarbeet plant populations for each plot were also recorded at this time and again prior to harvest. Sugarbeet leaf area was measured 14 d after the 4-leaf application by harvesting two representative plants from each plot at ground level. Leaf area for individual plants was measured using a LI-3000 Portable Area Meter[11]. Leaf area for each of the treated varieties was compared with the non-treated control for that specific variety and percent leaf area reduction was calculated.

Sugarbeet canopy development was measured in four of the sugarbeet varieties, Crystal 963, Hilleshog 7172RZ, Beta 5833R, and Beta 5451 at the St. Charles site in 2005 and 2006 by measuring the amount of light transmitted through the sugarbeet canopy. Measurements were taken, three per plot, at 1 to 2 week intervals at or near solar

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[10] Greenleaf Technologies, P.O. Box 1767, Covington, LA, 70434.
[11] LI-COR, 4647 Superior St., Lincoln, NE 68504.

noon beginning 14 d after the 4-leaf application (10 weeks after planting (WAP)) until peak canopy using the Sunscan Canopy Analysis System[12]. The SunScan system consisted of three components: 1) a wand that was 1 m long and 13 mm wide with sensors placed every 15.6 mm along the length of the wand with a spectral response of 400 to 700 nm to measure light beneath the crop canopy, 2) a tripod-mounted sensor that measured both incident and diffuse light above the crop canopy, and 3) a handheld Psion Workabout datalogger[13] that recorded simultaneous measurements of light above and beneath the crop canopy. Light transmission, as a percent of incident, was automatically calculated as each measurement was taken perpendicular to the two sugarbeet rows. Measurements for each treated variety were compared to the non-treated control for that same variety and percent canopy reduction was calculated.

Sugarbeets were flailed and topped with a four-row topper, and harvested October, 5, 2004, September, 23, 2005, and September 19, 2006 at St. Charles with a two-row mechanical lifter and on September 27, 2005 at E. Lansing with a one-row lifter. Sugarbeets were weighed and a sample of roots from each plot was analyzed for recoverable white sucrose by Michigan Sugar Company, Bay City, MI.

Greenhouse Experiments. Five seeds per pot (10-cm by 10-cm) of eight of the 12 sugarbeet varieties evaluated in the field were planted 2.5-cm deep in a Spinks loamy sand soil (sand, mixed, mesic Psammentic Hapludalfs) with 2.4 percent organic matter and a pH of 6.8. Sugarbeet plantings were staggered so that preemergence (PRE), and postemergence (POST) applications to 2-leaf and 4-leaf sugarbeets of *s*-metolachlor at 1.4 kg/ha and dimethenamid-P at 0.84 kg/ha could all be made at the same time. The

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

[13] Psion Digital, 1810 Airport Exchange Boulevard, Suite 500, Erlanger KY 41018.

experiment was arranged in a completely randomized design with four replications and repeated. Herbicides were applied with a single tip track-sprayer through a Teejet 8001E flat-fan nozzle[14] calibrated to deliver 187 L/ha at 207 kPa. Treatments were incorporated with 66 ml of water each day of the first five days to move herbicide into the soil profile, which simulated 64 mm of daily precipitation. Following the initial five days, pots were watered daily to maintain adequate soil moisture for plant growth. Pots were fertilized bi-weekly with 50 ml of a fertilizer solution containing 70 mg/L of 20% nitrogen, 20% P_2O_5, and 20% K_2O. Sugarbeets were grown in the greenhouse and sunlight was supplemented with sodium vapor lighting to provide a total midday light intensity of 1000 µmol/m/s photosynthetic photon flux at plant height with a 16 h day length. The greenhouse temperature was maintained at 25 ± 2 C.

Once plants emerged, germination percentages were determined and pots were then thinned to two sugarbeets per pot. Sugarbeets were visually evaluated 21 d after treatment (DAT) based on a rating scale from 0 (no effect) to 100 (plant death). At this time, aboveground plant tissue was harvested, dried, and weighed and converted to a percent of the non-treated control.

Statistical Analysis. Data from the field and greenhouse experiments were subjected to ANOVA, using the PROC MIXED procedure in SAS. Main effects and all possible interactions were tested using the appropriate mean square values as recommended by McIntosh (1983). Data were combined over experiments and/or environments when appropriate interactions were not significant. Mean separation for treatment differences was performed using Fisher's protected LSD at $P \leq 0.05$.

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[14] Spraying Systems Co., North Avenue, Wheaton, IL 60189.

RESULTS AND DISCUSSION

S-metolachlor and dimethenamid-P applied PRE and POST reduced sugarbeet growth and caused sugarbeet leaf crinkling. Across the four environments, total rainfall and the time of rainfall events varied (Table 11). Because of the variability in rainfall, sugarbeet injury differed across the environments. At the St. Charles 2006 site, rainfall occurred within 7 d of PRE herbicide applications (Table 11), sugarbeet injury was greatest at this site. However, upon closer examination of the data, differences between the St. Charles 2006 site and the other environments were due to the differences in the magnitude of sugarbeet injury not in treatment trends. Therefore, sugarbeet injury data were combined across environments.[15]

Effect of Application Timing. There was a significant herbicide by application timing interaction for sugarbeet injury and leaf area in the field and for sugarbeet biomass in the greenhouse, so data were combined over varieties. In the field and in the greenhouse, dimethenamid-P PRE caused the greatest damage to sugarbeets (Table 12). Injury in the field from this treatment was 35% and leaf area reduction was 31% averaged over varieties. In the greenhouse, where moisture and temperatures were ideal for herbicide uptake, dimethenamid-P PRE resulted in a 81% reduction in sugarbeet biomass. Even though injury was not as severe as injury caused by PRE applications of dimethenamid-P, PRE applications of *s*-metolachlor resulted in 23% sugarbeet injury and 23% leaf area reduction in the field. In the greenhouse, sugarbeet biomass was reduced 36% from this treatment.

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[15] Dr. A. Kravchenko, Michigan State University Statistical Center.

Injury from applications of *s*-metolachlor and dimethenamid-P to 2-leaf sugarbeets was not as severe as PRE applications of these herbicides (Table 12). However, injury from the application of dimethenamid-P to 2-leaf sugarbeets was similar to PRE applications of *s*-metolachlor, suggesting that even at this application timing, dimethenamid-P applications may cause excessive injury for use in sugarbeet. Applications of *s*-metolachlor and dimethenamid-P to 4-leaf sugarbeets caused the least amount of injury in both the field and greenhouse. Sugarbeet injury was 15% or less in the field and sugarbeet biomass was only reduced 10% from either of these treatments. Overall results of sugarbeet damage were similar between the field and the greenhouse. PRE applications of *s*-metolachlor and dimethenamid-P and POST applications of dimethenamid-P to 2-leaf sugarbeets may cause too much injury for use in sugarbeets.

Varietal Tolerance. There was a significant variety by herbicide interaction for sugarbeet injury and leaf area in the field and for sugarbeet biomass in the greenhouse. Therefore, data are presented separately by herbicide application timing.

Tolerance to Preemergence Applications. PRE applications of *s*-metolachlor and dimethenamid-P reduced sugarbeet populations at the St. Charles 2006 site (Table 13). At this location, 4-cm of rainfall occurred within 7 d of the PRE applications, which increased herbicide uptake and killed some of the sugarbeets (Table 11). At all other sites, significant rainfall did not occur within 7 d of the PRE applications.

Sugarbeet populations were reduced from *s*-metolachlor PRE in five of the twelve varieties evaluated (Table 13). Populations were reduced 22 to 37% in these five varieties compared with the non-treated controls for each variety. Of the five varieties where sugarbeet populations were reduced, two were triploid varieties and three were diploid varieties. There have been other reports of significant reductions in sugarbeet population from *s*-metolachlor PRE (Renner 2003).

Significant reductions in sugarbeet populations from dimethenamid-P PRE ranged from 28 to 42% of the eight varieties where populations were reduced compared with their non-treated controls (Table 13). Five of these varieties were the same varieties where populations were reduced from *s*-metolachlor PRE. There was only one variety, Hilleshog 7172RZ, where dimethenamid-P PRE reduced populations more than *s*-metolachlor PRE.

Sugarbeet varieties responded differently to *s*-metolachlor and dimethenamid-P PRE. *S*-metolachlor PRE caused significant damage to all sugarbeet varieties (Table 14). In the field, sugarbeet injury from *s*-metolachlor PRE ranged from 16 to 33% and leaf area was reduced 11 to 44%. Unlike sugarbeet variety research by Dexter and Kern (1977) on EPTC we could not separate the twelve varieties we evaluated into tolerant and susceptible groups, because sugarbeet injury between the different varieties was continuous. However, the three varieties that appeared to be the most tolerant from field evaluations were Crystal 271, Beta 5833R, and Hilleshog 2771RZ (Table 14). Of these varieties, Crystal 271 was the only variety that was evaluated in the greenhouse. In this experiment, it was also among the most tolerant varieties to *s*-metolachlor PRE. The most susceptible variety in the field and in the greenhouse to PRE *s*-metolachlor applications was Hilleshog 7172 RZ. There was no correlation of ploidy level to varieties that were either more tolerant or more susceptible to *s*-metolachlor PRE.

Similar to *s*-metolachlor PRE, dimethenamid-P PRE caused significant damage to all sugarbeet varieties (Table 14). In the field, sugarbeet injury from dimethenamid-P

PRE ranged from 25 to 46% and leaf area was reduced 16 to 48%. The twelve sugarbeet varieties could not be separated into tolerant and susceptible groups. However, the three varieties that had the least amount of injury in the field from dimethenamid-P PRE were Beta 5833R, Hilleshog 2763RZ, and Hilleshog 2771RZ (Table 14). Unfortunately, none of these varieties were evaluated in the greenhouse experiment. Similar to the response from *s*-metolachlor PRE, Hilleshog 7172RZ was among the most susceptible varieties to dimethenamid-P PRE. Additionally from the field and greenhouse evaluations, Crystal 963 and Hilleshog 2761 were also very susceptible to dimethenamid-P PRE. Sugarbeet injury was greater from dimethenamid-P PRE compared with *s*-metolachlor PRE in eight of the twelve varieties evaluated in the field (Table 14). In the greenhouse, biomass reductions from dimethenamid-P PRE were greater than reduction from *s*-metolachlor PRE for all eight varieties evaluated.

Tolerance to 2-Leaf Applications. In the field, sugarbeet injury from *s*-metolachlor applied POST to 2-leaf sugarbeets was not different between the twelve varieties evaluated (Table 15). Sugarbeet injury ranged from 13 to 21%. However, there was a significant difference in leaf area reduction from one variety, Hilleshog 7172RZ. This variety was also the most susceptible to PRE applications of *s*-metolachlor and dimethenamid-P. In the greenhouse, there were more differences in sugarbeet varietal responses to *s*-metolachlor applications to 2-leaf sugarbeets. Sugarbeet biomass reduction ranged from 18 to 51% (Table 15). Hilleshog 7172RZ was also the most susceptible variety in the greenhouse followed by Crystal 271. The most tolerant variety in the greenhouse was Beta 5451.

Sugarbeet varieties responded differently to dimethenamid-P applied POST to 2-leaf sugarbeets. In the field, sugarbeet injury ranged from 18 to 31% and leaf area was reduced 16 to 38% (Table 15). Five out of the twelve sugarbeet varieties evaluated in the field and six of the eight sugarbeet varieties evaluated in the greenhouse were more susceptible to dimethenamid-P applied POST to 2-leaf sugarbeets compared with the most tolerant varieties for sugarbeet injury and biomass reductions, respectively. Similar to the other application timings, Hilleshog 7172RZ was one of the more sensitive varieties.

Tolerance to 4-Leaf Applications. When *s*-metolachlor and dimethenamid-P were applied POST to 4-leaf sugarbeets, there were no differences in injury to sugarbeet varieties in the field (Table 16). In the greenhouse, the two most susceptible varieties to *s*-metolachlor applied POST to 4-leaf sugarbeets were Beta 5451 and Hilleshog E-17. Hilleshog E-17 was also the most susceptible variety to POST applications of dimethenamid-P.

Canopy Development. Sugarbeet canopy development was measured 10, 12, 13, and 15 WAP in four varieties, Beta 5451, Beta 5833R, Crystal 963, and Hilleshog 7172 RZ. Canopy development did not differ between the varieties; therefore reductions in sugarbeet canopy are averaged over varieties. At 10, 12, and 13 WAP, PRE applications of *s*-metolachlor and dimethenamid-P significantly reduced sugarbeet canopy development compared with the non-treated control (Table 17). However, by 15 WAP the sugarbeet canopy was similar to the non-treated controls. Sugarbeet canopy was also reduced from *s*-metolachlor and dimethenamid-P applied POST to 2-leaf sugarbeets, 10, 12, and 13 WAP (Table 17). The only time period when sugarbeet canopy reductions were greater for the PRE applications compared with the POST 2-leaf applications of *s*-metolachlor and dimethenamid-P was 10 WAP. *S*-metolachlor and dimethenamid-P applied POST to 4-leaf sugarbeets did not cause reductions in sugarbeet canopy development compared with the non-treated control, except with dimethenamid-P 10 WAP. For all treatments, sugarbeet canopy was the same as the non-treated controls 15 WAP. Others have also reported that sugarbeets can recover from early season injury (Smith and Schweizer 1983; Wilson 1999).

