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WEED MANAGEMENT PROGRAMS FOR USE IN HERBICIDE
RESISTANT SUGARBEET

presented by

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has been accepted towards fulfillment
of the requirements for

M.S. degree in Crop and Soil Sciences

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Date May 8, 2000

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WEED MANAGEMENT PROGRAMS FOR USE IN HERBICIDE RESISTANT SUGARBEET

By

Nathan Joseph Kemp

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

2000

ABSTRACT

WEED MANAGEMENT PROGRAMS FOR USE IN HERBICIDE RESISTANT SUGARBEET

By

Nathan Joseph Kemp

The recent introduction of sugarbeet modified to express resistance to the herbicides glufosinate and glyphosate provides a new method for weed management in this crop. Traditional weed management systems in sugarbeet follow a program approach utilizing preemergence herbicides, postemergence herbicides, cultivation, and hand-labor. Unlike conventional sugarbeet herbicides, glufosinate and glyphosate applied in herbicide resistant sugarbeet can effectively control weeds that exceed 5 cm in height, produce no crop injury, and eliminate the need for manual or mechanical weed control. Research was conducted in 1998 and 1999 as a cooperative effort between Michigan State University, Michigan Sugar Company, and Monitor Sugar Company to evaluate the use of glufosinate and glyphosate in sugarbeet production. Herbicide resistant sugarbeet was planted at four locations in Michigan each of two years. Research determined when annual weeds became competitive with sugarbeet, the need for using preemergence herbicides prior to postemergence applications of glufosinate or glyphosate, and the effect of cultivation on annual weed emergence.

ACKNOWLEDGMENTS

This section of my thesis may have been the most difficult to write since there are so many people who deserve credit for my accomplishment. I would like to thank Dr. Merrill Ross and Dr. Carole Lembi for being mentors as well as friends. If it were not for them I would have never continued my education. I also need to thank Richie and Mike for getting me through the Purdue years. A project such as this could not have been completed without the selfless hours given by my fellow graduate students, undergrads, and technicians in the program. G. Powell, Kyle, Kelly, Sherri, Chad, Jason, Andy, Dr. Sprague, Bart, Caleb, Joe, Amy, Biff, Pat, & Heather, you guys are the greatest. I think of our crew as being more like family then friends or colleagues. I need to especially thank my major Professor, Dr. Karen Renner, for her guidance and for giving me the opportunity to come to Michigan State. My time in Michigan has truly been a life altering experience. Dr. Kells, Dr. Saunders, Dr. Christenson, Dr. Black, and of course Doc Penner were always there when I had a question or needed help. I also need to acknowledge both the Michigan and Monitor Sugar Companies, whose support made this project possible. Tre, Lee, Rick and the crew, thank you. I can not forget the person who made the largest contributions to this assignment. Julie, you have given up more for this project then anyone realizes. Always supportive, never forgetting that our future was bright. Within these pages is only one chapter of our lives, the rest of the book has yet to be written.

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Introduction

Sugarbeet (*Beta vulgaris L.*) belongs to the botanical family Chenopodiaceae. Sugarbeet is characterized with a biennial growth habit; since the production of seed usually requires some period of thermal induction in which the plant must be exposed to a period of low temperatures (WCBSC 1990). The sugarbeet root is harvested for the production of sugar, although molasses and pulp are saleable byproducts. Approximately 37% of world sugar is derived from sugarbeet, making it the most important sucrose producing crop in temperate regions (D'Halluin *et al.* 1992). Sugarbeet is grown under a production contract in which the processor receives sugarbeet root produced on a specified piece of ground at an established pricing agreement. In Michigan the grower is paid a percentage of the revenue that the sugar companies generate from the sale of sugar. This payment is based upon the tons of sugarbeet root produced and delivered. A premium or deduction is based upon the relative sugar content of these roots (Michigan Sugar Company, 1999 Grower Contract).

In the United States there are five general geographic regions where sugarbeet is grown. These regions include the Great Plains, the Red River Valley, the Northwest, California, and the Great Lakes. Together these regions have approximately 470,000 ha of land in production (Schweizer and Dexter 1987). Even within these five regions there are differences in agronomic, ecological, and climatic conditions. There is also a differentiation between irrigated and non-irrigated land. Sugarbeet in Michigan is produced under non-irrigated conditions. In 1997 approximately 66,000 ha of sugarbeet was planted in Michigan resulting in over 2.7 million metric tons of harvested sugarbeet root (MASS 1998).

The recent development of sugarbeet varieties that are resistant to the herbicides glyphosate (*N*-phosphonomethylglycine) or glufosinate (2-amino-4-hydroxymethyl phosphinyl butanoic acid) has introduced the first substantial change in weed control programs for this crop in over 25 years. Most of the herbicides currently used in sugarbeet production were developed in the late 1960's and have a narrow margin of selectivity. Changes in environmental conditions can alter their phytotoxic effects, producing crop injury (Schweizer and Dexter 1987). Besides causing injury, traditional sugarbeet herbicides have the ability to control only very small weeds when applied postemergence (Wilson 1998). The precise timing required and the need for multiple reduced rate applications to avoid crop injury make current postemergence treatments less than ideal. In spite of this there has been a gradual shift towards the use of more postemergence products (Griffith 1994). Unlike traditional postemergence sugarbeet herbicides, glyphosate and glufosinate do not injure the resistant crop and have the ability to kill large weeds, making this technology the next step in the evolution of weed control programs.

In 1965 it was estimated that weed competition in the United States caused a loss in yield and quality equal to eight percent of the potential value of sugarbeet (Schweizer 1981). At that time only 33% of sugarbeet acres were treated with herbicides. From 1975-1979 weeds accounted for a 10% yield loss in sugarbeet. This resulted in an approximately $89 million loss (Schweizer and Dexter 1987). In 1984 approximately 90% of the sugarbeet acres received a herbicide treatment (Schweizer and Dexter 1987).

Despite this increase in herbicide use, and presumably the increased weed control that would be associated with this use, weeds continued to cause economic loss. More current estimates of economic loss are $350 million when no herbicides are applied and $60 million when best management practices are implemented (Morishita and Downard 1995). These crop losses are not due to new weed species invading U.S. sugarbeet growing regions, but are caused from inadequate control of common species. A 1985 survey listed pigweeds (*Amaranthus spp.*), common lambsquarters (*Chenopodium album* L.), kochia (*Kochia scoparia* L.), and smartweeds (*Polygonum spp.*) as the major broadleaf weeds in sugarbeet, with other species such as velvetleaf (*Abutilon theophrasti* Medic.) and nightshades (*Solanum spp.*) also becoming a problem (Schweizer and Dexter 1987). These weeds are among the most difficult to control in sugarbeet (Morishita and Downard 1995).

Glyphosate & Glufosinate

Glyphosate and glufosinate have herbicidal activity on most species of plants and can only be used for postemergence weed control in genetically altered, resistant crop varieties. Crops that are resistant to glyphosate are sold under the trademark Roundup Ready®; glufosinate resistant crops are known as Liberty Link®. Though both of these herbicides are in the same chemical family, each has a unique mode of action and can only be applied to the appropriate resistant variety. Resistance genes for these herbicides have been inserted into canola, corn, cotton, rice, soybean, and sugarbeet varieties (WSSA 1997). Glyphosate and glufosinate do not remain active in the soil, so there is no risk of herbicide carryover into other crops (WSSA 1994). There is also no residual effect on later emerging weed seedlings. Glyphosate is rapidly and tightly adsorbed to the soil and is therefore inactivated (Delannay *et al.* 1995).

Glufosinate is mobile in the soil; however, soil microbes rapidly degrade this herbicide (WSSA 1994). Glufosinate (2-amino-4-hydroxymethylphosphinyl butanoic acid) inhibits the enzyme glutamine synthase (D'Halluin *et al.* 1992, WSSA 1994). This enzyme facilitates the conversion of glutamate and ammonia to glutamine (WSSA 1994, Taiz and Zeiger 1998). When glutamine synthase is inhibited the plant is not able to assimilate ammonium. Accumulation of ammonia is toxic to plant cells and directly inhibits photosystem I and II reactions (WSSA 1994). The insertion of a synthetic phosphinothricin-*N*-acetyl transferase or PAT gene via *Agrobacterium tumefaciens* mediated transformation allows the crop plant to rapidly metabolize glufosinate (D'Halluin 1992, WSSA 1994, AgroEvo USA Company).

Glyphosate (*N*-phosphonomethyl glycine) inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate synthase or EPSP synthase (WSSA 1994, Delannay *et al.* 1995, Padgette *et al.* 1995). The inhibition of this enzyme does not allow 5-enolpyruvylshikimate-3-phosphate or EPSP to be produced from shikimate-3-phosphate and phosphoenolpyruvate in the shikimic acid pathway. This is part of the aromatic amino acid biosynthetic pathway, which is responsible for the production of tryptophan, tyrosine, and phenylalanine (WSSA 1994, Padgette *et al.* 1995). EPSP synthase is present only in plants, bacteria, and fungi (Delannay *et al.* 1995). Glyphosate is not readily metabolized within the plant (WSSA 1994). Herbicide resistance is accomplished through the insertion of a gene that encodes an insensitive target protein. Glyphosate does not bind to this tolerant EPSP synthase and the plant continues to produce aromatic amino acids (Padgette *et al.* 1995).

Increased use of herbicides in sugarbeet production

Limiting crop losses due to weeds is only one reason for increased herbicide use in sugarbeet. There are also many intangible reasons to use herbicides, such as aesthetic value, reduced weed seed production, and elimination of harbored pests (Schweizer and Dexter 1987). Another reason for the increased use of herbicides in sugarbeet is related to the cost of labor. Traditionally weeds were removed from the crop using hand labor and cultivation. The cost of hiring people to hand hoe a crop is increasing (Wilson 1994). Between 1970 and 1986 the cost of labor doubled (Schweizer and Dexter 1987). Herbicides also increased in cost, but still cost less then labor for removing weeds. This is especially true in fields with many weeds (Schweizer and Dexter 1987). Miller and Fornstrom (1989) reported that herbicide treatments reduced weed control costs compared with labor alone. The benefit of using herbicides ranged from $77 - $152 per acre, with the greatest return from preemergence herbicides used in combination with postemergence herbicides. Their studies showed that it required 4.4 hours per acre to walk through a weed free field twice, and an additional 0.5 hours per acre to remove 1000 weeds (Miller and Fornstrom 1989). As the cost of labor increased, the use of herbicides became essential for minimizing weed control costs. It is for this reason that sugarbeet producers in the U.S. rely on herbicides and cultivation for weed control.