Sugarbeet Yield. Sugarbeet yield did not differ significantly for the twelve sugarbeet varieties; therefore yield data were combined over varieties. Additionally, due to the differences in rainfall and sugarbeet populations at St. Charles 2006, this data is presented separately from the other sites. Recoverable white sucrose yield was not affected by herbicide application at the combined sites of St. Charles 2004, 2005 and East Lansing 2005 (Table 18). At St. Charles 2006, recoverable white sucrose yield was significantly lower for sugarbeets treated with *s*-metolachlor and dimethenamid-P PRE compared with the non-treated control. At this application timing, yield reductions were greater from the dimethenamid-P application. Yield reductions probably were a result of sugarbeet population reductions observed at this site due to significant rainfall within 7 d of the PRE applications (Table 11).

Our research indicates that PRE applications of *s*-metolachlor and dimethenamid-P and POST applications of dimethenamid-P to 2-leaf sugarbeets can cause significant injury to sugarbeets. In most cases, sugarbeets can recover from early season injury. However, if sugarbeet populations are reduced from PRE applications in years with rainfall close to application, reductions in recoverable white sucrose are probable.

Therefore, growers should not apply *s*-metolachlor and dimethenamid-P PRE because of possible yield reductions. Additionally, growers should also be cautious of POST applications of dimethenamid-P POST to 2-leaf sugarbeets, because of substantial early season sugarbeet injury. POST applications of *s*-metolachlor to sugarbeets that were at the 2-leaf stage or larger and POST applications of dimethenamid-P to sugarbeets at the 4-leaf stage were the application timings that caused the least amount of sugarbeet injury.

Differences in sugarbeet injury from POST applications of *s*-metolachlor and dimethenamid-P between the 2- and 4-leaf sugarbeet stages were probably due to the size of the plant at the time of application. Injury was more severe from POST *s*-metolachlor and dimethenamid-P to 2-leaf sugarbeets compared with 4-leaf sugarbeets. Because two-leaf sugarbeets are much smaller compared with 4-leaf sugarbeets, the root biomass is likely to be less at this stage. Previous research has shown chloroacetamide herbicides are absorbed primarily through the roots in dicotyledonous plants (Le Baron et al. 1988). Since a larger percentage of roots of 2-leaf sugarbeets are much closer to the soil surface, the likelihood of increased uptake of a herbicide applied to the soil surface would be higher. Greater herbicide uptake may cause more sugarbeet injury from POST applications to 2-leaf sugarbeets compared with 4-leaf sugarbeets. Additionally, since 2-leaf sugarbeet plants are smaller and have less leaf area, the plant has less tissue to dissipate the herbicide and less metabolic activity. Therefore, 4-leaf sugarbeets may be more efficient at metabolizing the herbicide resulting in less sugarbeet injury.

This research also indicates that sugarbeet varieties can vary in their response to *s*-metolachlor and dimethenamid-P. Varietal differences were greater at the PRE and POST 2-leaf application timings. Of the twelve sugarbeet varieties evaluated, Hilleshog

2771RZ and Beta 5833R tended to be most tolerant and Hilleshog 7172RZ was typically the most sensitive. Due to the importance of variety selection for other production factors, such as disease resistance and yield potential, growers will probably not choose varieties based on herbicide tolerance. However, if a grower has chosen a particular variety, this information may assist the grower in deciding if there are risks associated with using *s*-metolachlor or dimethenamid-P PRE or POST for weed control.

Table 11. Bi-weekly rainfall compared with the 30-yr average for St. Charles 2004, 2005, and 2006 and E. Lansing 2005, MI.[a]

	St. Charles				E. Lansing	
Date	2004[b]	2005[c]	2006[d]	30-yr ave[e].	2005[f]	30-yr ave.
	cm				cm	
April 1	0.0	0.0	4.1	—	0.0	—
April 15	3.2	3.4	0.6	7.4	2.0	7.1
May 1	9.8	3.3	6.0	—	1.8	—
May 15	6.8	1.2	4.5	6.9	1.6	6.9
June 1	4.5	10.1	2.6	—	9.0	—
June 15	2.3	2.4	2.5	7.4	1.8	8.6
July 1	3.7	1.1	7.5	—	2.2	—
July 15	2.3	7.1	7.0	5.6	9.4	6.9
August 1	0.9	1.7	0.8	—	1.1	—
August 15	5.0	0.4	5.9	8.1	0.6	8.1
September 1	1.5	0.0	2.9	—	0.1	—
September 15	0.0	1.8	3.5	9.9	7.5	8.6
Total	40.0	32.5	47.9	45.2	37.1	46.2

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

[b] Herbicide application dates were: April 7 (PRE), May 7 (2-leaf), and May 17 (4-leaf), 2004.

[c] Herbicide application dates were: April 4 (PRE), May 12 (2-leaf), and May 25 (4-leaf), 2005.

[d] Herbicide application dates were: April 6 (PRE), May 9 (2-leaf), and May 22 (4-leaf), 2006.

[e] Average for entire month.

[f] Herbicide application dates were: April 6 (PRE), May 13 (2-leaf), and May 20 (4-leaf), 2004.

Table 12. Effect of *s*-metolachlor and dimethenamid-P application timings on sugarbeet injury and leaf area (14 DAT) in the field and sugarbeet biomass (21 DAT) in the greenhouse.[a]

	Field - St. Charles 2004, 2005, & 2006 & E. Lansing 2005[b]				Greenhouse	
	Injury		Leaf area[d]		Biomass[e]	
Timing[c]	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P
	%		% reduction		% reduction	
PRE	23	35	23	31	36	81
2-leaf	15	24	18	25	30	39
4-leaf	13	15	16	15	10	10
$LSD_{(0.05)}$	5		6		5	

[a] Field data is averaged over 12 and greenhouse data is averaged over 8 sugarbeet varieties commercially grown in MI.
[b] Data was combined across all site years.
[c] Herbicides were applied preemergence (PRE) and to 2- and 4-leaf sugarbeets.
[d] Data for leaf area reduction was calculated using a comparison of leaf area from the non-treated control for each variety.
[e] Biomass data is from sugarbeet dry weights harvested 21 DAT and data was calculated using a comparison of biomass from the non-treated control for each variety.

Table 13. Sugarbeet population reductions from preemergence applications of *s*-metolachlor and dimethenamid-P at St. Charles in 2006.[a]

Variety	Ploidy level	*s*-metolachlor	dimethenamid-P
		% reduction[b]	
Beta 5451	Triploid	37	42
Beta 5310	Triploid	29	33
Crystal 963	Triploid	8	15
Crystal 271	Triploid	19	17
Hilleshog E-17	Diploid	11	29
Hilleshog 7172RZ	Diploid	16	38
Hilleshog 2761RZ	Diploid	22	31
SX Prompt	Diploid	28	41
Beta 4381R	Diploid	24	39
Beta 5833R	Diploid	0	9
Hilleshog 2763RZ	Diploid	10	28
Hilleshog 2771RZ	Diploid	2	12
$LSD_{(0.05)}$		21	

[a] Applications rates were 1.4 kg/ha of *s*-metolachlor and 0.84 kg/ha of dimethenamid-P.
[b] Stand reduction was calculated using a comparison of sugarbeet stand from the non-treated control from each variety.

Table 14. Differences in tolerance of sugarbeet varieties to preemergence applications of *s*-metolachlor and dimethenamid-P in field and greenhouse experiments.[a]

	Field - St. Charles 2004, 2005, & 2006 & E. Lansing 2005[b]				Greenhouse	
	Injury		Leaf area[c]		Biomass[d]	
Variety[c]	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P
	%		% reduction		% reduction	
Beta 5451	25	34	22	31	36	72
Beta 5310	23	35	34	23	44	80
Crystal 963	23	38	30	44	24	97
Crystal 271	16	34	16	32	26	87
Hilleshog E-17	22	35	28	28	28	74
Hilleshog 7172RZ	33	46	44	48	47	91
Hilleshog 2761RZ	23	39	29	38	39	79
SX Prompt	20	37	22	36	41	71
Beta 4381R	27	34	20	36	—	—
Beta 5833R	19	29	18	19	—	—
Hilleshog 2763RZ	29	32	24	16	—	—
Hilleshog 2771RZ	20	25	11	21	—	—
$LSD_{(0.05)}$	10		17		9	

[a] Sugarbeet injury and leaf area reduction were evaluated 14 days after treatment (DAT) in the field and sugarbeet biomass (dry weight) in the greenhouse was collected 21 DAT.

[b] Data was combined across all site years.

[c] Data for leaf area reduction was calculated using a comparison of leaf area from the non-treated control for each variety.

[d] Biomass data is from sugarbeet dry weights harvested 21 DAT and data was calculated using a comparison of biomass from the non-treated control for each variety.

Table 15. Differences in tolerance of sugarbeet varieties from applications of *s*-metolachlor and dimethenamid-P to 2-leaf sugarbeets in field and greenhouse experiments.[a]

	Field - St. Charles 2004, 2005, & 2006 & E. Lansing 2005[b]				Greenhouse	
	Injury		Leaf area[c]		Biomass[d]	
Timing[c]	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P
	%		% reduction		% reduction	
Beta 5451	13	28	21	31	18	38
Beta 5310	13	18	20	20	31	35
Crystal 963	21	28	20	23	24	38
Crystal 271	13	31	15	23	40	44
Hilleshog E-17	18	30	19	25	29	51
Hilleshog 7172RZ	20	26	36	38	51	57
Hilleshog 2761RZ	13	19	23	21	28	20
SX Prompt	13	28	19	25	22	26
Beta 4381R	13	20	16	27	—	—
Beta 5833R	15	20	12	16	—	—
Hilleshog 2763RZ	14	22	18	26	—	—
Hilleshog 2771RZ	14	22	13	24	—	—
$LSD_{(0.05)}$	9		14		10	

[a] Sugarbeet injury and leaf area reduction were evaluated 14 days after treatment (DAT) in the field and sugarbeet biomass (dry weight) in the greenhouse was collected 21 DAT.
[b] Data was combined across all site years.
[c] Data for leaf area reduction was calculated using a comparison of leaf area from the non-treated control for each variety.
[d] Biomass data is from sugarbeet dry weights harvested 21 DAT and data was calculated using a comparison of biomass from the non-treated control for each variety.

Table 16. Differences in tolerance of sugarbeet varieties from applications of *s*-metolachlor and dimethenamid-P to 4-leaf sugarbeets in field and greenhouse experiments.[a]

	Field - St. Charles 2004, 2005, & 2006 & E. Lansing 2005[b]				Greenhouse	
	Injury		Leaf area[c]		Biomass[d]	
Timing[c]	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P
	%		% reduction		% reduction	
Beta 5451	12	18	20	24	20	14
Beta 5310	10	15	14	11	8	6
Crystal 963	14	14	14	20	10	11
Crystal 271	13	15	14	18	6	8
Hilleshog E-17	16	12	21	11	17	23
Hilleshog 7172RZ	17	15	21	13	10	11
Hilleshog 2761RZ	10	15	19	11	10	7
SX Prompt	16	14	19	20	3	5
Beta 4381R	14	15	17	18	—	—
Beta 5833R	6	10	1	2	—	—
Hilleshog 2763RZ	9	21	10	20	—	—
Hilleshog 2771RZ	10	10	10	18	—	—
$LSD_{(0.05)}$	NS		NS		9	

[a] Sugarbeet injury and leaf area reduction were evaluated 14 days after treatment (DAT) in the field and sugarbeet biomass (dry weight) in the greenhouse was collected 21 DAT.

[b] Data was combined across all site years.

[c] Data for leaf area reduction was calculated using a comparison of leaf area from the non-treated control for each variety.

[d] Biomass data is from sugarbeet dry weights harvested 21 DAT and data was calculated using a comparison of biomass from the non-treated control for each variety.

Table 17. Effect of *s*-metolachlor and dimethenamid-P application timings on sugarbeet canopy reduction 10, 12, 13, and 15 weeks after planting (WAP) compared with the non-treated control in St. Charles, 2005 and 2006.[a]

	10 WAP		12 WAP		13 WAP		15 WAP	
Timing[b]	*s*-meto.	dimeth.	*s*-meto.	dimeth.	*s*-meto.	dimeth.	*s*-meto.	dimeth.
	— % reduction[c] —		— % reduction —		— % reduction —		— % reduction —	
PRE	27	30	15	17	11	14	5	7
2-leaf	17	23	9	14	11	11	6	6
4-leaf	9	11	5	3	8	5	6	5
$LSD_{(0.05)}$	10		7		9		NS	

[a] Data are combined over Beta 5451, Beta 5833R, Crystal 963, Hilleshog 7172RZ sugarbeet varieties, since there were no statistical differences in sugarbeet variety.

[b] Herbicides were applied preemergence (PRE) and to 2- and 4-leaf sugarbeets.

[c] Data for canopy reductions were calculated using a comparison of the canopy from the non-treated control for each variety.

Table 18. Effect of *s*-metolachlor and dimethenamid-P application timings on recoverable white sucrose yield.[a]

	St. Charles 2004 & 2005 & E. Lansing 2005[b]		St. Charles 2006	
Timing[c]	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P
	—— % reduction[d] ——		—— % reduction ——	
PRE	1	1	7	15
2-leaf	3	3	0	3
4-leaf	2	4	1	5
$LSD_{(0.05)}$	NS		5	

[a] Data are combined over all 12 sugarbeet varieties, since there were no statistical differences in sugarbeet variety.
[b] Data were combined across St. Charles 2004 & 2005 and E. Lansing 2005.
[c] Herbicides were applied preemergence (PRE) and to 2- and 4-leaf sugarbeets.
[d] Data for yield reductions were calculated using a comparison of the recoverable white sucrose yield from the non-treated control for each variety.

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CHAPTER 4

PHYSIOLOGICAL BASIS FOR TOLERANCE OF SUGARBEET VARIETIES TO *S*-METOLACHLOR AND DIMETHENAMID-P

Abstract. Greenhouse and laboratory experiments were conducted to evaluate the response of four commercial sugarbeet varieties to *s*-metolachlor and dimethenamid-P, determine the principal site of absorption of these herbicides, and determine the physiological basis for differences in herbicide and sugarbeet variety tolerances. Sugarbeet varieties responded differently to applications of *s*-metolachlor and dimethenamid-P. 'Beta 5833R' was the most tolerant sugarbeet variety and 'Hilleshog 7172RZ' was the most susceptible sugarbeet variety to *s*-metolachlor and dimethenamid-P. The primary site of *s*-metolachlor and dimethenamid-P absorption was through the sugarbeet roots; however some absorption did occur through the sugarbeet hypocotyl. The extent of sugarbeet injury was greatest from applications dimethenamid-P compared with *s*-metolachlor when sugarbeets were grown in soil. However, when sugarbeets were grown hydroponically differences in injury from the herbicides were not as great, indicating that differences in the availability of these herbicides in the soil greatly influenced sugarbeet injury. Reduced translocation and slower metabolism of ^{14}C-dimethenamid-P in both the roots and shoots of the sugarbeet plants most likely contributed to the greater susceptibility of sugarbeets to dimethenamid-P compared with *s*-metolachlor. Slower metabolism of ^{14}C-herbicides in sugarbeet shoots was likely the most significant factor contributing to differences in sugarbeet variety tolerance to both *s*-metolachlor and dimethenamid-P.

Nomenclature: *s*-metolachlor; dimethenamid-P; sugarbeet, *Beta vulgaris* L.

Key words: metabolism, herbicide uptake, herbicide translocation

INTRODUCTION

s-Metolachlor and dimethenamid-P are chloroacetamide herbicides that are registered for selective early preplant, preplant incorporated, or preemergence weed control in corn, soybeans, dry beans, and several other crops. *s*-Metolachlor and dimethenamid-P, used alone or in combination with other PRE herbicides, control annual grasses, yellow nutsedge, and some small-seed broadleaf weeds. Recently, these herbicides were registered for POST applications in sugarbeets after the crop has two-true leaves (Anonymous 2005a; Anonymous 2005b).

Under certain conditions, PRE and POST applications of *s*-metolachlor and dimethenamid-P resulted in significant sugarbeet injury. Dexter and Luecke (2003) observed significant sugarbeet injury from PPI and PRE applications of *s*-metolachlor. In Michigan, PRE applications of *s*-metolachlor resulted in a loss of sugarbeet stand and general plant stunting (Renner 2003). POST applications of dimethenamid-P on four- to six-leaf sugarbeets caused severe plant stunting and yellowing (Rice et al. 2002; Dexter et al. 2002).

s-Metolachlor and dimethenamid-P are chloroacetamide herbicides which act by inhibiting the biosynthesis of fatty acids, lipids, proteins, isoprenoids, and flavonoids. Previous research has shown chloroacetamide herbicides are absorbed by shoots of grasses as they grow through treated soil. In dicotyledonous plants, root absorption can also be very important in herbicide uptake (Le Baron et al. 1988). Tolerance of different plant species to these herbicides has been attributed to the ability of the plant to rapidly metabolize the herbicide within a short time of absorption (within 6 h) (Cottingham and Hatzios 1992; Dixon and Stoller 1982; Le Baron et al. 1988). In corn there have been reports of differences in hybrid or inbred tolerance to metolachlor. Cottingham and Hatzios (1992) reported the difference in tolerance of two corn hybrids was due to the ability of the tolerant hybrid to metabolize the herbicide at a faster rate compared with the susceptible hybrid. Osborne et al. (1995) observed that 7 of 32 and 1 of 32 soybean cultivars tended to be susceptible to injury when exposed to metolachlor and dimethenamid, respectively, under hydroponic conditions.

Currently, the site of absorption of *s*-metolachlor and dimethenamid-P in sugarbeet is unknown. In addition, herbicide uptake, translocation and metabolism of *s*-metolachlor and dimethenamid-P have not been examined in sugarbeet. However, there have been several studies investigating other herbicides applied to sugarbeets. Tolerance of sugarbeet to ethofumesate was reportedly due to the ability of the sugarbeet plant to not absorb or translocate as much herbicide as the susceptible weed species (Duncan et al. 1981). Hendrick et al. (1974) demonstrated that the tolerance of sugarbeet to applications of phenmedipham and desmedipham was metabolism based.

Previous research has shown that sugarbeet varieties respond differently to herbicides. Applications of EPTC to 19 sugarbeet varieties resulted in losses of recoverable white sugar yields ranging from 7 to 24% (Dexter and Kern 1977). These varieties tended to fall into two groups, a tolerant group and a susceptible group. The yield reduction in the tolerant group of varieties ranged from 7 to 16% compared with the susceptible group which ranged from 24 to 27%. Wilson (1999) investigated the response of sugarbeet varieties to different POST treatments that included desmedipham plus phenmedipham with triflusulfuron, clopyralid, ethofumesate, or sethoxydim. Wilson documented that varieties responded differently to herbicides and the response varied between years. There is some speculation that differences in environment and production practices of sugarbeet seed lots may contribute to some of the varietal differences observed across years and environments (Dale et al. 2005). However, there is no information or research available that validates this speculation.

The objectives of this research were to: (1) evaluate the sensitivity of four sugarbeet varieties and four seed lots of one variety to applications of *s*-metolachlor and dimethenamid-P, (2) determine the principal site of absorption of *s*-metolachlor and dimethenamid-P by sugarbeet, and (3) determine the physiological basis for differences in herbicide and sugarbeet variety tolerances.

MATERIALS AND METHODS

Plant Culture in Soil. Sugarbeet seeds were planted in plastic pots (10-cm by 10-cm) filled with a Spinks loamy sand soil (sand, mixed, mesic Psammentic Hapludalfs) with 2.4 percent organic matter and a pH of 6.8. Sugarbeets were grown in the greenhouse and sunlight was supplemented with sodium vapor lighting to provide a total midday light intensity of 1000 µ/m/s photosynthetic photon flux at plant height in 16-h day. Greenhouse temperature was maintained at 25 ± 2 C. Pots were watered daily to maintain adequate soil moisture for plant growth. At 14 and 28 days after planting, 50 ml of a fertilizer solution containing 70 mg/L of 20% nitrogen, 20% P_2O_5, and 20% K_2O was applied to each pot. After emergence, pots were then thinned to two plants per pot.

Sugarbeet Tolerance and Site of Absorption. One seed lot of 'Crystal 963,'[16] 'Hilleshog 7172RZ,'[17] and 'Beta 5833R,'[18] and four seed lots of 'Beta 5451'[3] were treated with *s*-metolachlor and dimethenamid-P when sugarbeets were at the two-leaf stage. Application rates for *s*-metolachlor were 0, 0.7, 1.4, 2.8, and 5.7 kg/ha. Application rates for dimethenamid-P were 0, 0.4, 0.8, 1.7, and 3.4 kg/ha. The recommended use rates were 1.4 and 0.8 kg/ha for *s*-metolachlor and dimethenamid-P, respectively. Each herbicide was applied to the leaf surface only, the soil surface only, and to the leaf plus soil surfaces. Soil surface treatments were applied via a 25-ml surface drench. Leaf surface only and the leaf plus soil surface treatments were applied using an overhead single tip track-sprayer with a Teejet[19] 8001E flat-fan nozzle calibrated to deliver 187 L/ha at 207 kPa. A 1-cm layer of vermiculite was used as a barrier on the leaf only treatments and was carefully removed after herbicide application once the leaf surface had dried.

Aboveground sugarbeet plant tissue was harvested 21 d after treatment (DAT), dried, and weighed to determine reductions in plant biomass. Dry weights were converted to percent of the non-treated controls and were regressed against herbicide application rate using the log-logistic dose-response model, $y = a + b/[1 + (x/GR_{25})^c]$, where y is the herbicide activity as a percent control, x is rate of application, a is the upper limit, b is the lower limit, and c is the rate of change. The herbicide rates required to reduce sugarbeet growth by 25% (GR_{25}) were then calculated.

[16] American Crystal Sugar Company, 101 North 3rd Street, Moorhead, MN 56560
[17] Syngenta Seeds Inc., 1020 Sugarmill Road, Longmont, CO 80501
[18] Betaseed, Inc., 1788 Marshall Road, P.O. Box 195, Shakopee, MN 55379
[19] Spraying Systems Co., North Avenue, Wheaton, IL 60189

Specific Site of Absorption. *s*-Metolachlor at 5.68 kg/ha and dimethenamid-P at 3.36 kg/ha were applied to the roots, hypocotyl, and to the hypocotyl plus roots when the sugarbeet variety Hilleshog 7172RZ was at the two-leaf stage. Preliminary experiments were used to determine the herbicide rates needed to cause approximately 50% injury to Hilleshog 7172RZ. Herbicide applications to the roots were made by carefully removing the soil to just below the sugarbeet hypocotyl. Twenty-five ml solutions containing *s*-metolachlor or dimethenamid-P were carefully applied to the soil surface so that the solution would not come into contact with the hypocotyl. A 0.5-cm layer of Activated Carbon Charcoal[20] was then added. The pots were then filled with soil to the original soil levels. Similar to the root treatments, soil for the hypocotyl treatments were removed to just below the sugarbeet hypocotyls. A 0.5-cm layer of Activated Carbon Charcoal was then added. The soil that was removed was mixed with 25 ml of the herbicide solutions and placed on the activated charcoal layer. Twenty-five ml of the herbicide solutions were poured on the soil surface for the hypocotyl plus root treatments. Plants were watered via both surface- and sub-irrigation to maintain adequate soil moisture for plant growth. Sugarbeet injury was assessed on a scale from 0 (no injury) to 100 (plant death) and plant were harvested 21 DAT.

Plant Culture in Hydroponics. Sugarbeet seeds were germinated for 12 to 14 d in washed silica sand at 25 ± 2 C. Sand was watered as needed to maintain field capacity and was spiked with a modified Hoagland's nutrient solution. Once the sugarbeet seedlings reached the cotyledon stage, plants were transferred to 125 ml glass jars filled with Hoagland's nutrient solution wrapped in aluminum foil. Seedlings were supported

[20] Fisher Scientific, 1 Reagent Lane, Fair Lawn, NJ 07410

by Parafilm[21] and were aerated through glass Pasteur pipettes attached to a dual-diaphragm air pump. The nutrient solution was maintained at pH of 7 and additional solution was added as needed. Sugarbeets were grown in the greenhouse and sunlight was supplemented with sodium vapor lighting to provide a total midday light intensity of 1000 μ/m/s photosynthetic photon flux at plant height in 16-h day. Greenhouse temperature was maintained at 25 ± 2 C.

Variety Tolerance. Roots of Crystal 963, Hilleshog 7172RZ, Beta 5833R, and Beta 5451 sugarbeet varieties were exposed to 0, 0.3, 0.6, 3.2, and 6.4 ppm of *s*-metolachlor and 0, 0.2, 0.4, 1.9, 3.8 ppm of dimethenamid-P when plants were at the 2-leaf stage. These exposures are equivalent to a 0, 0.5, 1, 5, and 10 X dose of each herbicide used during one field season in Michigan. Sugarbeet injury was visually evaluated based on a rating scale of 0 (no injury) to 100 (plant death), 21 DAT. Plants were removed from the solutions, dried, and weighed to determine reduction of plant biomass. Herbicide rates required to reduce sugarbeet growth 25% (GR_{25}) were then calculated using regression analyses previously described.

Herbicide Uptake, Translocation, and Metabolism. An experiment was conducted to compare the uptake, translocation, and metabolism of *s*-metolachlor between four sugarbeet varieties, dimethenamid-P between two sugarbeet varieties, and compare differences in metabolism between the two herbicides. Crystal 963, Hilleshog 7172RZ, Beta 5833R, and Beta 5451 sugarbeet varieties propagated in hydroponics were transferred into radiolabeled herbicide solutions once sugarbeets were at the 2-leaf stage. The 100 ml hydroponic solutions contained 8.3 kBq of phenyl-U-labeled ^{14}C-*s*-

[21] Alcan Packaging, 175 Western Ave, Neenah, WI 54956

metolachlor (2020 kBq/mg specific activity, 99.9% purity) or thienyl-5-labeled ^{14}C-dimethenamid-P (60 kBq/mg specific activity, 99.8% purity). The exposure time was for 8 h. Due to limited supply of radiolabeled ^{14}C-dimethenamid-P, Hilleshog 7172RZ and Beta 5833R were the only two varieties examined for the dimethenamid-P portion of the experiment. In addition to the radiolabeled herbicides, each vial included unlabeled herbicide, formulation blank, and water to equal 1.6 and 0.95 ppm (2.5 X herbicide dose) of *s*-metolachlor and dimethenamid-P, respectively.