Sugarbeet injury from herbicides

Herbicides used in sugarbeet production can injure the crop as well as control weeds. Loss of crop vigor can range from 0% to 3% for either preemergence or postemergence programs. A combined program using both preemergence and postemergence products caused as much as 15% visible injury to sugarbeet (Miller and Fornstrom 1989). Though this injury is significant, sugarbeet recovery was excellent, with yield or percent sucrose in the herbicide-treated sugarbeet being statistically similar to the hand-weeded control (Miller and Fornstrom 1989). Sugarbeet exhibits variable crop tolerance to conventional sugarbeet herbicides. Sugarbeet genotypes differ in their tolerance to cycloate or ethofumesate followed by desmedipham and phenmedipham (Smith *et al.* 1982, Smith and Schweizer 1983). Sugarbeet tolerance to EPTC differed by cultivar (Dexter and Kern 1977, Schweizer and Dexter 1987).

Many herbicides that are used in other crops have the ability to injure sugarbeet. Residual products that can harm sugarbeet include chlorsulfuron (2-chloro-*N*-[[(4-methyl-6-methyl-1,3,5-triazin-2yl)amino]carboxyl]benzenesulfonamide), dicamba (3,6-dichloro-2-methoxybenzoic acid), metribuzin (4-amino-6-(1,1-dimethyl)-3-(methythio)-1,2,4-triazin-5(4*H*)-one), pendimethlin (*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine), picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid), trifluralin (2,6-dinitro-*N,N*-dipropyl-4-(trifluoromethyl)benzenamine), and atrazine (6-chloro-*N*-ethyl-*N*-(1-methylethyl)1,3,5-triazine-2,4,-diamine) (Schweizer and Dexter 1987, Dexter *et al.* 1994). One of the most detrimental herbicides is imazethapyr (2[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl] 5-ethyl-3-pyridinecarboxylic acid), which has the ability to injure sugarbeet for 40 months after application (Renner and Kells 1999). Crop injury from residual herbicides occurs most frequently on sandy or low organic matter soils. Carryover problems can be lessened with plowing, or by avoiding excessive herbicide rates.

Residual herbicide from application in other crops in the rotation is not the only way sugarbeet can be injured. Crop yield or quality can also be affected by inadvertent exposure due to herbicide drift or volatilization. An excellent example would be exposure of sugarbeet to the herbicides 2,4-D ((2,4-dichlorophenoxy) acetic acid) and dicamba (Schweizer 1978, Schroader *et al.* 1983). These herbicides not only reduce root yield, but can also cause sucrose loss during post harvest storage. The level of impact depends on the growth stage of the crop and the herbicide concentration at the time exposure. Sugarbeet exposed to these herbicides should be processed immediately after harvest and not placed in piles (Schweizer 1978, Schroeder *et al.* 1983).

The Basis for Weed Competition

The basis for weed competition in crops is that a plant will only compete with another plant when there are one or more limiting resources. In the field the basic resources limiting crop growth are nutrients, water, and light (Kropff 1988). In most field situations nutrients are provided in the form of fertilizer, where the grower controls the amount of nutrients applied. In arid regions water may become the most limiting resource; however, in these areas sugarbeet is grown under irrigation. In irrigated beets where water and nutrients are plentiful, competition for these resources does not occur early in the growing season. Therefor competition for light is the main factor causing a yield loss due to weeds (Brimhall *et al.* 1965, Dawson 1965, Schweizer and Bridge 1982). It is only after a weed dominates light interception that weeds gains a competitive advantage and become more effective in water and nutrient uptake (Dawson 1970). The period of weed competition that a crop can tolerate is influenced by the vigor of the weed species and the specific environmental resource the plants are in competition for. As long as the only limited resource is light, then the crop can tolerate weeds for a fairly long time (Dawson 1970).

Effect of Weeds on Sugarbeet Yield and Quality

Yield loss in sugarbeet due to weed competition can be attributed to the decrease in diameter and not the length of sugarbeet roots (Brimhall *et al.* 1965). The effect of weeds on recoverable sugar per acre/hectare is a direct result of decreased root yield, since weed density does not affect percent sucrose or purity of brei (Brimhall *et al.* 1965, Zimdahl and Fertig 1967, Schweizer and Bridge 1982).

The competition of weeds with sugarbeet has the ability to decrease not only the weight of harvested roots, but also affects the growth of beet tops. This loss of weight is not offset by the gain in weed growth (Schweizer 1981, Schweizer 1983). The biomass of a specific weed-beet community is less then that of a weed-free community (Schweizer and Bridge 1982). For every 1120 kg/ha of above ground weed biomass that was produced there was a corresponding yield decrease of 10500 to 11600 kg/ha (Wicks and Wilson 1983). Weed biomass at any stage is influenced by weed species composition (Bond and Burton 1996). It is important to note that limiting resources such as moisture and light are critical for both weeds and the crop.

Weed biomass from areas where weed density has been reduced is comparable to that of an unweeded control (Miller and Hopen 1991). The effect of weed density is minimized by the increased growth of the remaining weeds (Brimhall *et al.* 1965, Zimdahl and Fertig 1967). The total biomass of *Setaria fatua* and *A. hybridus* stayed constant in corn and soybean crops, despite differences in weed densities (Schweizer 1983). The average weight of weeds such as *K. scoparia* is affected by weed density only when the density is equal to one or more plants per 2 foot of row (Weatherspoon and Schweizer 1971).

<u>Critical Period for Weed Control</u>

There have been two traditional types of weed competition studies. To determine when weeds can infest the crop, a weed free period is maintained for various time intervals after crop emergence. After this initial weed-free period, weeds are allowed to remain in the crop. To determine how long weeds can remain in the crop from the time of crop emergence, weeds are allowed to grow uninterrupted initially, and are then removed at various stages in the development of the crop and continually removed until the end of the growth cycle (Van Heemst 1985). Performing these types of studies allows the researcher to determine the critical period for weed control in a crop. The critical period is the time during the crop lifecycle in which the presence of weeds has the strongest effect on yield (Van Heemst 1985).

Dawson (1970) described two stages associated with full season weed control. During stage one the grower must provide weed control via tillage, herbicides, or hand labor. Stage one is shorter where fast growing crops are planted in warm conditions, or when nutrients and water are scarce. This first stage will persist longer if crops are planted during cool weather. The period of time during which crops can tolerate weeds becomes shorter if planting is delayed. This is because warmer temperatures allow weeds to grow rapidly. This period may become even shorter if moisture is in short supply. As an example, wheat and flax grown in semi-arid regions can only tolerate two weeks of weed competition. In contrast, sugarbeet grown under irrigation in these regions can tolerate weeds for eight to 12 weeks after planting or five to nine weeks after crop emergence (Dawson 1965, Dawson 1970). Sugarbeet withstands this lengthy period of competition when the crop is planted early and water is in adequate supply (Dawson 1970).

Stage two begins when crop dominance is established over weeds after being favored by weed control practices. The length of this stage can vary according to crop stand and vigor; however, vigor of weeds has no effect when this stage begins (Dawson 1970). As an example, during the first ten to 12 weeks of sugarbeet growth a grower should apply weed control practices, while the crop controls weeds that emerge later (Zimdahl and Fertig 1967). Competition for light appears to be responsible for suppression of new weeds by beets from ten to 12 weeks until harvest (Dawson 1965). The crop is a significant part of season-long weed control. The critical point in the season at which the crop can suppress weeds is determined by each crop situation (Dawson 1970).

<u>Sugarbeet Tolerance to Weed Competition</u>

There are several theories for how long weeds can remain in sugarbeet. Moisture and relative date of beet emergence are critical factors in determining the degree of competition. Weed competition for 24 to 28 days after crop emergence had no effect on sugarbeet yield in Wyoming (Brimhall *et al.* 1965). Sugarbeet can tolerate weeds for two to eight weeks after emergence depending on weed species, emergence of weeds relative to crop emergence, and environmental conditions (Scott et al. 1979, Schweizer and May

1993). Yield is drastically decreased only when weeds are allowed to remain in the crop for the duration of the season.

Weeds were most competitive if they emerged within eight weeks after planting (Wicks and Wilson 1983, Wilson 1992) or within four weeks after the crop reached the two-leaf stage (Wicks and Wilson 1983, Schweizer and Dexter 1987, Schweizer and May 1993). Research that supports this idea has shown that *E. crus-galli* and *A. retroflexus*, which emerge at the end of June, were not competitive with the sugarbeet crop (Dawson 1974, Schweizer and Dexter 1987). Studies by Dawson (1965) showed that maximum sugarbeet yield was achieved if weed control was maintained for eight to 12 weeks after planting or five to 9 weeks after crop emergence. Maintaining weed control for five weeks after time of emergence may not be long enough. When *K. scoparia* was removed at this time sugarbeet yield was still lost (Weatherspoon and Schweizer 1969). One *K. scoparia* per 4.8 foot of row was able to emerge and cause a 2.7 ton per acre loss in harvested root yield. In contrast, full season competition from early emerging weeds resulted in a yield loss of 9.2 tons per acre (Weatherspoon and Schweizer 1971). Though later emerging weeds decreased sugarbeet yield, the loss was considerably less then that from full season competition. The ability for sugarbeet to compete with late emerging weeds is diminished if the crop is not at normal vigor or full stand (Dawson 1974, Schweizer and Dexter 1987).

Time of Weed Emergence

The relative dates of emergence were important in determining the competitive efficiency of weeds and sugarbeet (Zimdahl and Fertig 1967, Kropff 1988). Weeds that emerge early are troublesome and have the most potential to cause yield loss in sugarbeet

(Dawson 1965, Weatherspoon and Schweizer 1969, Wicks and Wilson 1983). Variation accounted for by weed density was 13%, whereas differences in the period between crop and weed emergence explained 96% of variation in yield loss between experiments (Kropff 1988). Weeds that emerge early have the opportunity to grow for a longer period of time before the sugarbeet canopy is formed. This can be thought of as a race in which each species must shade the other first in order to win. An excellent example of a weed that is competitive with sugarbeet is *C. album*. Dawson has shown that season-long competition from *C. album* has the ability to reduce sugarbeet yield by 94% (Dawson 1965, Zimdahl and Fertig 1967). This species grows tall, provides dense shade, and tends to emerge with sugarbeet. Another problem weed *A. retroflexus* also grows tall and dense. This weed however, does not have as great an effect on yield as *C. album*. The presence of *C. album* was associated with 86% of sugarbeet yield variability, whereas the presence of both *C. album* and *A. retroflexus* explained 91% of yield variability (Wicks and Wilson 1983). *A. retroflexus* is not as competitive with sugarbeet due to a later date of emergence (Dawson 1965). Also, C-4 plants like *A. retroflexus* are more competitive in warmer climates, while C-3 plants such as *C. album* are suited to cooler climates. However, if either of these weed species emerge before the crop, they will become competitive more quickly (Dawson 1965).