After the 8-h exposure period, roots were rinsed with deionized water. A subsection of plants were harvested as the 0 h harvest. Plants were sectioned into roots and shoots and were frozen immediately and stored at -30 C until further analysis. Seedlings for later harvest times were transferred into a 125 ml vial filled with deionized water. Remaining plants were harvested at 6-, 12-, 24-, and 48 h after the radiolabeled pulse. For the dimethenamid-P portion of the experiment plants were only harvested at 0-, 6-, and 24 h, due to the limited supply of ^{14}C-dimethenamid-P. Final volume of all vials was taken, and two 1-ml aliquots were radioassayed by liquid scintillation spectrometry (LSS) to determine the amount of unabsorbed herbicide.

Shoots and roots were ground separately in a tissue homogenizer[22] with 25 ml of 90% methanol (by volume). The homogenate was then vacuumed filtered[23] and rinsed with methanol. The residue with the filter paper was air dried and then combusted in a biological sample oxidizer[24] to determine unrecoverable radioactivity. The volume of the extract was measured and two 1-ml aliquots were radioassayed with LSS to determine

[22] Tissue homogenizer, Sorval Omni-mixer. Sorval, Inc., Newton, CT.
[23] Vacuum filter, Whatman #1. Whatman International Ltd., Maidstone, Engalnd.
[24] Biological sample oxidizer, R. J. Harvey Instruments Corp., 123 Patterson St., Hillsdale, NJ 07642.

total extractable ^{14}C. The extract was evaporated to a volume of 1 ml using a rotary evaporator. The solution was then filtered again using a using 0.22 μm filter[25], transferred into a test tube, and stored at -30 C.

The test tube was warmed to air temperature and concentrated to 100 to 150 μl under a stream of nitrogen in a 50 C water bath. Fifty microliters of the concentrated extracts and 1 μl of the parent ^{14}C were spotted on separate lanes of a 20- by 20-cm silica gel thin layer chromatography (TLC) plates[26] for metabolite separation. Plates were eluted with butanol:acetic acid:water (12:3:5 by volume) for ^{14}C-*s*-metolachlor. Plates were eluted twice in the same direction using a chloroform:methanol:formic acid:water solvent system, the first elution contained 75:25:4:2 v/v/v/v solution and the second elution contained 60:40:4:2 v/v/v/v solution for ^{14}C-dimethenamid-P (Miller et al. 1996). Radioactivity distribution was determined using a radiochromatogram scanner[27].

Herbicide uptake was calculated as the total ^{14}C recovery in the plant divided by the total ^{14}C recovered in the plant and in the hydroponic solution. Translocation of ^{14}C herbicide was calculated by dividing the amount of extractable and unextractable ^{14}C in the shoots by total ^{14}C in the plant. R_f values were calculated for each area of radioactivity on the TLC plates. Areas with the same R_f values as the ^{14}C standards on the TLC plates were determined to be the parent (active) compounds. Herbicide metabolism was presented as a percent of the active compound metabolized.

Statistical Analysis. All experiments were replicated four times and repeated. Data from all experiments were analyzed by ANOVA using the PROC MIXED in SAS to test

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[25] Millipore Corporation, Billerica, MA 01821.

[26] Plates, Whatman® Linear-K Preadsorbant Silica Gel, Whatman International Ltd., Maidstone, England.

[27] Radiochromatogram scanner, Ambis Systems, Inc., 3939 Ruffin Road, San Diego, CA 92123

for interactions. Data were presented as the average of the repeated experiments because there were no significant experiment-by-treatment interactions. The SLICE option in SAS was used when main effects were significant (herbicide and variety). Fisher's Protected LSD ($P \leq 0.05$) was used to compare and separate means. Regression curves and equations were calculated using TableCurve 2D[28] software. GR_{25} values were calculated for each replicate and were subjected to ANOVA means were compared using Fisher's Protected LSD at the $P \leq 0.05$. Differences in T_{80} values in metabolism study were determined by comparing 95% confidence intervals. Average recovery of ^{14}C over all harvest times and experiments was 93%.

RESULTS AND DISSCUSSION

Plant Culture in Soil. *Sugarbeet Tolerance and Site of Absorption.* Sugarbeet injury symptoms from applications of *s*-metolachlor and dimethenamid-P consisted of plant stunting, reduced plant growth, and sugarbeet leaf crinkling. Sugarbeet tolerance to *s*-metolachlor and dimethenamid-P were determined by comparing GR_{25} values of four sugarbeet varieties for three different herbicide applications, leaf only, soil only, and leaf plus soil. GR_{25} values were calculated using the X use rates for each herbicide in order to compare tolerance levels between the herbicides. For example, the GR_{25} values for Crystal 963 from the leaf plus soil application were 0.9X and 0.7X the field use rates of *s*-metolachlor and dimethenamid-P, respectively, indicating there were no differences in the tolerance of Crystal 963 between these herbicides when they were applied to the leaf plus soil (Table 19).

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[28] TableCurve 2D v. 5.01. Jandel Scientific, 2591 Kerner Blvd., San Rafael, CA 94901.

Sugarbeet varieties responded differently to applications of *s*-metolachlor and dimethenamid-P. Beta 5833R was the most tolerant variety to *s*-metolachlor, regardless of application. The *s*-metolachlor rate that caused a 25% reduction in sugarbeet growth from the leaf plus soil application was 1.4X the recommended use rate (2.0 kg/ha) (Table 19). The most susceptible variety to *s*-metolachlor was Hilleshog 7172RZ. The *s*-metolachlor rates that caused a 25% reduction in sugarbeet growth were 0.6X, 2.1X, and 0.5X the recommended use rate from the leaf plus soil, leaf only, and soil only applications. Crystal 963 and Beta 5451 GR_{25} values for *s*-metolachlor were intermediate to the most tolerant and susceptible sugarbeet varieties.

Sugarbeet varieties were more susceptible to dimethenamid-P compared with *s*-metolachlor for the leaf plus soil and soil only applications for all varieties, except Crystal 963 with the leaf plus soil application (Table 19). Sugarbeet tolerance levels were similar between herbicides when the herbicides were applied to the leaf only. Rankings of sugarbeet variety tolerance for dimethenamid-P were similar to *s*-metolachlor; Beta 5833R was the most tolerant variety with the soil only and leaf only applications and Hilleshog 7172RZ was the most susceptible sugarbeet variety to dimethenamid-P. GR_{25} values were 0.7X, 2.8X, and 0.7X the recommended use rate of dimethenamid-P from leaf plus soil, leaf only, and soil only applications, respectively, for Beta 5833. GR_{25} values were 0.2X, 1.9X, and 0.2X the recommended dimethenamid-P use rate for similar applications to Hilleshog 7172RZ (Table 19).

Researchers have speculated that differences in herbicide tolerance of different sugarbeet varieties may not be due to the genetics of that variety, but to differences in the environments for which the seed was produced (Dale et al. 2005). To test this theory, four seed lots of the commercial variety Beta 5451 were examined. Irregardless of whether the herbicides were applied to the leaf plus soil, leaf only, or soil only, seed lots did not respond differently to *s*-metolachlor or dimethenamid-P applications (Table 20). Therefore, differences in sugarbeet variety tolerance to *s*-metolachlor and dimethenamid-P are likely due to differences in the genetics of the different varieties.

Across all varieties and seed lots, the leaf only application resulted in the least amount of sugarbeet injury and reductions in sugarbeet growth compared with the soil only and the leaf plus soil applications, regardless of herbicide (Tables 19 and 20). However, within each herbicide no differences were observed between the soil and the leaf plus soil applications, indicating that *s*-metolachlor and dimethenamid-P are primarily absorbed through the roots and/or the hypocotyl of the sugarbeet plant. Under field conditions, POST applications of *s*-metolachlor or dimethenamid-P may cause less sugarbeet injury if rainfall was limited after application and the herbicide was not incorporated into the hypocotyl and/or root zones. However, if significant rainfall occurs shortly after application the herbicide can be incorporated into the sugarbeet root zone resulting in increased herbicide absorption and more severe plant injury.

Specific Site of Absorption. Applications of *s*-metolachlor and dimethenamid-P to the hypocotyl of the sugarbeet plant caused the least amount of injury and reduction in sugarbeet growth, regardless of herbicide (Table 21). Applications to the roots or roots plus hypocotyl resulted in the greatest injury. These results indicate that *s*-metolachlor and dimethenamid-P are primarily absorbed through the roots of sugarbeet. However, a small amount of either herbicide can be absorbed through the hypocotyl of the sugarbeet plant. These results are similar to observations by Le Baron et al. (1988), that chloroacetamide herbicides are most efficiently absorbed by the roots of dicot plants. Although not always significant, sugarbeets were more sensitive to applications of dimethenamid-P compared with *s*-metolachlor (Table 21).

Plant Culture in Hydroponics. *Variety Tolerance.* Injury symptoms from exposure of sugarbeet roots to *s*-metolachlor and dimethenamid-P in hydroponics consisted of plant stunting, reduced plant growth, and sugarbeet leaf crinkling. Similar to the experiments conducted in the presence of soil, Beta 5833R was the most tolerant variety to *s*-metolachlor and dimethenamid-P and Hilleshog 7172RZ was among the most susceptible varieties (Table 22). However, unlike the experiments conducted in the presence of soil the sugarbeet variety Crystal 963 was also amongst the most susceptible varieties and responded similar to Hilleshog 7172RZ. The response of Beta 5451 was intermediate to the most tolerant variety, Beta 5833R and the most susceptible variety, Hilleshog 7172RZ.

Sugarbeets did not respond differently between *s*-metolachlor and dimethenamid-P at the X use rates required to reduce sugarbeet growth 25% (Table 22). For example, with the most tolerant variety Beta 5833R the X use rates required to reduce sugarbeet growth 25% were 4.4X and 3.8X the recommended use rates for *s*-metolachlor and dimethenamid-P, respectively. This is different than experiments conducted in the presence of soil, where Beta 5833R was 2-fold more tolerant to *s*-metolachlor than dimethenamid-P when the herbicides were applied to the leaf plus soil or soil only (Table 19). The differences in injury between these two herbicides may be attributed to the difference in water solubility and the K_{oc} values of *s*-metolachlor and dimethenamid-P. The average K_{oc} values of *s*-metolachlor and dimethenamid-P are 200 and 155 ml/g, respectively, and the water solubility's are 488 and 1174 mg/L, respectively (Vencill 2002). When dimethenamid-P is applied to soil it is less likely to bind to the organic matter due to the lower K_{oc} value compared with *s*-metolachlor. In addition, when water is applied dimethenamid-P is more likely to move back into solution because of its higher water solubility compared with *s*-metolachlor. This may also cause dimethenamid-P to leach faster into the root zone, thus causing dimethenamid-P to be more available for root uptake of the sugarbeet plant.

Herbicide Uptake, Translocation, and Metabolism.

s-Metolachlor. Root absorption of ^{14}C-*s*-metolachlor ranged between 1.9 and 2.4% for the four sugarbeet varieties after the 8-h pulse in the radiolabeled hydroponic solution (Table 23). Differences in sugarbeet variety tolerance are not likely due to differences in herbicide uptake, since root absorption of ^{14}C-*s*-metolachlor was not different between the sugarbeet varieties Beta 5833R, Crystal 963, Beta 5451, and Hilleshog 7172RZ.

s-Metolachlor movement in the plant was determined by measuring ^{14}C translocation into the shoot. Equal percentages of ^{14}C from ^{14}C-*s*-metolachlor were translocated into the shoot of all four sugarbeet varieties at the first harvest time (0 h) after the 8-h pulse (Table 23). Movement of ^{14}C-*s*-metolachlor continued to increase from the roots to the shoots in three of the four sugarbeet varieties Crystal 963, Beta 5451, and Hilleshog 7172RZ. Acropetal movement of ^{14}C-metolachlor has also been observed in corn and sorghum (Dixon and Stoller 1982, Zama and Hatzios 1986). However, for the more tolerant sugarbeet variety Beta 5833R the amount ^{14}C-*s*-metolachlor translocated to the sugarbeet shoot did not increase over time and was similar for the 0- and 48 h harvests. In fact, the amount of ^{14}C-*s*-metolachlor translocated in this variety was lower than the other three varieties Crystal 963, Beta 5451, and Hilleshog 7172RZ. At the 48 h harvest time, only 63% of ^{14}C-*s*-metolachlor had translocated into the shoot of the more tolerant variety Beta 5833R, whereas in the other varieties over 67% of ^{14}C-*s*-metolachlor had been translocated into the shoot (Table 23). The data indicates that translocation of *s*-metolachlor may be one of the factors that contribute to the differences in tolerance of the four sugarbeet varieties.

Two distinct metabolites of ^{14}C-*s*-metolachlor (R_f= 0.74) were separated from the parent herbicide. Both of these metabolites were present in all four sugarbeet varieties after the first harvest, 8 h after the initiation of ^{14}C pulse. The metabolites were detected in both the roots and shoots of the sugarbeet plants and had R_f values of 0.52 and 0.31. Metabolites of chloroacetamide herbicides are not herbicidally active (Breaux 1986).

After the 8-h pulse, the amount of active ^{14}C-*s*-metolachlor present in the roots was less than 6% for all sugarbeet varieties (Table 23). The percentage of active herbicide present was less in the more tolerant variety, Beta 5833R, than in more susceptible varieties Crystal 963, Beta 5451, and Hilleshog 7172RZ. All four sugarbeet varieties completely metabolized the ^{14}C-*s*-metolachlor by the 6 h harvest time, indicating that the active ^{14}C-*s*-metolachlor is rapidly metabolized in sugarbeet roots.