Competitiveness of Various Species

The time of weed emergence is not the only factor that can influence a plants ability to compete for light. In sugarbeet, broadleaf weeds are more damaging to yield then grassy weeds (Brimhall *et al.* 1965, Dawson 1965, Schweizer and Dexter 1987). This is because broadleaf weeds such as *C. album* have wider leaves, which provide dense shade

(Dawson 1965). *E. crus-galli* reduced sugarbeet yield by 49% compared to 94% for *C. album* (Dawson 1965, Zimdahl and Fertig 1967, Schweizer and Dexter 1987). *C. album* emerged first and remained the dominant competitor though *E. crus-galli* was more numerous. Two broadleaf weeds had a greater effect on sugarbeet yield than 20 grasses (Zimdahl and Fertig 1967). As the season progressed, individual weeds became fewer as the older, larger ones crowd the others. When comparing full season competition between the two weed species, *E. crus-galli* lost 70% of its yield compared with 13% for *C. album* (Dawson 1965). The grass *Setaria viridis* only reduced beet yield by 26% at a density of 1 weed per beet compared with a 70% yield loss from *A. retroflexus* at the same density (Brimhall *et al.* 1965, Schweizer and Dexter 1987).

Competitive Weed Densities

Sugarbeet yield is adversely affected as weed density increases (Weatherspoon and Schweizer 1971, Schweizer 1981). At lower populations, weed density may influence the competitive effect of weeds significantly. Because of intra-specific competition, heavy weed populations have a saturating competitive effect. When infestations are severe a several fold difference in the population of weeds will influence the total effect very little (Dawson 1970).

Weeds have the ability to be competitive with sugarbeet at low densities. It is estimated that even if one to five percent of weeds escape, yield may be reduced by six to 12% (Schweizer and Dexter 1987). A mixed population of various weed species at the density of six plants per 30 meters of row reduced sugarbeet yield 11 to 14% (Schweizer 1981, Schweizer and Bridge 1982). Eight *A. retroflexus* plants per 30 meters of row reduced sugarbeet yield 16% (Brimhall *et al.* 1965, Schweizer and Dexter 1987). Other broadleaf weeds such as *K. scoparia* reduced sugarbeet yield at densities as low as one weed per 25 foot of row (Weatherspoon and Schweizer 1971). *K. scoparia* can compete with sugarbeet plants within a 48 inch radius (Weatherspoon and Schweizer 1971). *C. album* at a density of four to six plants per 30 meters of row reduced sugarbeet yield by eight to 12% (Schweizer 1983). In general, a grower will experience a decrease in sugarbeet yield from three to six broadleaf weeds per 30 meters of row (Schweizer 1981). In contrast, grasses such as *S. viridis* are competitive only at densities greater than one weed per sugarbeet (Brimhall *et al.* 1965).

Weeds within the row

Competition from weeds begins first within the row (Dawson 1965). Weeds emerging within the row compete directly with the crop for resources. It can be argued that the only weeds that matter are those which emerge within a four inch band over the row. This is because the space within the row is shaded quickly by the crop and weeds between the rows can be easily removed with cultivation (Dawson 1970). The competitive effects of weeds may extend 32 inches in most cases (Weatherspoon and Schweizer 1971). The yield of sugarbeet in cultivated plots where weed densities were only in a ten inch band over the row, was not impacted as greatly as in uncultivated plots (Zimdahl and Fertig 1967).

Program approach to weed control in sugarbeet

Weed control in sugarbeet often relies on preemergence herbicides at planting followed with one or more postemergence herbicide applications. In Michigan the use of preemergence herbicides is common. This is also true for areas such as Nebraska and Wyoming where over 50% of the sugarbeet is treated with a residual, soil-applied herbicide (Renner 1999; personal communication). Sugarbeet growers in North Dakota and Minnesota use few soil applied, residual herbicides. In 1998 only 11% of these growers used soil-applied herbicides (Dexter and Luecke 1999).

Preemergence herbicides are biologically active in the soil, controlling newly emerging weed seedlings. The pre-mixture of the postemergence herbicides phenmedipham (3 [(methoxy carbonyl) amino] phenyl (3-methyl phenyl) carbamate) and desmedipham (ethyl [3-[[(phenylamino) carbonyl]oxy]phenol]carbamate) controlled weeds more effectively when applied to areas previously treated with the preemergence herbicide cycloate (5-ethyl cyclohexylethylcarbamothioate) (Dexter 1994). The greatest reduction in broadleaf weed density occurred in the preemergence followed by postemergence herbicide treatments (Wilson 1992). The number of postemergence treatments and the need to include a preemergence herbicide to achieve the most cost-effective weed control varies according to weed density (Miller et al. 1997). The greatest gross return in $/ha was when preemergence and postemergence herbicides were both applied. Preemergence followed by postemergence herbicides have proven to be effective in providing season long weed control (Schweizer 1980, Winter and Weise 1982, Wicks and Wilson 1983, Miller and Fornstrom 1988, Miller and Fornstrom 1989, Miller *et al.* 1992).

The high cost of traditional sugarbeet herbicides such as desmedipham, pyrazon (5-amino-4-chloro-2-phenyl-3(2*H*)-pyridazinone), and ethofumesate (2-ethoxy-2,3-dihydrox-3,3-dimethyl-5-benzofuranyl methane sulfonate) has led many growers to apply these products in a way that reduces the amount of active ingredient applied per hectare. These herbicides are applied in a band over the row of the crop, thus controlling weeds within this band (Schweizer and Dexter 1987). Cultivation between the rows controls the remaining weeds. Sugarbeet producers presently use a combination of chemical, mechanical, and manual weed control methods (Miller *et al.* 1992).

Weed emergence and cultivation

Cultivation between the rows of the crop is a common technique for weed control in sugarbeet. With the introduction of sugarbeet varieties that are resistant to herbicides such as glufosinate or glyphosate, cultivation as a weed control strategy will no longer be required. This is because these herbicides can be economically applied broadcast and provide excellent weed control. In spite of this new technology, growers have expressed an interest in continuing to cultivate sugarbeet. Many growers employ a "cutaway" cultivation early in the season to aerate and loosen the soil, facilitating the establishment of young sugarbeet plants. In addition to weed control, cultivation may be used to loosen the soil, apply nitrogen fertilizer, place soil around the sugarbeet plants to aid in harvest, and enhance the aesthetics of the crop in the field.

One argument against using cultivation with herbicide resistant crops is that tilling the soil may increase the emergence of new weed seedlings (Egley and Williams 1990). Glufosinate and glyphosate have no residual soil activity and only control emerged weeds (WSSA 1994). New weed emergence after herbicide application could translate into decreased control. Seed germination and dormancy is complicated and can be influenced by many factors including soil temperature, soil moisture, and exposure to light (Baskin and Baskin 1990, Alm *et al.* 1993, Salisbury and Ross 1992, Taiz and Zeiger 1998). Cultivation can affect the distribution of seeds or the environment needed for germination (Egley 1986, Egley and Williams 1990). These affects can be both positive and negative to weed emergence.

One way in which tillage may influence seedling emergence is by affecting soil temperature and moisture. Research has shown a relationship between weed growth and soil temperature and soil moisture (Wiese and Binning 1987). A reduction in tillage can reduce soil temperature and increase soil moisture (Oryokot *et al.* 1997c). Reducing tillage concentrates weed seeds near the soil surface (Clements *et al.* 1996). As temperature increases above a minimum threshold, the rate of seed germination and shoot elongation is increased. For some species there is a temperature above which germination and elongation decrease (Oryokot *et al.* 1997b & 1997c). Temperature and moisture are also known to regulate secondary dormancy of some annual weed seeds. Low soil temperature may break seed dormancy, while high temperatures induce dormancy (Forcella *et al.* 1997). The actual effect tillage has on soil moisture, soil temperature, and weed seed germination can be somewhat limited. As an example, *A. retroflexus* seedlings are physiologically restricted to germination depths of less then 2.5 cm. At shallow soil depths heat and moisture transfer between soil and atmosphere is rapid, reducing the affect of tillage on seed germination. This phenomenon varies by soil type or sites with different cropping histories (Oryokot *et al.* 1997a). These criteria may also limit the effect of tillage on annual grasses such as *S. faberi*, which has the greatest emergence from a soil depth of less then a centimeter (Fausey and Renner 1997).

Exposure to light is another variable affected by tillage (Wesson and Wareing 1969, Buhler 1997, Gallagher and Cardina 1998). Exposure to light can break seed dormancy in some plant species. This requirement for light would keep propagules that are buried more than a few centimeters from germinating, which is an advantage for plant species with small seeds (Salibury and Ross 1992, Buhler 1997). The response of seeds to light is mediated by phytochrome, which exists in two forms. Phytochrome red (Pr), the inactive form, is converted by exposure to red light to phytochrome far red (Pfr) (Ascard 1994). Phytochrome in the buried seeds is in the Pr form and is converted to Pfr upon exposure to sunlight, resulting in a series of physiological events that lead to germination (Gallagher and Cardina 1998, Taiz and Zeiger 1998). In research by Buhler (1997), emergence of small-seeded weeds such as *C. album* and *Polygonum pennsylvanicum* decreased when tillage was performed in the dark. Similar results were reported by Ascard (1994), in which the germination of some weed species was reduced when tillage implements excluded light. Unlike Buhler's, Ascard's experiments did not show a decrease in *C. album* germination when tillage was performed at night. Gallagher and Cardina (1998) reported a decrease in emergence of some weed species when tillage was performed at night versus during the day; however, variability of this result does not make night tillage a viable approach for reducing the number of emerging weeds. Though the microclimate variable that accounted for the most variation in the emergence of *C. album* was temperature, exposure to light prolonged non-dormancy (Forcella *et al.* 1997). This interaction between temperature, light requirement, and moisture on weed seed germination is complex and varies by weed species.

The effect of cultivation on weed emergence may vary according to the time of year. When soil is cultivated there is a small proportion of the total seed bank which is released from dormancy (Roberts 1984). Weeds such as *C. album* tend to appear more frequently after spring tillage and continue to appear whenever the soil is disturbed.

Temperature largely determines this seasonal pattern of emergence, however soil moisture also seems to have an overriding affect.

Will Herbicide Resistant Crops Lead to Resistant Weeds?

For thousands of years people have tried to manipulate plants for their own use. At first this was simply through the harvest and eventually the domestication of wild plants into cultivated crops. Technology has ushered in a new era in agriculture. Through the use of crop breeding, machinery, mineral fertilizers, and pesticides, world crop production continues to increase. One of the most recent advancements is the use of biotechnology to create genetically transformed crops. An example of one such crop is canola, which now exists with transgenic resistance to several herbicides, increased methionine in the seed meal, male sterility, heavy metal tolerance, and insect resistance (Brown and Brown 1996). Even with all of the improvements that can be made, herbicide resistance is the most common genetically engineered trait (Brown and Brown 1996). There are several reasons for the development of herbicide resistant crops, including increased options for the grower and the use of "environmentally safer" herbicides. Some however, argue that the use of biotechnology could result in detrimental effects to the environment. That argument in itself is a broad topic that may never be resolved, but for the weed scientist thought should be given as to whether herbicide resistant crops could facilitate the occurrence of herbicide resistant weeds. At this point it is uncertain if crops that are resistant to herbicides will decease the incidence of herbicide resistance in weeds or enhance it (Radosevich *et al.* 1992).