Less than 50% of the active ^{14}C-*s*-metolachlor was found in the shoots of all four sugarbeet varieties at the first harvest (Table 23). The rapid metabolism ^{14}C-*s*-metolachlor occurred during the 8-h pulse in the ^{14}C hydroponic solution. At the first harvest time the more tolerant sugarbeet variety Beta 5833R had metabolized more of the active ^{14}C-*s*-metolachlor than the most susceptible variety, Hilleshog 7172RZ. Similar to the first harvest time, the amount of active ^{14}C-*s*-metolachlor was the greatest in the most susceptible variety Hilleshog 7172RZ and was the least in the most tolerant variety Beta 5833R at the 6 h harvest time. All four sugarbeet varieties metabolized the active ^{14}C-*s*-metolachlor to 3% or less by the 12 h harvest time.

The time required to metabolize 80% of the active ^{14}C-*s*-metolachlor was 2.1 h for the most tolerant sugarbeet variety Beta 5833R, which was less time than the other three varieties. Hilleshog 7172RZ, Crystal 963, and Beta 5451 required at least 4.1 h to metabolize 80% of the active ^{14}C-*s*-metolachlor. The rate of metabolism was a major factor in determining the differential tolerance of the most tolerant sugarbeet variety Beta 5833R.

Dimethenamid-P. Root absorption of ^{14}C-dimethenamid-P was similar between the tolerant sugarbeet variety Beta 5833R and the sensitive variety Hilleshog 7172RZ (Table 24). Absorption of ^{14}C-dimethenamid-P was 3.5 and 2.7% for Beta 5833R and Hilleshog 7172RZ, respectively. Unlike the movement of ^{14}C-*s*-metolachlor from the sugarbeet roots to the shoots, there were no differences in translocation of ^{14}C-dimethenamid-P between Beta 5833R and Hilleshog 7172RZ. Therefore, differences in tolerance to dimethenamid-P between Beta 5833R and Hilleshog 7172RZ was not likely due to herbicide uptake or translocation.

Similar to ^{14}C-*s*-metolachlor, two distinct metabolites (R_f = 0.86 and 0.52) were separated from the parent ^{14}C-dimethenamid-P (R_f= 0.95) in roots and shoots of the four sugarbeet varieties. Less than 17% of active ^{14}C-dimethenamid-P was present in the roots of Beta 5833R and Hilleshog 7172RZ at the first harvest, 8 h after the initiation of the ^{14}C pulse (Table 24). Metabolism of ^{14}C-dimethenamid-P in the sugarbeet roots was not different between the two varieties and ^{14}C-dimethenamid-P was completely metabolized by the 24 h harvest.

The amount of active ^{14}C-dimethenamid-P in the sugarbeet shoots was different for the most tolerant sugarbeet variety Beta 5833R and the most susceptible sugarbeet variety Hilleshog 7172RZ, at the first two harvest times. The amount of active ^{14}C-dimethenamid-P in the more tolerant Beta 5833R was 51.4 and 23.6% at the 0- and 6 h harvests, respectively (Table 24). The amount of active ^{14}C-dimethenamid-P in the susceptible Hilleshog 7172RZ was 35 and 26% more than the tolerant variety at the 0- and 6 h harvests, respectively. However, by the 24 h harvest differences in metabolism could not be detected between the two varieties. The time required to metabolize 80% of the active herbicide was also similar between the two varieties. Differences in sugarbeet variety tolerance to dimethenamid-P appear to be due to one varieties ability to metabolize the active herbicide in the shoot immediately after absorption, rather than metabolizing it over time.

Comparison of s-metolachlor and dimethenamid-P. Root absorption by Beta 5833R and Hilleshog 7172RZ was similar for both herbicides and ranged between 2 and 3.5% (Tables 23 and 24). Translocation of the ^{14}C-herbicide from the sugarbeet roots to the shoots was greater for ^{14}C-*s*-metolachlor than ^{14}C-dimethenamid-P at all harvest intervals, regardless of sugarbeet variety (Figure 1a). Metabolism of active ^{14}C-herbicide in sugarbeet roots was rapid for both herbicides. However, there were differences in the time required to completely metabolize the active ^{14}C-herbicide. The ^{14}C-*s*-metolachlor was completely metabolized by the 6 h harvest in both varieties, where metabolism of the active ^{14}C-dimethenamid-P was slower and was not completely metabolized until the 24 h harvest (Figure 1b).

The largest difference in metabolism of the ^{14}C-herbicides occurred in the shoots of the sugarbeet plants (Figure 1c). Metabolism was not only different between herbicides, but was also different between the two sugarbeet varieties. *s*-Metolachlor was metabolized to a greater extent at the 0-, 6-, and 24 h harvests compared with metabolism of ^{14}C-dimethenamid-P for the individual varieties. The ^{14}C-herbicides were also metabolized to a greater extent in the more tolerant sugarbeet variety Beta 5833R compared with the more sensitive variety Hilleshog 7172RZ at the earlier harvest times. Metabolism of the ^{14}C-herbicides in the shoots not only accounts for the differences in tolerance between the sugarbeet varieties, but also appears to be one of the major factors that contributed to differences in tolerance between the two herbicides. Metabolism is often reported as the basis for differential tolerance of cultivars to metolachlor in other crops (Cottingham and Hatzios 1992; Le Baron et al. 1988: O'Connell et al. 1988, Rowe et al. 1990). Additionally in sugarbeets metabolism has been reported as the basis of tolerance to other herbicides (Hendrick et al. 1974; Zhang et al. 1999).

Overall, sugarbeet varieties responded differently to applications of *s*-metolachlor and dimethenamid-P. Beta 5833R was the most tolerant sugarbeet variety and Hilleshog 7172RZ was the most susceptible sugarbeet variety to *s*-metolachlor and dimethenamid-P. The primary site of *s*-metolachlor and dimethenamid-P absorption was through the sugarbeet roots; however some absorption did occur through the sugarbeet hypocotyl. The extent of sugarbeet injury was greatest from applications dimethenamid-P compared with *s*-metolachlor when sugarbeets were grown in soil. However, when sugarbeets were grown hydroponically differences in injury from the herbicides were not as great, indicating that the herbicides behavior in the soil greatly influenced sugarbeet injury. Reduced translocation and slower metabolism of ^{14}C-dimethenamid-P in both the roots and shoots of the sugarbeet plants most likely contributed to the greater susceptibility of sugarbeets to dimethenamid-P compared with *s*-metolachlor. Slower metabolism of ^{14}C-herbicides in the sugarbeet shoots was likely the greatest contributor to differences in sugarbeet variety tolerance to both *s*-metolachlor and dimethenamid-P.

Due to the importance of variety selection for other production factors, such as disease resistance and yield potential, growers will probably not choose varieties based on herbicide tolerance. However, if a grower has chosen a particular variety, this information may assist the grower in deciding if there are risks associated with using *s*-metolachlor or dimethenamid-P.

Table 19. *s*-Metolachlor and dimethenamid-P rates required to reduce sugarbeet growth by 25% (GR_{25}) from applications to the leaf plus soil, the leaf only, and the soil only for four sugarbeet varieties.

Variety	Leaf plus soil		Leaf only		Soil only		
	s-metolachlor[a]	dimethenamid-P[b]	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P	$LSD_{0.05}$
	– X use rate[c] (actual rate kg/ha) –		— X use rate (actual rate kg/ha) —		– X use rate (actual rate kg/ha) –		
Beta 5833R	1.4 (2.0)	0.7 (0.6)	3.0 (4.2)	2.8 (2.4)	1.3 (1.8)	0.7 (0.6)	0.5
Crystal 963	0.9 (1.3)	0.7 (0.6)	2.6 (3.6)	2.4 (2.0)	0.8 (1.1)	0.4 (0.3)	0.3
Beta 5451	0.8 (1.1)	0.6 (0.5)	2.6 (3.6)	2.3 (1.9)	0.9 (1.3)	0.5 (0.4)	0.2
Hilleshog 7172RZ	0.6 (0.8)	0.2 (0.2)	2.1 (2.9)	1.9 (1.6)	0.5 (0.7)	0.2 (0.2)	0.3
$LSD_{0.05}$	0.3	0.2	0.4	0.3	0.3	0.2	

[a] The recommended use (1X) rate for *s*-metolachlor was 1.4 kg/ha.
[b] The recommended use (1X) rate for dimethenamid-P was 0.84 kg/ha.
[c] To compare *s*-metolachlor to dimethenamid-P, GR_{25} values are expressed as the amount of the recommended use rate for each product needed to reduce sugarbeet growth by 25%. Values in parentheses are the actual herbicide rates.

Table 20. *s*-Metolachlor and dimethenamid-P rates required to reduce sugarbeet growth by 25% (GR_{25}) from applications to the leaf plus soil, the leaf only, and the soil only for four seed lots of Beta 5451.

	Leaf plus soil		Leaf only		Soil only		
Beta 5451	*s*-metolachlor[a]	dimethenamid-P[b]	*s*-metolachlor	dimethenamid-P	*s*-metolachlor	dimethenamid-P	$LSD_{0.05}$
	– X use rate[c] (actual rate kg/ha) –		– X use rate (actual rate kg/ha) –		– X use rate (actual rate kg/ha) –		
Seed lot 1	1.4 (2.0)	0.7 (0.6)	2.2 (3.1)	1.7 (1.4)	1.3 (1.8)	0.3 (0.3)	0.8
Seed lot 2	1.2 (1.7)	0.7 (0.6)	2.3 (3.2)	1.9 (1.6)	1.0 (1.4)	0.3 (0.3)	0.8
Seed lot 3	0.9 (1.3)	0.8 (0.7)	2.1 (2.9)	1.6 (1.3)	0.9 (1.3)	0.6 (0.5)	0.5
Seed lot 4	0.8 (1.1)	0.6 (0.5)	2.2 (3.0)	1.7 (1.4)	0.8 (1.1)	0.4 (0.3)	0.6
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	

[a] The recommended use (1X) rate for *s*-metolachlor was 1.4 kg/ha.
[b] The recommended use (1X) rate for dimethenamid-P was 0.84 kg/ha.
[c] To compare s-metolachlor to dimethenamid-P, GR_{25} values are expressed as the amount of the recommended use rate for each product needed to reduce sugarbeet growth by 25%. Values in parentheses are the actual herbicide rates.

Table 21. Specific site of *s*-metolachlor and dimethenamid-P absorption in sugarbeet[a] as determined by injury and biomass reduction.

	Injury		Biomass	
Site of absorption[b]	*s*-metolachlor[c]	dimethenamid-P[d]	*s*-metolachlor	dimethenamid-P
	%		% reduction	
Root	41	51	65	75
Hypocotyl	14	31	29	41
Root + hypocotyl	39	68	54	63
$LSD_{0.05}$	12		14	

[a] The sugarbeet variety Hilleshog 7172RZ was chosen for this experiment.
[b] Herbicides were applied to the various regions of the sugarbeet plant when sugarbeets were at the two-true leaf stage.
[c] *s*-Metolachlor was applied at 5.6 kg/ha.
[d] Dimethenamid-P was applied 3.4 kg/ha.

Table 22. *s*-Metolachlor and dimethenamid-P rates required to reduce growth by 25% (GR_{25}) of four sugarbeet varieties in hydroponics.

Variety	*s*-metolachlor	dimethenamid-P
	X use rate (actual rate kg/ha)	
Beta 5833R	4.4 (6.2)	3.8 (3.2)
Crystal 963	1.9 (2.7)	1.4 (1.2)
Beta 5451	2.4 (3.4)	2.4 (2.0)
Hilleshog 7172RZ	1.4 (2.0)	1.2 (1.0)
$LSD_{0.05}$	0.7	

[a] The recommended use (1X) rate for *s*-metolachlor was 1.4 kg/ha.
[b] The recommended use (1X) rate for dimethenamid-P was 0.84 kg/ha.
[c] To compare s-metolachlor to dimethenamid-P, GR_{25} values are expressed as the amount of the recommended use rate for each product needed to reduce sugarbeet growth by 25%. Values in parentheses are the actual herbicide rates.

Table 23. Uptake, translocation, and metabolism of *s*-metolachlor in four sugarbeet varieties.

Harvest times[a]	Beta 5833R	Crystal 963	Beta 5451	Hilleshog 7172RZ	$LSD_{0.05}$
	Varieties				
Root absorption (%)[b]					
0 h	2.4	1.9	1.9	2.0	NS
Translocation (% in shoot)[c]					
0 h	55.1	54.1	58.5	59.1	NS
6 h	57.3	54.1	58.7	63.2	5.3
12 h	57.4	56.8	60.7	63.2	NS
24 h	60.7	61.3	63.4	69.1	7.5
48 h	63.0	67.1	67.4	71.4	6.2
$LSD_{0.05}$	NS	4.7	6.5	6.6	
Metabolism in root (% active)[d]					
0 h	0.4	3.3	4.5	5.1	1.3
6 h	0.0	0.0	0.0	0.0	NS
$LSD_{0.05}$	NS	1.3	1.7	1.7	
Metabolism in shoot (% active)[e]					
0 h	33.0	36.8	40.8	49.2	7.6
6 h	8.0	15.5	15.9	18.3	9.2
12 h	0.0	2.9	1.1	3.0	NS
24 h	0.0	2.2	0.0	2.9	NS
48 h	0.0	0.1	0.0	0.1	NS
$LSD_{0.05}$	9.1	9.0	8.8	9.1	
Rate of metabolism (T_{80}) (h)[f]					
Time (h)[g]	2.1 (1.0-3.6)	4.2 (2.8-5.8)	4.1 (3.2-5.5)	4.2 (3.2-5.5)	

[a] Harvest times are after an 8-h pulse in the ^{14}C hydroponic solution.
[b] Root absorption expressed as a percentage of ^{14}C in hydroponic solution.
[c] Translocation to shoot is expressed as a percentage of the total amount of ^{14}C absorbed.
[d] Metabolism is expressed as the amount of active herbicide in the extractable component of root.
[e] Metabolism is expressed as the amount of active herbicide in the extractable component of shoot.
[f] Time required for 80% of the active herbicide to be metabolized.
[g] T_{80} values followed by 95% confidence limits.

Table 24. Uptake, translocation, and metabolism of dimethenamid-P in two sugarbeet varieties.

	Varieties		
Harvest times[a]	Beta 5833R	Hilleshog 7172RZ	P-value
Root absorption (%)[b]			
0 h	3.5	2.7	NS
Translocation (% in shoot)[c]			
0 h	40.0	39.5	NS
6 h	40.0	39.5	NS
24 h	48.6	44.2	NS
$LSD_{0.05}$	6.3	NS	
Metabolism in root (% active)[d]			
0 h	13.8	16.5	NS
6 h	11.8	14.6	NS
24 h	0.0	1.7	NS
$LSD_{0.05}$	8.7	9.5	
Metabolism in shoot (% active)[e]			
0 h	51.4	79.3	0.0134
6 h	23.6	32.1	0.0307
24 h	9.8	15.3	NS
$LSD_{0.05}$	16.2	18.3	
Rate of metabolism (T_{80}) (h)[f]			
Time (h)[g]	7.4 (4.4-14.2)	8.1 (6.6-12.0)	

[a] Harvest times are after an 8-h pulse in the ^{14}C hydroponic solution.
[b] Root absorption expressed as a percentage of ^{14}C in hydroponic solution.
[c] Translocation to shoot is expressed as a percentage of the total amount of ^{14}C absorbed.
[d] Metabolism is expressed as the amount of active herbicide in the extractable component of root.
[e] Metabolism is expressed as the amount of active herbicide in the extractable component of shoot.
[f] Time required for 80% of the active herbicide to be metabolized.
[g] T_{80} values followed by 95% confidence limits.

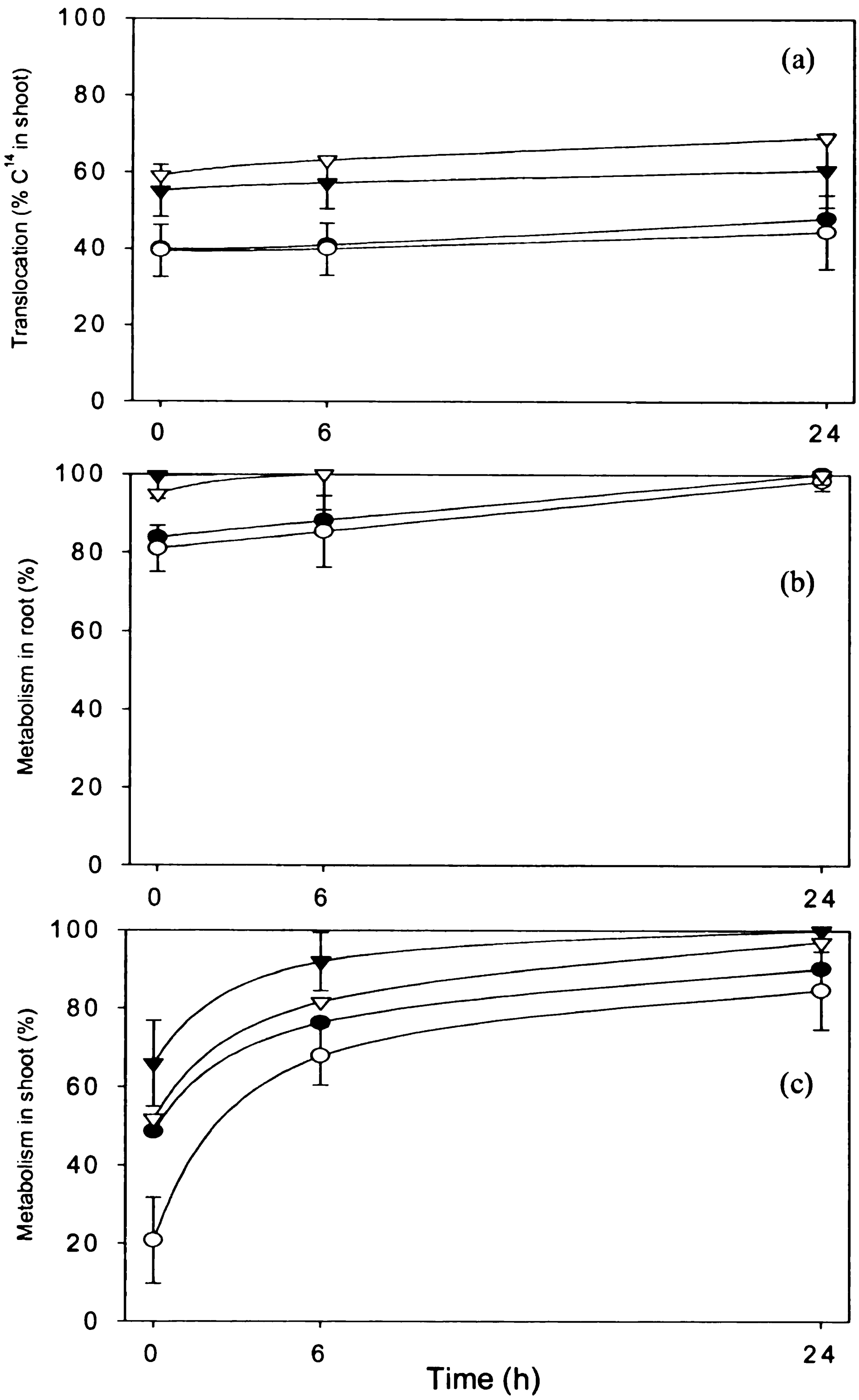

Figure 1. Translocation (a), metabolism in the roots (b), and metabolism in the shoots (c) of ^{14}C-dimethenamid-P by Beta 5833R (●) and Hilleshog 7172RZ (○), and ^{14}C-*s*-metolachlor by Beta 5833R (▼) and Hilleshog 7172RZ (▽). Time$_0$ represents the point after an 8-h pulse in the ^{14}C hydroponic solution. Means of treatments were separated using Fisher's Protected LSD (P $\leq$0.05).

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CHAPTER 5

EFFECT OF TILLAGE AND SOIL-APPLIED HERBICIDES ON WEED CONTROL AND SUGARBEET (*Beta Vulgaris)* GROWTH

Abstract. Fields trials were conducted to determine if tillage and soil-applied herbicides had an effect on weed control and sugarbeet growth in a micro-rate herbicide program. Sugarbeet emergence occurred earlier in the moldboard plow system compared with the chisel plowed system at three of four sites. Conditions were dry and sugarbeets emerged 5 d later in the moldboard plowed system compared with the chisel plowed system at the fourth site. Even though the rate of sugarbeet emergence differed between the two tillage systems at all four sites, final sugarbeet populations did not differ at two of the four sites. Sugarbeet injury from the PRE treatments of *s*-metolachlor, ethofumesate, and ethofumesate plus pyrazon followed by four POST micro-rate applications ranged from 11 to 27% and 1 to 18% in the chisel and moldboard plowed treatments, respectively, 6 WAP compared with no injury from the no-PRE treatment. Under wet conditions, injury was greatest from PRE applications of *s*-metolachlor and sugarbeet stand was reduced. Common lambsquarters, pigweed (redroot pigweed and Powell amaranth), and giant foxtail control in mid-August was consistently higher when a PRE herbicide was applied prior to the micro-rate herbicide treatments. Even though there were differences between the PRE and no-PRE treatments in sugarbeet injury and weed control, recoverable white sucrose yield did not differ between herbicide treatments. However, recoverable white sucrose yield was greater in the moldboard plowed treatments compared with the chisel plowed treatments at three out of the four sites.

Nomenclature: *s*-metolachlor; ethofumesate, pyrazon; common lambsquarters, *Chenopodium album* L. CHEAL; pigweed species, *Amaranthus retroflexus* L. and *Amaranthus powellii* S. Wats. AMASS; velvetleaf, *Abutilon theophrasti* Medik. ABUTH; giant foxtail, *Setaria faberi* Herrm. SETFA.

Key words: canopy closure, emergence, micro-rate.

INTRODUCTION

In recent years, minimum or reduced tillage acreage has increased in an effort to reduce fossil fuel use, prevent soil erosion, retain valuable soil organic matter, and increase profitability (Glenn and Dotzenko 1978; Derksen et al. 1996; Beyaert et al. 2002). Reduced tillage is a form of conservation tillage, which is defined as any tillage and planting system that maintains at least 30% of the soil surface covered by residue after planting (Mannering et al. 1987). Reduced tillage decreases soil compaction, and produces and preserves more soil aggregates, which lead to increased water infiltration (Mannering et al. 1966). In several cropping systems, yield has been comparable between crops grown under reduced tillage to those grown under a conventional moldboard plowed system (Al-Darby and Lowery 1987; Griffith et al. 1973; Lund et al. 1993). However, researchers have reported that as the intensity of tillage decreases, soil temperature decreases and soil moisture increases because of increased surface residue (Beyaert et al. 2002). These changes in soil temperature and moisture have led to reductions in early-season crop growth and loss of yield (Vyn and Raimbault 1993).

Reduced tillage systems have been used in sugarbeet production, but not to the same extent as in other crops. Residue left on the soil surface in reduced tillage fields can act as a windbreak protecting young sugarbeet seedlings from leaf tissue damage caused by soil particle movement in strong winds. Residues from previous crops have also been shown to increase the concentration of arthropod and nematode pests in the sugarbeet row compared with conventional tillage systems (Henriksson and Håkansson 1993), possibly increasing the impact of these pests on the crop. However, reduced tillage effects on sugarbeet yield have been variable. In some experiments, sugarbeet yields in reduced tillage systems were as high as yields using conventional tillage methods (Glenn and Dotzenko 1978; Miller and Dexter 1982; Michel et al. 1983; Henriksson and Håkansson 1993), however in others yields in the conventional tillage systems were superior (Smith and Yonts 1986).

Changes in tillage systems can have a profound effect on weed population dynamics. The majority of weed seeds in a reduced tillage system are found near the soil surface compared with a conventional moldboard plow system where weed seeds are generally buried deeper into the soil profile (Yenish et al. 1992). Seeds tend to germinate and emerge better when they are at or near the soil surface adapt better to reduced tillage and no-tillage systems (Buhler 1995). Small seeded weeds, like redroot pigweed (*Amaranthus retroflexus* L.), may become more problematic if growers switch from conventional to reduced tillage systems. Oryokot et al. (1997) reported that redroot pigweed seeds would only germinate if they were located within 2.5-cm of the soil surface. However, other seeds that need to be buried to break dormancy would more likely thrive in conventional tillage systems. Buhler (1995) documented that as tillage intensity decreased, the duration of new emergence and total density of giant foxtail increased, thus becoming more of a problem to control. On the other hand, velvetleaf's duration of emergence and population decreased as tillage increased. As a result, if sugarbeet growers do decide to change tillage systems, they must be aware of possible changes in weed dynamics.

In sugarbeets, several studies have been conducted to determine the effect of preemergence (PRE) herbicides on sugarbeet emergence and growth. Applications of pyrazon during cool, wet springs have been shown to reduce emergence and growth (Sadowska 1973). Additionally, Dawson (1971) reported that all treatments of pyrazon that provided adequate weed control, reduced sugarbeet stand, regardless of application depth or soil moisture. Wilson et al. (1990) documented that applications of either cycloate or ethofumesate reduced sugarbeet stand. When the two herbicides were mixed in combination at a reduced rate, the sugarbeet stand was reduced more than if either herbicide was used alone. Dale et al. (2006) reported that both cycloate and *s*-metolachlor can reduce sugarbeet stand. Soil-applied herbicides can also increase the instances of injury from POST applications (Dexter and Luecke 1988; Smith et al. 1982).

Although applications of PRE herbicides to sugarbeet can cause some crop injury, many times sugarbeets can recover from injury and there is not an adverse effect on yield. Dawson (1971), Wilson et al. (1990), and Dale et al. (2006) all observed significant sugarbeet injury from one or more PRE herbicides, however in each case, the recoverable white sucrose yield was not reduced. In each case the sugarbeet plant was able to recover from early-season injury and yield was comparable to the weed-free control. One factor that may have allowed sugarbeets to recover from injury in these studies was that they were grown in conventional tillage systems where soil can dry out and warm up quicker. It is unknown if sugarbeet plants would be able to recover as well in reduced tillage systems where the soil tends to be cooler and wet.