Herbicide resistance in weeds could develop if the increased use of a single product allows for the selection of naturally resistant plants, the crop itself becomes a weed, or through cross fertilization of crops with weedy species. It is common to experience a weed shift with different management methods, allowing tolerant species to dominate in a given area. The proper use of resistant crops should not increase this problem (Burnside 1992). Similarly, natural selection for resistance would be the result of abusing technology. Knowing that misuse of a herbicide resistant crop could result in natural selection for resistance or shifts in weed populations, concern now falls to the uncertainty of a resistance gene being inadvertently released into the environment.

It is conceivable that the crop itself could become a weed, and with it a genome expressing the trait for herbicide resistance would be released uncontrolled into the environment. There are examples of plant species that exist as both crops and weeds, including shattercane and wild proso millet. In both of these cases seed dormancy allowed evolution to a "weedy" plant, and would have happened whether these species displayed herbicide resistance or not (Burnside 1992). Another example would be wild oats, differing from cultivated oats by only one gene that determines seed shedding at maturity and hair on the seeds (Darmency 1994). Still, it is unlikely that the crop itself will become a problem weed. Crops are genetically uniform compared to wild relatives, and selection would have little opportunity to operate on an individual escaped plant. In addition, crops lack the longevity in the amount of time the seed is viable. If crops were to display seed dormancy, dispersal through time would be a concern (Linder and Schmitt 1994).

It is clear that crops and weeds can spontaneously hybridize in the field, and this flow of genes from genetically engineered crops into wild plant relatives could result in the escape of transgenes (Arriola and Ellstrand 1996). Examples of hybridization between crop and weed include sorghum crossing with wild sorghum to give rise to johnsongrass, and sugarbeet crossing with a wild beet to yield weed beets (Brown and Brown 1996). Recently a botanist found a variety of green foxtail that was actually a cross of the crop foxtail millet and green foxtail (Darmency 1994). Outcrossing may not only be a problem between related species. Existing literature describes intergeneric cross compatibility within the family Brassicaceae (Brown and Brown 1996). This family includes canola, wild mustard, shepherdspurse, and field pennycress. Concern about hybridization between weed and crop is justified, since as much as wild forms can be repositories for genetic information they can also be sinks for genes flowing from the crop (Arriola and Ellstrand 1996).

One well-documented example of crop-weed cross compatibility is that of the weed beet in Europe. Considerable genetic variability can exist in sugarbeet. The major difference in weed beets and cultivated beets is the life cycle. A cultivated beet, like those grown in Michigan is a biennial plant, while beets with weedy characteristics are annuals. This life cycle depends on the presence or absence of the vernalization requirement. Natural selection for an annual life cycle, early flowering and seed maturation, and seed shattering allows weed beets to reproduce in cultivated fields. The weed beet is likely a result of wild beets pollinating the seed production of cultivated beets (Boudry *et al.* 1993). Since all of these are considered the same species and are inter-fertile, great care should be taken around seed production areas. Furthermore, cultivated beets should not be allowed to set seed, meaning growers need to destroy any bolting plants in their fields (Boudry *et al.* 1993).

Though there are several other good examples of gene flow out of crops into wild relatives, the future of herbicide resistant crops may not be bleak. In reality the chances of a gene escaping from most crops is very small. There are few crops that are compatible to interbreed with wild relatives in such a manner as previously described. Even if a wild plant is capable of crossing with a crop species, high selection pressure is necessary to exclude competition from each species own pollen (Gressel and Kleifeld 1994). Furthermore, pollination does not mean that hybridization will be successful. Hybrid infertility is a problem for many interspecific crosses, and the frequency of such hybrids that backcross with the wild parents would be low (Darmency 1994). Under greenhouse conditions only about 1 in 25 crosses of field mustard to canola produced seeds. Of those only 2% were fertile, due to cytological defects and lack of chromosome pairing (Brown and Brown 1996). In the field so few viable seeds would pose little risk of gene flow. One more problem that exists preventing the formation of weed-crop hybrids is that crops and wild relatives may not flower at the same time. In this situation there is said to be a hybridization barrier. With canola and wild mustard there was 7 times more pollen and 18 times more wild stigmas, if a late flowering cultivar is planted instead of an early flowering cultivar. A similar trend is seen between foxtail millet and green foxtail, where a late maturing crop cultivar translated into a 30-fold increase in hybridization (Darmency 1994). Manipulating the time of crop pollination may help reduce the potential for loss of genes, but may adversely affect grain yield.

Historically, hybridization between crops and weeds was of little concern. Desirable traits in crops are often detrimental to weeds, resulting in hybrids that are poor competitors in native habitats (Arriola and Ellstrand 1996). The ability of a plant to become a weed is only possible if it has an adaptive or competitive advantage. A transgene for herbicide resistance confers higher fitness in a herbicide treated area, but is not beneficial in wild areas (Darmency 1994). It is unlikely that a plant acquiring a herbicide resistance gene will become a weed, since this trait by itself is basically neutral. Wild species will remain "weedy" only until more aggressive plants begin competition or until other herbicides are used (Gressel and Kleifeld 1994). Herbicide resistance by itself can not make a wild plant be a persistent pest.

When assessing the risk of transgene escape several steps should be followed. First, what is the potential for interspecific compatibility of the genomes of crops and wild plants in the area? Second, how will the gene behave in wild populations (Darmency 1994)? Basically if there are no wild relatives capable of crossing with a crop there is virtually no risk of transgene escape. Even if hybridization is possible, unless the hybrid that is formed is apometic the genetic material has to be preserved through backcrossing with wild relatives.

The last consideration may be the most complicated. That is, will an escaped gene impact the environment? Keep in mind that there will be an increase in plant population only if the most limiting factor is manipulated (Radosevevich *et al.* 1992). So, it is important to know a plant species' limiting factor in order to evaluate potential environmental impact. If a transgene has the ability to alter some limiting factor for wild plants, release of the gene is more of a concern.

There are several traits that have been transformed into crop plants in recent years. These improved crops will undoubtedly change agriculture, and improve the lives of many people. Though the risks of developing herbicide resistant crops are minor compared with the potential benefits, there is still concern existing over the possible escape of these genes into the environment. This idea is justified, and environmental impact of escaped genes should be assessed. The evolution of new herbicide resistant weeds, or the crop itself becoming a weed is possible, but unlikely if breeders, molecular biologists, agronomists, and weed scientists respect the new technology that is available to them.

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Chapter 2

Competitiveness of Annual Weeds in Herbicide Resistant Sugarbeet

Abstract

With the recent introduction of sugarbeet modified to express resistance to glyphosate or to glufosinate, growers will have a new option for weed control. Unlike conventional sugarbeet herbicides, glyphosate or glufosinate can control weeds that exceed 5 cm in height. Research was conducted in 1998 and 1999 to determine when weeds became competitive in herbicide resistant sugarbeet. The research consisted of six trials located at three sites in both 1998 and 1999. Glyphosate was applied POST at 0.63 kg ae/ha to weeds less then 10 cm in height and at 0.84 kg ae/ha to weeds greater then 10 cm in height. Similarly, glufosinate was applied POST at 0.29 or 0.40 kg ai/ha to weeds less then 10 cm in height and 0.40 kg/ha to weeds greater then 10 cm in height. The dominant weed species at each site were *Amaranthus retroflexus* and *Chenopodium album*. To evaluate when weeds become competitive herbicide was applied to the appropriate sugarbeet cultivar when weeds attained an average of 2.5, 5, 10, 20, or 30 cm in height. Plots were then maintained weed-free for the duration of the growing season by additional herbicide applications. To evaluate the length of time weed control must be maintained in sugarbeet, either herbicide was applied to 2.5 cm weeds and then weed-free conditions were maintained until the crop reached the four to five leaf pair growth stage, or for two, four, or six weeks after this growth stage. Sugarbeet yield and weed control data was then used to establish a critical weed control period in sugarbeet.

Sugarbeet yield was not reduced in 1998 or 1999 by weeds that emerged with sugarbeet and grew to 10 cm or greater in height prior to herbicide application, when compared with a weed-free control. This suggests that weed removal did not need to commence until five weeks after planting. In 1998 sugarbeet yield decreased when weed-free conditions were maintained only until the crop reached the fourth to fifth leaf pair stage, five weeks after planting. In contrast, weeds emerging after the fourth to fifth leaf pair stage of the crop, five to six weeks after planting did not reduce yield in 1999. The critical period for weed control in sugarbeet was five to seven weeks after planting.

Introduction

In 1965 weed competition caused an estimated 8% loss in the potential value of the sugarbeet crop in the United States (Schweizer 1981). From 1975-1979 weeds caused an estimated 10% yield loss in sugarbeet which resulted in an approximately $89 million loss (Schweizer and Dexter 1987). Current estimates of economic loss in sugarbeet from weeds totaled $60 million even when best management practices were implemented (Morishita and Downard 1995).

Sugarbeet root yield is reduced when low weed densities are allowed to remain in the crop for the duration of the season (Table 1). Weed competition decreased sugarbeet yield by affecting the diameter of the root, but did not affect root length (Brimhall *et al.* 1965). Decreased root yield resulted in the loss of recoverable sucrose per hectare, but had no affect on percent sucrose or purity of brei (Brimhall *et al.* 1965, Zimdahl and Fertig 1967, Schweizer and Bridge 1982).

Weeds compete with crops for nutrients, water, and light (Kropff 1988, Schweizer and May 1993). If water and nutrients are plentiful competition for light is the main factor in sugarbeet yield loss due to weeds (Brimhall *et al.* 1965, Dawson 1965, Schweizer and Bridge 1982). Weeds may also become problematic in sugarbeet by contributing to increased crop disease and interfering with pesticide application or harvest.

Weeds can compete with sugarbeet for a period of time before yield loss occurs. The period of weed competition that a crop can tolerate is influenced by weed species, weed density, relative time of weed emergence, crop vigor, and the availability of resources (Zimdahl and Fertig 1967, Dawson 1970, Schweizer 1981, Wicks and Wilson 1983, Kropff 1988). Weeds that emerge early in relation to crop emergence have the most potential to cause yield loss (Dawson 1965, Weatherspoon and Schweizer 1969, Wicks and Wilson 1983, Kropff 1988). Weeds are most competitive if they emerge within eight weeks after planting (Wicks and Wilson 1983, Wilson 1992) or within four weeks after the crop reaches two-leaf stage (Wicks and Wilson 1983, Schweizer and Dexter 1987, Schweizer and May 1993). Studies by Dawson (1965) showed that maximum yield was achieved when weed-free conditions were maintained for eight to 12 weeks after planting, or five to nine weeks after crop emergence. When light was the only limiting resource the sugarbeet crop tolerated weeds for four to eight weeks after emergence (Brimhall *et al.* 1965, Scott *et al.* 1979, Schweizer and May 1993). The ability of sugarbeet to compete with late emerging weeds is diminished if the crop is not at normal vigor or full stand (Dawson 1974, Schweizer and Dexter 1987).