Currently, a majority of Michigan sugarbeet producers use the micro-rate herbicide program for weed control[29]. The micro-rate, desmedipham + phenmedipham at 45 + 45 g/ha plus triflusulfuron at 4.4 g/ha plus clopyralid at 26 g/ha plus methylated seed oil at 1.5% v/v is applied on 7 to 10 d or 125 growing degree day (GDD) intervals (Dale and Renner 2005; Dexter and Lueke 1998). A small percentage of these growers will also apply a PRE herbicide prior to a micro-rate program to provide residual control of problematic weeds. Issues related to sugarbeet injury from the micro-rate program have arisen. Anecdotal observations indicate that sugarbeet injury has been greater in reduced tillage fields. Reduced sugarbeet growth and vigor in sugarbeets grown in reduced tillage fields, as well as the possible injury from PRE herbicides, may cause the sugarbeet plant to be more vulnerable to micro-rate herbicide applications. If sugarbeet growth and emergence is reduced in fields that are chisel plowed compared with moldboard plowed fields, weed emergence and growth could also be affected. Recommendations for weed control strategies in these two tillage systems could be different based on sugarbeet growth and weed spectrum present. Therefore, the objectives of this research were to: 1) determine the effect of tillage on sugarbeet emergence and growth, 2) evaluate the effect of tillage and PRE herbicides on sugarbeet injury from micro-rate herbicide applications, and 3) evaluate weed control from micro-rate herbicide applications under two different tillage systems.

[29] Sprague, C. L. Michigan sugarbeet grower survey 2003.

MATERIAL AND METHODS

Large plot field experiments were conducted in 2005 on a grower's field in Saginaw County, 2005 and 2006 at the Saginaw Valley Bean and Beet Research Farm in St. Charles, and in 2006 at the Michigan State University Agronomy Research Farm in E. Lansing, MI. The soil at the Saginaw County site was a Zilwaukee clay (fine mixed, mesic Aeric Haplaquepts) with a soil pH of 7.3, and 8.1 % organic matter. The soil at St. Charles was a Misteguay silty clay loam (fine-loamy, mixed, mestic Aeric Endoaquepts) with a soil pH of 8.2, and 2.7 % organic matter. The soil at E. Lansing was a Capac loam (fine-loamy, mixed, mesic, Aeric Ochraqualfs) with a soil pH of 6.7, and 3.2 % organic matter.

The experimental design was a split-plot with four replications. The main plot was tillage system, and the sub-plot was the PRE herbicide treatment. The two tillage systems were fall moldboard plowed and fall chisel plowed corn stubble. Across the entire experiment, a S-tined harrow equipped with rolling baskets was used as secondary tillage to a depth of approximately 5 cm at St. Charles and East Lansing in the spring prior to planting. At the Saginaw County site, secondary tillage in the spring consisted of a disk harrow equipped with rolling baskets to an approximate depth of 8 cm. 'Crystal 963'[30] sugarbeet seed was planted 2.5-cm deep in 76-cm rows on April 4, 2005 at the grower's field in Saginaw County, April 6, 2005 and March 30, 2006 at St. Charles, and April 11, 2006 at E. Lansing. Due to a poor stand because of soil crusting at E. Lansing, sugarbeets were replanted on May 8, 2006. Within each tillage system, treatments consisted of four base treatments: 1) no-PRE herbicide, 2) *s*-metolachlor at 1.4 kg/ha, 3)

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[30] American Crystal Sugar Company, 101 North 3rd Street, Moorhead, MN 56560

ethofumesate at 1.7 kg/ha, and 4) ethofumesate at 1.7 kg/ha plus pyrazon at 4.5 kg/ha. Depending on location, plot sizes ranged from 6 to 12 m wide and 15 to 30 m long. The entire experimental area received four postemergence (POST) applications of the micro-rate herbicide treatment of desmedipham + phenmedipham at 45 + 45 g/ha plus triflusulfuron-methyl at 4.4 g/ha plus clopyralid at 26 g/ha plus methylated seed oil at 1.5% v/v applied at 125 GDD (base 1.1 C) intervals.

At the St. Charles and E. Lansing locations, precipitation and temperature data were recorded by weather stations operated by the Michigan Automated Weather Network[31] (Table 25). Unfortunately, the closest weather station to the Saginaw County grower's field was the St. Charles location, which was 30 km away. In 2005 and 2006, four Hobo®[32] soil temperature probes were buried 2.5-cm deep in each of the two tillage systems. Soil temperature data for 2005 was lost due to a computer malfunction.

Sugarbeet emergence counts were taken weekly, three to five sub-samples per plot, until emergence ceased. Sugarbeet injury was visually evaluated 30, 45, and 60 d after planting (DAP), data will be presented from the 45 DAP rating. Late-season weed control was visually evaluated in mid-August, 100 to 125 DAP. Sugarbeet injury and weed control were assessed using a rating scale from 0 (no injury) to 100 (plant death) percent. The amount of light transmitted through the sugarbeet canopy was measured at or near solar noon 7, 8, 10 and 11 weeks after planting (WAP), when peak canopy occurred. Measurements were taken in each plot using the Sunscan Canopy Analysis System[33]. The SunScan system consisted of three components: 1) a wand that was 1 m long and 13 mm wide with sensors placed every 15.6 mm along the length of the wand

[31] Web site: http://www.agweather.geo.msu.edu/mawn/
[32] Onset Computer Corporation, PO Box 3450, Pocasset, MA 02559
[33] Delta-T Device LTC, 128 Low Road, Burwell, Cambridge CB5 0EJ, England.

with a spectral response of 400 to 700 nm that measured light beneath the crop canopy, 2) a tripod-mounted sensor that measured both incident and diffuse light above the crop canopy, and 3) a handheld Psion Workabout datalogger[34] that recorded simultaneous measurements of light above and beneath the crop canopy. Light transmission, as a percent of incident, was automatically calculated as each measurement was taken perpendicular to the sugarbeet rows.

Prior to harvest, sugarbeets were counted to determine final harvest populations. Sugarbeets were flailed and topped with a four-row topper, and harvested October 5, 2005 at the Saginaw County grower's site, September 23, 2005, and September 20, 2006 at St. Charles, and October 9, 2006 at E. Lansing. At St. Charles and E. Lansing, plots were harvested with a two-row mechanical lifter and at the Saginaw County grower's field plots were harvested with a six-row commercial harvester. Sugarbeets were weighed and a sample of roots from each plot was analyzed for recoverable white sucrose by Michigan Sugar Company, Bay City, MI.

Statistical Analysis. Sugarbeet emergence was regressed against time using the log-logistic dose response model, $Y = A + B/[1 + (X/C)^D]$, where Y is the emergence, X is the date after application, A is the upper limit, B is the lower limit, C is date halfway between the upper and lower limits, and D is the rate of change. Regression curves and equations were calculated using TableCurve 2D[35] software. Fifty-percent sugarbeet emergence was calculated from for each replication from the regression analysis. All data were analyzed using the PROC MIXED procedure of SAS. Main effects and all possible interactions were tested using the appropriate expected mean squared values as

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[34] Psion Digital, 1810 Airport Exchange Boulevard, Suite 500, Erlanger KY 41018.

[35] TableCurve 2D v. 5.01. Jandel Scientific, 2591 Kerner Blvd., San Rafael, CA 94901.

recommended by McIntosh (1983). Data were pooled across site and/or year when interactions with the factors were not significant. Data were analyzed separately when interactions with site and/or year were significant. Mean separation for individual treatment differences was performed using Fisher's protected LSD test at the 0.05 significance level.

RESULTS AND DISCUSSION

Sugarbeet emergence data were combined across PRE treatments within each tillage system, since tillage by herbicide interactions were not significant. The days to 50% sugarbeet emergence was significantly earlier in the moldboard plow treatment compared with the chisel plow treatment at three of the four sites (Table 26). Differences in the speed of crop emergence are often explained by soil temperature and moisture. Sugarbeets emerged 5.7, 2.1, and 1.8 d earlier in the moldboard plow treatment compared with the chisel plow treatment at Saginaw Co. in 2005 and at St. Charles, and East Lansing in 2006, respectively. Soil temperature data from the 2006 sites indicated that soil temperature was not different between the moldboard and chisel plowed treatments (data not shown). Sugarbeet seeds need adequate moisture for germination. Water is transferred to the seed by contact with the soil. If soil aggregates are too large, sugarbeet seeds may not receive adequate moisture to germinate due to poor seed-to-soil contact and the rate of emergence may be reduced (Brown et al. 1996; Vamerali et al. 2006). Because soil aggregates are larger in soil that has been chisel plowed compared with moldboard plowed systems (Mikha and Rice 2004), earlier emergence of sugarbeets in the moldboard plowed treatment may be expected.

However, unlike the other sites, sugarbeet emergence was 5 d later in the moldboard plow treatment compared with the chisel plow treatment at St. Charles in 2005 (Table 26). Beyaert et al. (2002) reported that as the intensity of tillage decreases, soil temperature decreases and soil moisture, increases because of increased surface residue. In years with limited soil moisture sugarbeet emergence may occur earlier in a reduced tillage system. At St. Charles in 2005, rainfall was 4-cm below the 30-yr average within the first month after sugarbeet planting this site (Table 25). The delayed emergence of the moldboard plowed treatment may be explained by the lower available moisture at this site. Although the St. Charles and Saginaw Co. sites were only 30-km apart in 2005, rainfall at St. Charles was lower than and Saginaw Co. site (personal observation). Smith et al. (2002) reported that when rainfall occurred within a few days of planting, the rate of sugarbeet emergence was not different between reduced and conventional tillage systems.

There was a significant year by location interaction for sugarbeet injury, therefore data are presented separately by year and combined over locations. Sugarbeet injury from the PRE treatments followed by four micro-rate applications ranged from 13 to 16% and 8 to 10% in the chisel and moldboard plowed treatments, respectively, 6 WAP in 2005 (Table 27). Injury from the PRE treatments consisted of plant stunting. Within a tillage system, there were no differences in sugarbeet injury between the PRE treatments. However, sugarbeet injury from PRE applications of *s*-metolachlor and ethofumesate plus pyrazon was greater in the chisel plowed treatments compared with the moldboard plowed treatments. In 2006, sugarbeet injury was also greater in the chisel plowed treatments compared with the moldboard plowed treatments for all PRE treatments.

Sugarbeet injury from PRE *s*-metolachlor was greater than the other PRE treatments in both tillage systems. Rainfall was not limiting in 2006 (Table 25). PRE applications of *s*-metolachlor have been reported to cause significant sugarbeet injury when moisture is not limiting (Dexter and Luecke 2003; Dexter and Luecke 2004; Renner 2003).

Sugarbeet populations 6 WAP were similar across herbicide treatments and tillage systems in 2005 (Table 27). However, in 2006 when rainfall was not limited after planting and PRE applications, sugarbeet populations were different between PRE treatments and tillage systems. Smith et al. (2002) reported that sugarbeet populations were lower in reduced tillage systems, because these systems left the soil cloddy and loose at the seed depth. Sugarbeet populations were always greater in the moldboard plowed treatments compared with the chisel plowed treatments, except with PRE *s*-metolachlor. Sugarbeet populations were 10 and 17% lower in the chisel and moldboard plowed systems, respectively, from PRE applications of *s*-metolachlor compared with the no-PRE treatment. Dale et al. (2006) and Renner (2003) reported loss of sugarbeet stand from PRE applications of *s*-metolachlor under wet conditions. Sugarbeet populations were also 12% lower from the PRE ethofumesate plus pyrazon treatment in the chiseled plowed system.

Even though there were differences in sugarbeet injury between the PRE herbicide treatments, sugarbeet canopy development was not influenced by herbicide treatment. However, there were differences in canopy development between the two tillage systems. Canopy closure for sugarbeets in the chisel plowed treatment was slower than the moldboard plowed treatment throughout the growing season (Figure 2). Canopy closure was 7-, 10-, 12-, and 6% lower in the chisel plowed treatment compared with the moldboard plowed treatment, 7, 8, 10, and 11 WAP, respectively.

Weed control data were combined over locations and years. Regardless of tillage system, common lambsquarters, pigweed (redroot pigweed and Powell amaranth), and giant foxtail control in mid-August was consistently higher when a PRE herbicide was applied prior to the micro-rate herbicide treatments (Table 28). There were very few differences in control between the three PRE treatments, *s*-metolachlor, ethofumesate, and ethofumesate plus pyrazon. Velvetleaf was the only weed species where a PRE herbicide prior to the micro-rate treatments did not improve control. Common lambsquarters control ranged from 86 to 93% when a PRE herbicide was applied prior to the micro-rate applications compared with less than 75% control without a PRE. Pigweed control was at least 19% greater when a PRE herbicide was applied prior to the micro-rate applications compared with the micro-rates alone. Even with the increase in control from the PRE treatments, pigweed control was only 74 to 83%. Giant foxtail control was greater than 90% when a PRE herbicide was applied prior to the micro-rate herbicide treatments compared with less than 70% control from the micro-rate treatments alone.

Even though there were differences between the herbicide treatments for sugarbeet injury and populations 60 DAP, there were no differences in recoverable white sucrose yield between the herbicide treatments; therefore recoverable white sucrose yield was averaged across herbicide treatments at each site. Recoverable white sucrose yield was greater in the moldboard plowed treatments compared with the chisel plowed treatments in three out of the four sites. Yield was 14-, 17-, and 39% lower in the chisel plowed system compared with the moldboard plowed system at St. Charles 2005, Saginaw Co. 2005, and St. Charles 2006, respectively (Table 29). Throughout the growing season sugarbeets in the chisel plowed treatments were further behind in growth compared with the moldboard plowed treatments, as observed in canopy development (Figure 2). However, at East Lansing in 2006, recoverable white sucrose yield was not different between the two tillage systems. This was the site where sugarbeets were replanted on May 8 due to poor stands from crusting. Temperatures were above normal and moisture was not limited (Table 25). Smith et al. (2002) reported similar results indicating that yield was not different between tillage systems when rainfall occurred within 2 weeks of planting.