The critical period is the time during which the presence of weeds reduces crop yield (Figure 1). Weed control methods should be employed before yield loss occurs, and then should continue until the crop can compete with newly emerging weeds.

Literature suggests that the critical period for sugarbeet is approximately four weeks in length, when the crop is from the four to the 12-leaf stage in development (Dawson 1974, Scott *et al.* 1979, Van Heemst 1985, Schweizer and May 1993).

In traditional sugarbeet production systems, timing of weed control is restricted by postemergence herbicides which control weeds less then 2.5 cm in height, and the availability of hand-labor (Schweizer and May 1993, Thorsness et al. 1999). With the recent introduction of sugarbeet modified to express resistance to glyphosate or to glufosinate, growers will have the ability to effectively remove weeds that are 8 cm or greater in height (Dexter et al. 1999, Guza et al. 1999, Thorsness et al. 1999). Excellent control of annual weeds is obtained with two to three sequential applications of glyphosate or glufosinate starting when sugarbeet is in the two or four leaf stage (Mesbah and Miller 1999). The ability to control large weeds and provide consistent results will allow these herbicides to be applied at multiple times to optimize weed control and sugarbeet yield. The purpose of this research was to employ the advantages associated with herbicide resistant sugarbeet to determine when weeds were competitive in sugarbeet. This information could then be used to plan an effective weed management program in herbicide resistant sugarbeet.

Materials and Methods

Research was conducted at three sites in Michigan in 1998 and 1999 in cooperation with Michigan and Monitor Sugar Companies (Table 2). Each of the locations consisted of one glyphosate resistant sugarbeet study and one glufosinate resistant sugarbeet study. The first site was established at the Michigan State University Saginaw Valley Bean and Beet Research Farm in Saginaw County. Michigan Sugar's sites were located in a grower's fields in Saginaw County, while Monitor Sugar's sites were located in Bay County. Each study at each site was arranged as a randomized complete block design with four replications. The sugarbeet varieties used in all studies were Betaseed '891LL' and Hillshog Monotty 'RH3RR'.

In both 1998 and 1999 glyphosate was applied at 0.63 kg ae/ha when weeds were less then 10 cm in height, and 0.84 kg/ha when weeds were 10 cm or greater in height at the time of the first herbicide application. In 1998 glufosinate was applied at 0.29 kg ai/ha to weeds less then 10 cm in height, and 0.40 kg/ha when weeds were 10 cm or greater in height. Glufosinate was applied to all treatments at 0.40 kg/ha in 1999 because of inconsistent weed control from 0.29 kg/ha in 1998, and to recognize recommended rates. Ammonium sulfate at 2.8 kg/ha was included in each herbicide application.

Herbicides were applied postemergence to the respective transgenic sugarbeet varieties with a tractor-mounted compressed air sprayer, when weeds were 2.5, 5, 10, 20, or 30 cm in height (Table 3). Plots were then hand-weeded when necessary four to seven days after herbicide application, and kept weed-free with glyphosate and glufosinate for the remainder of the growing season. These treatments determined the length of time that sugarbeet could tolerate weeds. In other plots glyphosate and glufosinate were applied when weeds reached 2.5 cm in height, and treatments were maintained weed-free with the use of additional herbicide applications until the crop reached either the four or five leaf pair (8 or 10 leaf) stage (Table 3). The total amount of glyphosate and glufosinate applied in any treatment did not exceed the maximum seasonal rates proposed on the herbicide label of 3.36 and 1.2 kg/ha respectively (J. Kauffman, Monsanto, personal communication, August 1998 and K. Thorsness, AgroEvo, personal communication, February 1999). After these time periods weeds were allowed to infest the sugarbeet. Together these treatments determined the crop stage at which weeds no longer needed to be controlled. These weed-free periods determined the critical period for weed control in sugarbeet. Two additional treatments were also included to evaluate the effect of two versus three applications of glyphosate or glufosinate during the same four-week period.

The number of emerged weeds prior to the first application of glyphosate and glufosinate was recorded by counting seedlings in a 20 cm by 69 cm quadrant over the row (Table 4). A flag was placed in the corner of each quadrant in the untreated control plots. Weed biomass in each plot was estimated in August by harvesting above ground weed growth in a 20 cm band placed over the sugarbeet row for the entire length of the plot with the exception of the untreated control. Visual percent weed control was also recorded at this time. Weeds were collected from the untreated control in the previously marked quadrant only. All harvested weed biomass was dried and weights recorded. In 1998 both the Michigan and Monitor Sugar Co. locations were machine harvested for root yield October 5 through October 9. The third site at the Bean and Beet Research Farm was not harvested in 1998 due to stand loss from seedling disease. In 1999 sugarbeet was harvested from October 5 through October 15. The glyphosate resistant sugarbeet at the Monitor location was not harvested because of inadequate stand due to poor crop emergence. In both years all sugarbeet samples were analyzed for sugar content and clear juice purity by Michigan Sugar Company (Michigan Sugar, Carrollton, MI 48724).

All data was subjected to analysis of variance using the general linear means procedure in SAS (SAS Institute, Cary, NC 27513). Mean separation was performed using Fisher's Least Significant Difference (LSD) at the 0.05 level. An F-max, Hartley's, test was performed to determine if sites could be combined (Kirk 1982). Data across sites could be combined; however, data across years could not be combined due to year by treatment interactions. Treatments evaluating the length of time weeds could remain in the crop and the crop stage to which weed-free periods must be maintained were also subjected to separate analysis of variance. The adjusted means were then graphed. SAS was used to generate coefficients for orthogonal polynomials for testing the order of trends associated with these graphs; however not enough data points were present for this analysis. Regression of weed density, weed biomass in the untreated plots, and sugarbeet root yield was performed.

Results and Discussion

Much of the Michigan sugarbeet producing region endured drought in 1998 with many growers experiencing inconsistent crop emergence, slow crop growth, and slow canopy development. Crop emergence and initial growth in our studies was rapid due to warm temperatures and good soil moisture at planting at all sites in 1998. Sugarbeet growth was later slowed due to a lack of precipitation (Table 3). In contrast the 1999 season received adequate rainfall and sugarbeet growth through June and July was rapid. Initial growth in May was slower in 1999 compared with 1998 due to a short period of cool weather. The dominant weed species present at all sites in both years were *Amaranthus retroflexus* and *Chenopodium album*.

The presence of weeds did not affect the sugar content or purity in any of the studies. Lower recoverable sucrose was a direct result of lower sugarbeet root yield. Sugarbeet root yield was lower when weed density or weed biomass is higher.

Regression of sugarbeet root yield and weed density was represented by an exponential curve, which can be linearized with a logarithmic transformation (Figure 2a). When weed densities are low a linear regression may be used (Cousens 1991); however, the influence of weed density on yield loss diminishes at higher weed populations due to a saturating effect (Dawson 1970). The ability to predict yield reductions in sugarbeet using linear regression diminished when weed densities exceed 24 plants per 30 m of row at harvest (Schweizer 1981).

Weed density was a better predictor of yield loss than weed biomass (Figures 2a and 2b). Similar to results by Wicks and Wilson (1983) an increase in weed biomass accounted for 47% of the variability in sugarbeet yield (Figure 2b).

In 1998 weeds reduced sugarbeet root yield in the untreated plots by more then 70% compared to yield where weeds were removed at 2.5 cm (Figures 3a and 3b). However, root yield was not reduced in either glyphosate or glufosinate resistant sugarbeet when weeds were allowed to reach 20 cm in height, six weeks after planting, prior to herbicide application. Although root yield was not reduced, sugarbeet was visually stunted and hand-labor was required to remove these 20 cm weeds. Similar results were reported the same year in North Dakota where crop stunting and yield loss were observed when weeds were not removed until three to four weeks after the sugarbeet cotyledon stage (Dexter *et al.* 1999).

In 1999 root yield was not reduced in either glyphosate or glufosinate resistant sugarbeet when weeds were allowed to reach 30 cm in height, seven weeks after planting, prior to herbicide application (Figures 4a and 4b). Sugarbeet yield in untreated plots reduced by 35% compared with 'weed removal at 2.5 cm' plots. Sugarbeet growth in

1999 was not visually stunted in any treatment and hand-labor was required only to remove weeds that exceeded 20 cm in height. Absence of visual stunting in 1999 may have been due to increased soil moisture and differences in weed densities. Weed densities at sites harvested in 1999 were 67% lower then in 1998 (Table 4). In non-irrigated sugarbeet, yield loss due to weed competition can differ from year to year. Research in New York showed 44% yield loss in 1964 compared with 62% yield loss in 1965 (Zimdahl and Fertig 1967). In studies conducted by Hubbell (1997) in Michigan from 1992 through 1995 the same density of *Amaranthus retroflexus* reduced sugarbeet yield from eight to 65% depending on the year.

Sugarbeet yield in 1998 was also reduced in treatments where the crop remained weed-free until the eighth leaf stage (five weeks after planting) and then weeds were allowed to grow (Figures 5a and 5b). Yield was greater where weed control was extended an additional two weeks, until seven weeks after planting when the crop reached the 12-leaf stage. Weed biomass was 99% less when weed control was maintained until seven weeks after planting (12-leaf crop stage).

Sugarbeet yield in 1999 was not reduced when the crop remained weed-free until the four-leaf crop stage, four weeks after planting, and then weeds were allowed to grow (Figures 6a and 6b). Weed biomass was 99% less if weed control was maintained for five weeks after planting (eight-leaf crop stage).

The beginning of the critical weed control period was arbitrarily set at a time when no relative yield loss or crop stunting was observed, and weeds could be removed with glyphosate or glufosinate. We set the end of the critical weed control period at the time when there was no relative yield loss and weed biomass was reduced by 99%.

These studies suggest that under adverse growing conditions (high weed densities and/or low soil moisture such as in 1998) weed control must begin prior to weeds reaching 10 cm in height, 5 weeks after planting (sugarbeet was at the eight-leaf stage), and then must be maintained until the crop reaches the 12-leaf stage, 7 weeks after planting (Figures 7a and 7b). Under favorable growing conditions such as in 1999, weed control must begin prior to weeds reaching 20 cm in height, 6 weeks after planting, and then must be maintained until the crop reaches the eight-leaf stage, 5 weeks after planting (Figures 8a and 8b). It is important to note that all weeds that emerged prior to the 12-leaf crop stage in 1998 and the eight-leaf crop stage in 1999 were removed with herbicides. This would include any small weeds that were emerging but not yet visible. Weed-free conditions extended for a short period beyond the final herbicide application.