Our results indicate that the use of PRE herbicides prior to micro-rate applications could improve control of common lambsquarters, pigweed, and giant foxtail late in the season. These results are different from Dale et al. (2006), who reported that the use of PRE herbicides was not needed when micro-rates were applied. In Dale's research weed control was greater than 90% with all treatments including the micro-rate treatment alone. Our evaluations were made in mid-August for late-season weed control, so there was opportunity for new weed emergence. Late in the season growers rely on the sugarbeet canopy for weed control. However, in Michigan growers typically plant in 76-cm rows and canopy closure is not always complete. This may even be more of an issue when sugarbeets are grown in a chisel plowed system, where canopy development was slower. Even though there may be benefits for late-season weed control, the use of PRE herbicides can increase the risk of sugarbeet injury and stand loss, especially during wet springs. This may be even more of an issue if sugarbeet growers are applying micro-rates in a chisel plowed system, where sugarbeet emergence can be slower, populations lower, and sugarbeet growth reduced.

Table 25. Deviations from the 30-yr average monthly precipitation and mean temperature in 2005 and 2006 at St. Charles and in 2006 at E. Lansing, MI[a].

	St. Charles				E. Lansing	
	Precipitation		Temperature		Precipitation	Temperature
Month	2005	2006	2005	2006	2006	2006
	—— cm ——		—— C ——		— cm —	— C —
April	-4.0	-0.6	0.9	1.7	-0.9	3.0
May	-2.5	3.4	-2.1	1.1	4.2	1.0
June	5.2	-2.2	3.0	0.2	-1.5	0.2
July	2.5	8.9	0.2	0.4	1.1	1.0
August	-6.0	-1.5	0.6	-0.4	1.1	0.7
September	-8.1	2.5	2.1	-1.3	1.7	-1.1

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

Table 26. Number of days until 50% sugarbeet emergence in chisel and moldboard plowed systems at four locations in 2005 and 2006[a].

	2005		2006	
Tillage	St. Charles	Saginaw Co.	St. Charles	E. Lansing
	days after planting[b]			
Chisel plow	22.8	30.0	14.2	21.0
Moldboard plow	27.6	24.3	12.1	19.2
P-value	0.0026	<0.0001	0.0221	0.0039

[a] Data are combined across herbicide treatments, since tillage by herbicide treatment was not significant.

[b] Emergence data was regressed against time using a log-logistic dose response model and 50% emergence was calculated.

Table 27. Effect of soil-applied herbicides and micro-rate herbicide applications on sugarbeet injury and plant population 6 weeks after planting in chisel and moldboard plowed systems in 2005 and 2006.[a]

		Sugarbeet injury				Sugarbeet population			
		2005		2006		2005		2006	
PRE Treatment[b]	Rate	Chisel	Moldboard	Chisel	Moldboard	Chisel	Moldboard	Chisel	Moldboard
	- kg/ha -	— % —		— % —		— plants/30 m —		— plants/30 m —	
None	—	0	0	0	0	170	186	214	246
s-metolachlor	1.4	14	8	27	18	165	179	193	205
ethofumesate	1.7	13	10	11	1	168	174	205	238
ethofumesate + pyrazon	1.7 + 4.5	16	8	18	9	179	188	190	237
$LSD_{0.05}$		5		8		NS		16	

[a] Data are combined over locations for each year, since locations were not significant.

[b] All treatments received four POST micro-rate applications of desmedipham + phenmedipham at 45 + 45 g/ha plus triflusulfuron at 4.4 g/ha plus clopyralid at 26 g/ha plus methylated seed oil at 1.5% v/v.

Table 28. Weed control in mid-August (100-125 d after planting) from soil-applied herbicides followed by micro-rate herbicide applications in chisel and moldboard plowed systems in 2005 and 2006.[a]

		Common lambsquarters[c]		Pigweed species[d]		Velvetleaf[e]		Giant foxtail[f]	
PRE Treatment[b]	Rate	Chisel	Moldboard	Chisel	Moldboard	Chisel	Moldboard	Chisel	Moldboard
	- kg/ha -	%		%		%		%	
None	—	66	72	49	55	74	71	60	69
s-metolachlor	1.4	88	92	74	79	80	82	99	99
ethofumesate	1.7	86	93	81	77	81	80	96	94
ethofumesate + pyrazon	1.7 + 4.5	88	93	83	76	83	80	99	99
$LSD_{0.05}$		5		8		NS		16	

[a] Data are combined over locations and year, since there were not any interactions.

[b] All treatments received four POST micro-rate applications of desmedipham + phenmedipham at 45 + 45 g/ha plus triflusulfuron at 4.4 g/ha plus clopyralid at 26 g/ha plus methylated seed oil at 1.5% v/v.

[c] Common lambsquarters was present at St Charles 2005, Saginaw Co. 2005, and E. Lansing 2006.

[d] Pigweed was present at St Charles 2005, Saginaw Co. 2005, and E. Lansing 2006. Pigweeds were a mixture of Powell amaranth and redroot pigweed.

[e] Velvetleaf was present at Saginaw Co. 2005 and E. Lansing 2006.

[f] Giant foxtail was present at E. Lansing 2006.

Table 29. Recoverable white sucrose yield in chisel and moldboard plowed systems at four locations in 2005 and 2006.[a]

	2005		2006	
Tillage	St. Charles	Saginaw Co.	St. Charles	E. Lansing
	kg/ha			
Chisel plow	4838	6534	3549	6255
Moldboard plow	5611	7827	5786	6726
P-value	<0.0001	<0.0001	<0.0001	0.1297

[a] Data are combined across herbicide treatments, since tillage by herbicide treatment was not significant.

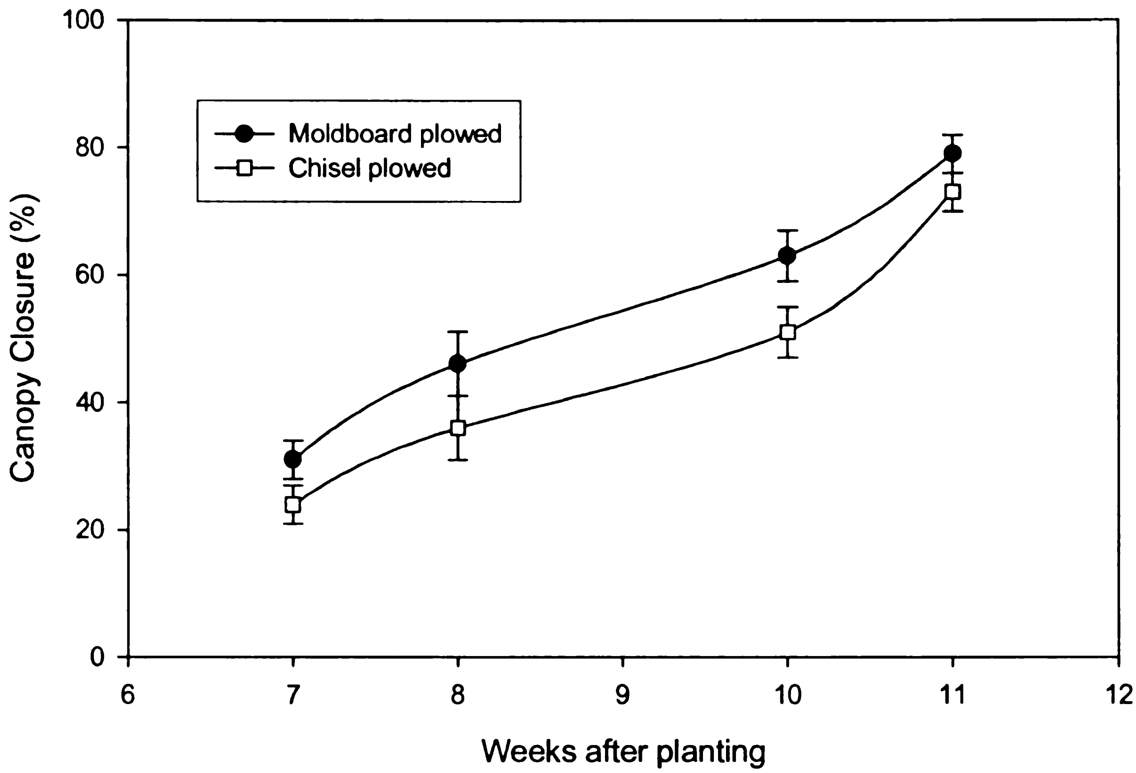

Figure 2. Percent canopy closure for sugarbeets grown in chisel and moldboard plowed systems. Data is combined over year, location, and herbicide treatment since none of these factors were significant.

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SUMMARY

Weed control in sugarbeets continues to be a challenge due to limited herbicide options, slow crop canopy development, and the long growing season. With the recent registrations of *s*-metolachlor and dimethenamid-P, Michigan sugarbeet growers have two additional options for residual control of late-emerging weeds. Currently, both of these herbicides are labeled for lay-by applications after sugarbeets have reached the 2-leaf stage (2-fully expanded leaves) and *s*-metolachlor has had a 24(C) Special Local Needs Label for preemergence (PRE) and preplant incorporated (PPI) applications. However, under certain conditions growers have observed significant injury from applications of *s*-metolachlor and dimethenamid-P alone and in tank-mixtures with other herbicides.

To reduce potential for sugarbeet injury, *s*-metolachlor should be applied after the first micro-rate application or to sugarbeets at the 2-leaf stage or larger, with the exception of applying one-fourth of the *s*-metolachlor rate in each of four micro-rate applications. Dimethenamid-P applications should be applied after the second micro-rate application or once sugarbeets are at the 4-leaf stage. The addition of *s*-metolachlor or dimethenamid-P to the micro-rate program improved control of common lambsquarters and pigweed (redroot pigweed and Powell amaranth) by varying degrees over the base micro-rate treatment. Late-season giant foxtail control was also improved, except when *s*-metolachlor or dimethenamid-P was applied in the fourth micro-rate application; by the fourth micro-rate application giant foxtail had already emerged. Results also indicate that the residual activity of *s*-metolachlor was greater than that of dimethenamid-P, except

split-applications of both herbicides provided similar residual control of giant foxtail compared with full-application rates.

Previous work with sugarbeets has shown that varieties differ in response to herbicide applications. Field trials were conducted to evaluate the response of twelve sugarbeet varieties to *s*-metolachlor and dimethenamid-P applied PRE, and when sugarbeets were at the 2-, and 4-leaf growth stages. Dimethenamid-P applied PRE and to 2-leaf sugarbeets resulted in the greatest crop injury. Injury from applications of dimethenamid-P at these timings was significantly greater than *s*-metolachlor. Sugarbeet injury from *s*-metolachlor applied PRE ranged from 16 to 33% compared with 25 to 46% injury from PRE applications of dimethenamid-P across all varieties. Applications of either herbicide to sugarbeets at the 4-leaf stage caused little to no sugarbeet injury. Of the twelve sugarbeet varieties tested, Beta 5833R was more tolerant to both herbicides compared with the other eleven varieties and HM 7172RZ was the most sensitive variety. Differences in herbicide and variety tolerance were primarily due to differential metabolism rates. The tolerant variety, Betaseed 5833R, was able to metabolize both radio-labeled (^{14}C) *s*-metolachlor and dimethenamid-P faster than the sensitive variety, Hilleshog 7172RZ.

Fields trials were also conducted to determine if tillage and soil-applied herbicides had an effect on sugarbeet injury and weed control from micro-rate herbicide applications. Sugarbeets emerged earlier in the moldboard plow system compared with the chisel plowed system. However, under dry conditions sugarbeet emergence was later in the moldboard plowed system. PRE treatments of *s*-metolachlor, ethofumesate, and ethofumesate plus pyrazon followed by four micro-rate applications increased sugarbeet injury compared with the no-PRE treatment. Common lambsquarters, pigweed (redroot pigweed and Powell amaranth), and giant foxtail control in mid-August was consistently higher when a PRE herbicide was applied prior to the micro-rate herbicide treatments. Recoverable white sucrose yield was greater in the moldboard plowed treatments compared with the chisel plowed treatments in three out of four sites tested.

Overall, including *s*-metolachlor or dimethenamid-P in sugarbeet weed management programs improved control of several species, especially late-season grass control. Applications of these herbicides prior to the second micro-rate herbicide or to sugarbeets with less than 2-fully expanded leaves increase the chances of significant sugarbeet injury and possible yield reductions. When using *s*-metolachlor, applications should not be made prior to sugarbeets reaching the 2-true-leaf stage. In a micro-rate application this is typically the second micro-rate applications. When using dimethenamid-P, growers may want to wait to apply dimethenamid-P when sugarbeets are at the 4-leaf stage. At this timing the potential for significant injury is greatly reduced. Due to the importance of variety selection for other production factors, such as disease resistance and yield potential, growers will probably not choose varieties based on herbicide tolerance. However, if a grower has chosen a particular variety, this information may assist the grower in deciding if there are risks associated with using *s*-metolachlor or dimethenamid-P for weed control.