There was no difference in sugarbeet yields if weeds were initially removed at a height of 2.5 cm with glyphosate or glufosinate and then retreated 14 and 28 days later compared to plots retreated only 28 days later (Tables 5 and 6). This suggests that after the initial herbicide application newly emerging weeds were not competitive for 28 days after the first herbicide application. Therefore subsequent herbicide applications could have been delayed for four weeks after the first herbicide application in our research.

Conclusions

The critical weed control period for sugarbeet was from 5 to 7 weeks after planting in 1998 and at 5 weeks after planting in 1999. Under favorable growing conditions and lower weed densities sugarbeet was able to compete with weeds more effectively. Our studies support previous research that suggested weed control must be maintained for four to nine weeks after crop emergence (Dawson 1965, Weatherspoon and Schweizer 1969, Wicks and Wilson 1983, Van Heemst 1985, Schweizer and Dexter 1987, Schweizer and May 1993). Herbicide applications should be made so that all weeds that emerge prior to the end of the critical weed control period are controlled. Weed control in sugarbeet will require at least two applications of glyphosate or glufosinate (Figure 9). Studies in 1999 suggested that one properly timed herbicide application at the eight-leaf crop stage could have maintained sugarbeet yield and quality. This is optimistic considering the difficulty of achieving weed control with a herbicide that does not have soil activity, the variability of environmental conditions, and the numerous factors that can affect sugarbeet stand and crop development.

Conventional sugarbeet herbicides can cause crop injury and must be applied when weeds are less then 2.5 cm in height. Application of glyphosate or glufosinate to resistant sugarbeet could injure the crop less, give greater weed control, and 'save time' by allowing multiple, cost effective herbicide applications to be made. Since sugarbeet tolerated the presence of weeds exceeding 10 to 20 cm in height, the first herbicide application was restricted only by the ability to consistently remove the weeds that are emerged. A grower could make a second application of glyphosate or glufosinate two to four weeks later to attempt to remove newly emerging weeds. Sugarbeet that is larger then the eight to 12-leaf stage would probably grow quickly, providing a canopy that would restrict the competitive ability of weeds. A third herbicide application could be made without crop injury or yield loss if weed control was not satisfactory.

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Table 1 – Minimum weed densities that are reported to be competitive and reduce sugarbeet root yield and recoverable sucrose.

Weed Species	Weed Density	Irrigation	Author	Year
Amaranthus retroflexus & Setaria viridis	1 per 8 sugarbeet	Yes	Brimhall	1965
Kochia scoparia	4 per 30m row	Yes	Weatherspoon & Schweizer	1971
Amaranthus retroflexus Chenopodium album & Kochia scoparia	3-6 per 30m row	Yes	Schweizer	1981
Chenopodium album	4-6 per 30m row	Yes	Schweizer	1983
Amaranthus retroflexus & Chenopodium album	12 per 30m row	No	Hubbell	1997

Table 2 – Soil series, type, organic matter, and planting dates for glufosinate and glyphosate resistant sugarbeet at each location in 1998 and 1999.

--------Site--------		-------------Soil-------------			-------------Planting-------------			
Location	Year	Series	Type	OM[a]	Gluf[b]	Glyt[c]	Row Width	Plant Spacing
				(%)	(date)	(date)	(cm)	(cm)
Michigan State Univ.	1998	Zilwaukee	Silty-clay loam	<3	4/27[d]	5/11[d]	71	11
Michigan Sugar Co.	1998	Sloan-Ceresco	Silt loam	>3	4/28	5/6	71	11
Monitor Sugar Co.	1998	Londo	Loam	<3	5/7	5/7	76	15[e]
Michigan State Univ.	1999	Zilwaukee Mistequay	Silty-clay	>3	4/28	4/28	71	15[e]
Michigan Sugar Co.	1999	Sloan	Silt loam	>3	4/30	4/30	71	15[e]
Monitor Sugar Co.	1999	Londo	Loam	<3	5/4	5/4[d]	76	15[e]

[a] OM – organic matter
[b] Gluf – glufosinate resistant sugarbeet
[c] Glyt – glyphosate resistant sugarbeet
[d] Trial could not be harvested due to stand loss.
[e] Trials were thinned from a 6 cm spacing.

Table 3 – Growth stage of sugarbeet[a] and weed height[a] at various weeks after planting in 1998 and 1999.

	1998		1999	
weeks after planting	crop growth stage	weed height (cm)	crop growth stage	weed height (cm)
1	emergence	emergence	emergence	emergence
2	coty - 2 lf	1	coty	1
3	4 lf	2.5	2 lf	2.5
4	6 lf	5	4 lf	5
5	8 lf	10	6 - 10 lf	10
6	10 lf	20	8 - 12 lf	20
7	12 lf		12 - 14 lf	30
8	12 - 14 lf		14 - 18 lf	
9	14 lf		row closure	

[a] Average growth of weeds and crop for three sites each year.

Table 4 – Number[a] of common lambsquarters, redroot pigweed, and mixed species[b] per 30 m of row in glyphosate or glufosinate resistant sugarbeet for the Michigan State University, Michigan Sugar Co., and Monitor Sugar Co. sites in 1998 and 1999.

Site	Year	Glyt[c]			Gluf[c]		
		Colq	Rrpw	Total[b]	Colq	Rrpw	Total[b]
Michigan State University	1998	11	8	25	11	11	74
Michigan Sugar Company	1998	62	184	256	56	262	329
Monitor Sugar Company	1998	7	23	51	18	56	89
Michigan State University	1999	11	62	73	29	44	80
Michigan Sugar Company	1999	29	7	36	56	18	87
Monitor Sugar Company	1999	7	1	24	5	13	21

[a] Counts are from untreated plots when weeds were an average height of 2.5 cm.

[b] Total species varied by site and included common lambsquarters, redroot pigweed, velvetleaf, Pennsylvania smartweed, eastern black nightshade, and annual grass.

[c] Glyt – glyphosate, Gluf – glufosinate, Colq – common lambsquarters, Rrpw – redroot pigweed

Table 5 – Glyphosate resistant sugarbeet root and sugar yield in 1998 and 1999, combined over two locations.

Treatments	-----1998 Yield----- Tonnage (Mg/ha)	Sucrose (kg/ha)[a]	-----1999 Yield----- Tonnage (Mg/ha)	Sucrose (kg/ha)[b]
Untreated	13.6	1330	47.0	5700
Remove 2.5 cm weeds and maintain weed-free	48.2	4820	67.8	8030
Remove 5 cm weeds and maintain weed-free	43.4	4310	70.6	8490
Remove 10 cm weeds and maintain weed-free	45.3	4370	66.2	7900
Remove 20 cm weeds and maintain weed-free	44.7	4330	70.3	8480
Remove 30 cm weeds and maintain weed-free	-	-	65.3	7890
Remove 2.5 cm weeds	-	-	69.1	8280
Maintain weed-free until 4 leaf pair	38.6	3870	68.4	8190
Maintain weed-free until 14 days after 4 leaf pair	53.1	5220	69.2	8300
Maintain weed-free until 28 days after 4 leaf pair	46.1	4590	69.8	8310
Maintain weed-free until 42 days after 4 leaf pair	50.6	5130	-	-
Remove 2.5 cm weeds then retreat 28 days later	47.0	4620	67.6	8100
Remove 2.5 cm weeds then retreat 14 and 28 days later	47.2	4690	67.5	8100
Mean	43.3	4240	66.6	7970
P-value	0.0001	0.0001	0.0001	0.0001
CV %	18.3	20.0	8.5	9.0
$LSD_{0.05}$	8.2	879	5.6	717

[a] Average sugar concentration was 15.1%

[b] Average sugar concentration was 17.4%

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Table 6 – Glufosinate resistant sugarbeet root and sugar yield in 1998 and 1999, combined over two and three locations respectively.

Treatments	------1998 Yield------		------1999 Yield------	
	Tonnage	Sucrose	Tonnage	Sucrose
	(Mg/ha)	(kg/ha)[a]	(Mg/ha)	(kg/ha)[b]
Untreated	10.9	1320	42.6	5100
Remove 2.5 cm weeds and maintain weed-free	46.6	5430	58.3	6310
Remove 5 cm weeds and maintain weed-free	46.3	5510	63.7	7120
Remove 10 cm weeds and maintain weed-free	47.3	5620	60.7	6790
Remove 20 cm weeds and maintain weed-free	46.7	5610	60.2	6780
Remove 30 cm weeds and maintain weed-free	-	-	59.2	6600
Remove 2.5 cm weeds	-	-	57.7	6050
Maintain weed-free until 4 leaf pair	36.5	4800	61.6	6820
Maintain weed-free until 14 days after 4 leaf pair	45.7	5570	61.4	6670
Maintain weed-free until 28 days after 4 leaf pair	45.7	5570	59.6	6540
Maintain weed-free until 42 days after 4 leaf pair	46.8	5800	-	-
Remove 2.5 cm weeds then retreat 28 days later	45.8	5300	59.8	6690
Remove 2.5 cm weeds then retreat 14 and 28 days later	45.0	5140	62.4	6750
Mean	41.8	4950	59.1	6519.8
P-value	0.0001	0.0001	0.0001	0.0001
CV %	15	15.6	9.5	9.6
LSD	6.7	828	4.6	508

[a] Average sugar concentration was 16.9%

[b] Average sugar concentration was 18.2%

Figure 1 – Illustration of an average critical weed control period for sugarbeet (sources: Dawson 1965, Weatherspoon and Schweizer 1969, Wicks and Wilson 1983, Van Heemst 1985, Schweizer and May 1993).

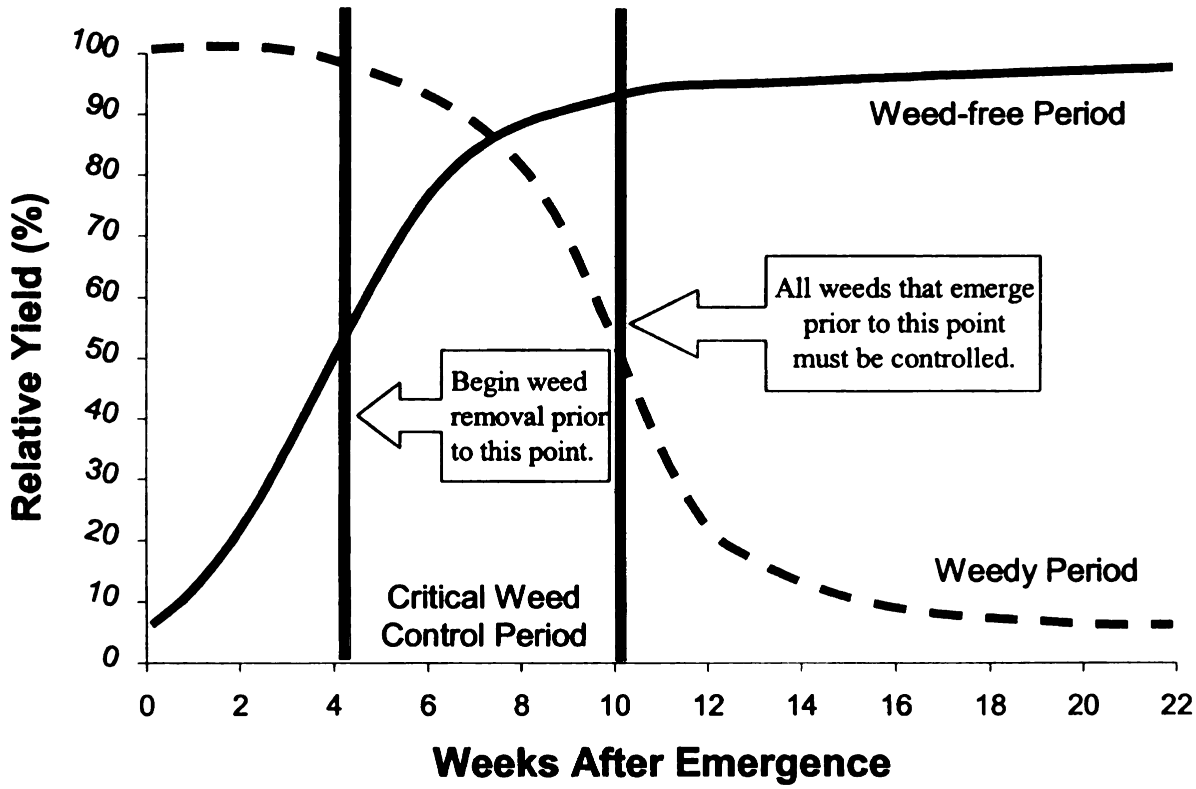
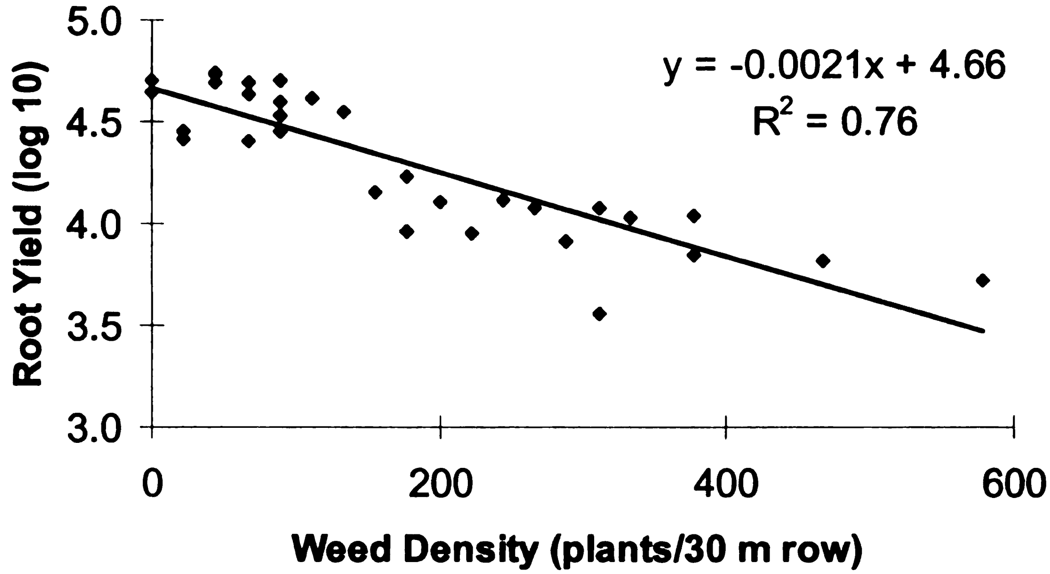


Figure 2 – Influence of a) weed density and b) weed biomass on the root yield of sugarbeet from nine studies in 1998 and 1999.

a)



b)

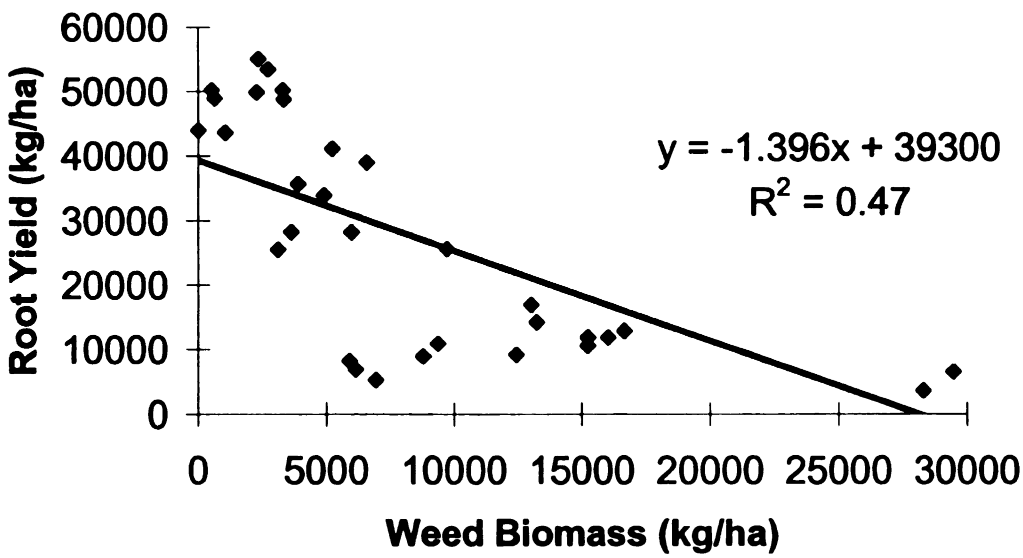
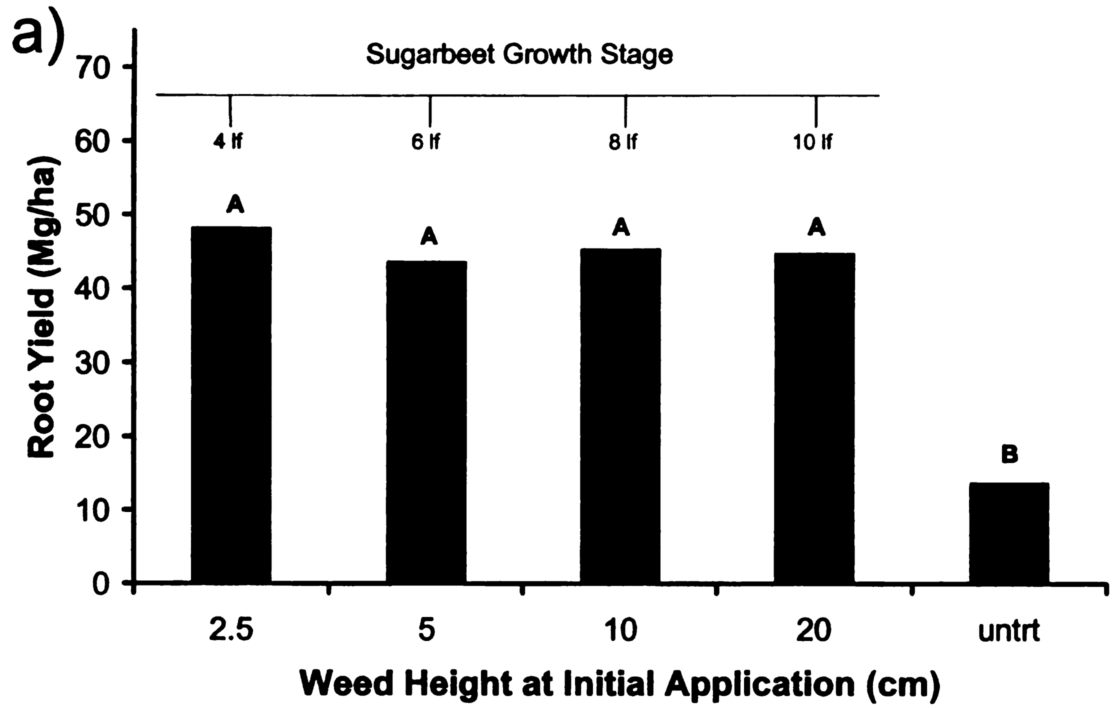


Figure 3 – Root yields for a) glyphosate resistant sugarbeet averaged over two sites, and b) glufosinate resistant sugarbeet averaged over two sites, where weeds were removed at various heights and weed-free conditions were then maintained by the herbicide in 1998.



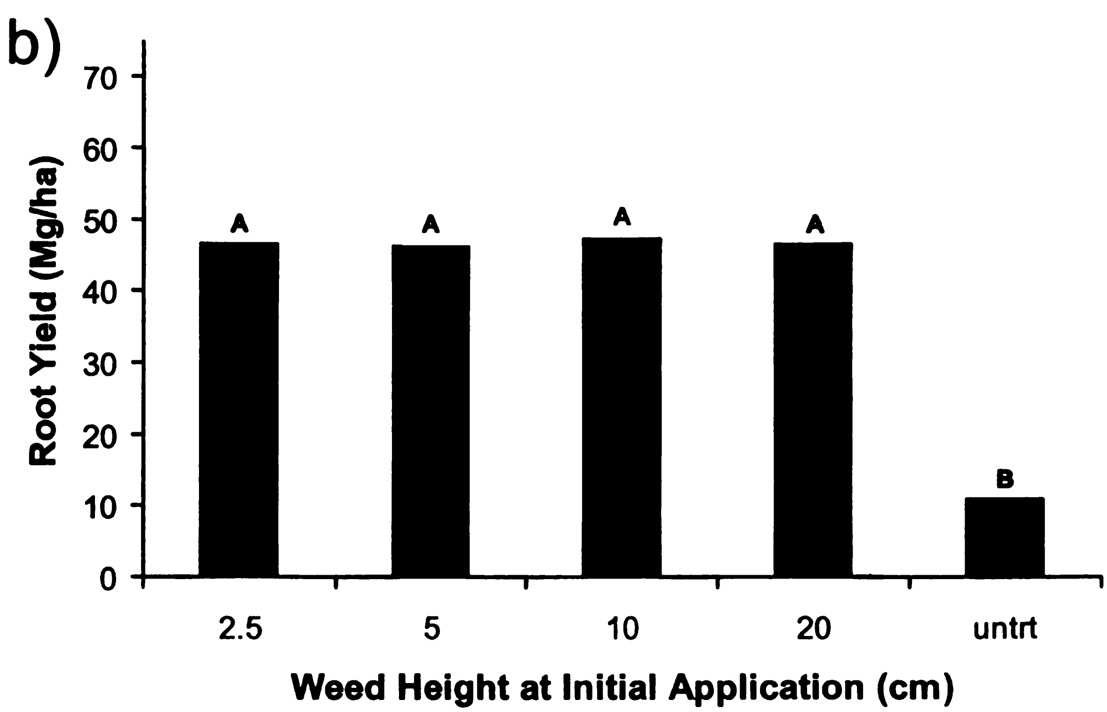


Figure 4 – Root yields for a) glyphosate resistant sugarbeet averaged over two sites, and b) glufosinate resistant sugarbeet averaged over three sites, where weeds were removed at various heights and weed-free conditions were maintained by the herbicide in 1999.

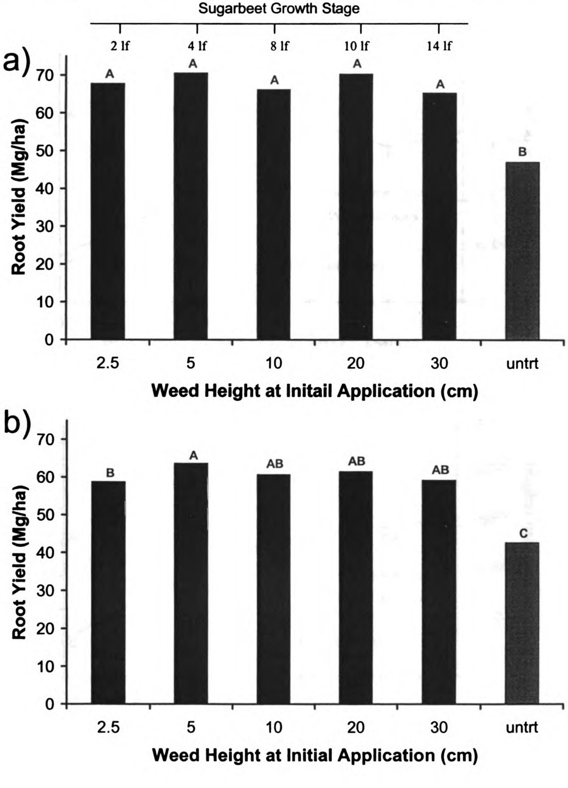
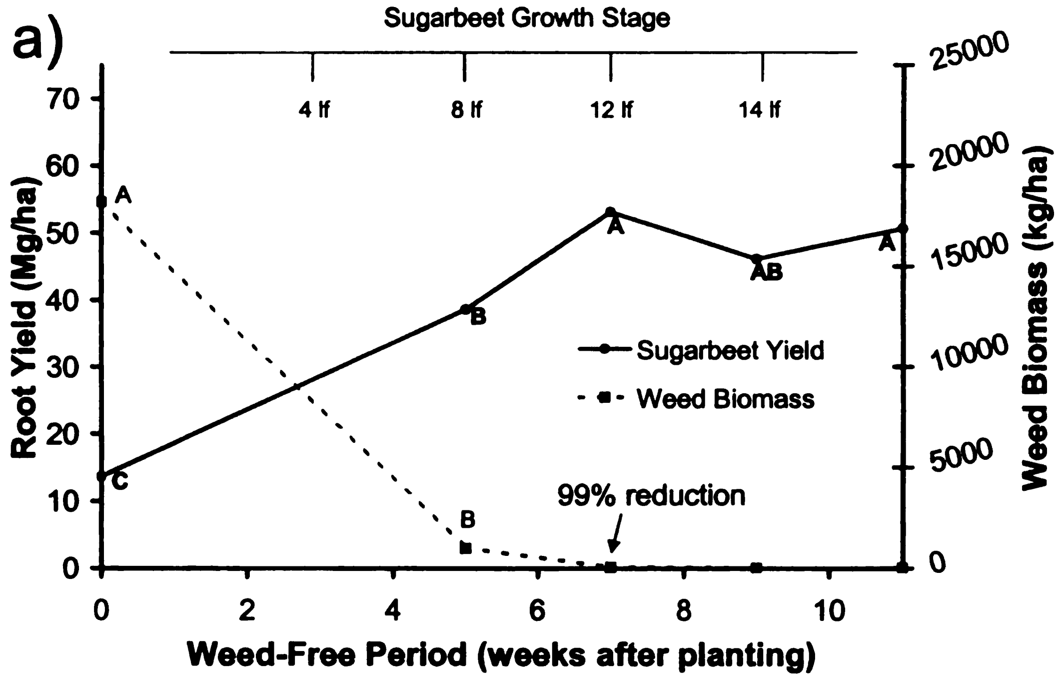


Figure 5 – Root yield of a) glyphosate and b) glufosinate resistant sugarbeet and weed biomass in 1998 where weed control was maintained for progressively longer periods after crop emergence (root yield and weed biomass are not comparable).

a)



b)

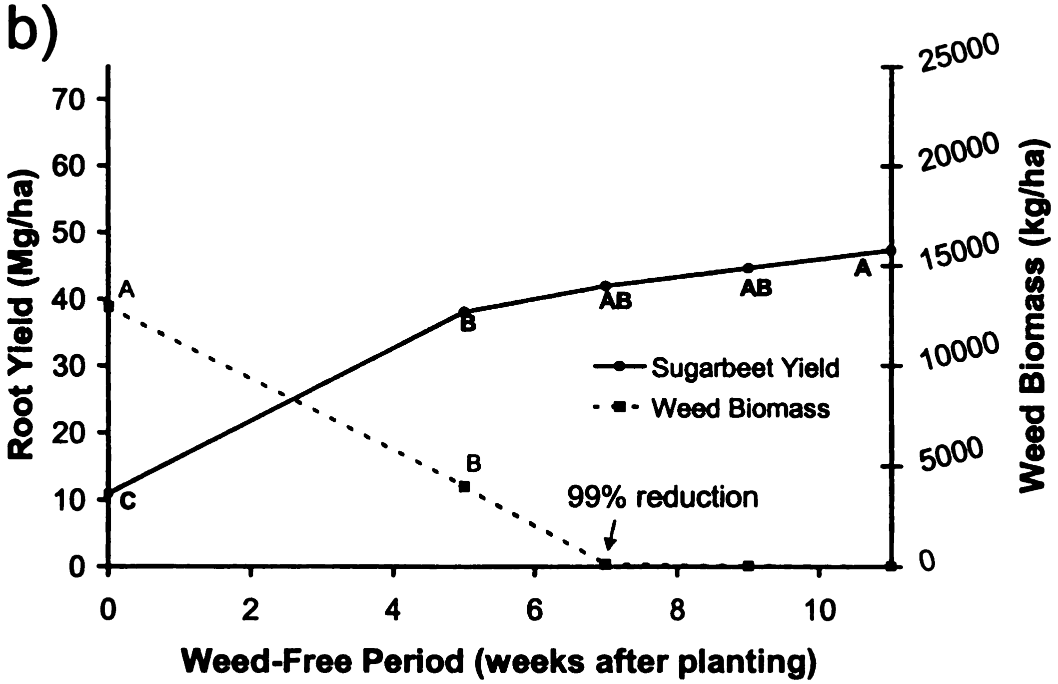


Figure 6 – Root yield of a) glyphosate and b) glufosinate resistant sugarbeet and weed biomass in 1999 where weed control was maintained for progressively longer periods after crop emergence (root yield and weed biomass are not comparable).

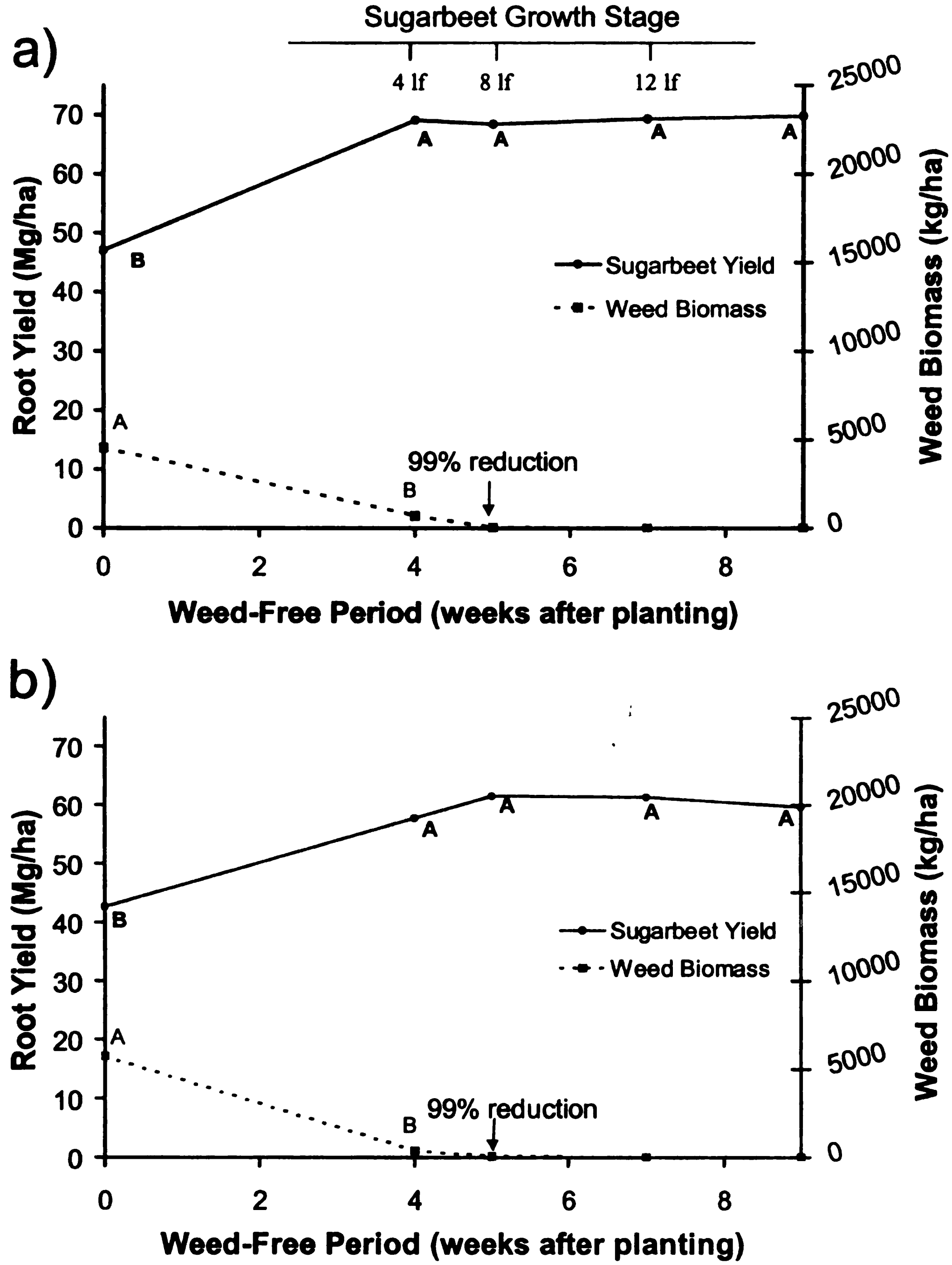


Figure 7 – Critical weed control period for a) glyphosate and b) glufosinate resistant sugarbeet in 1998.

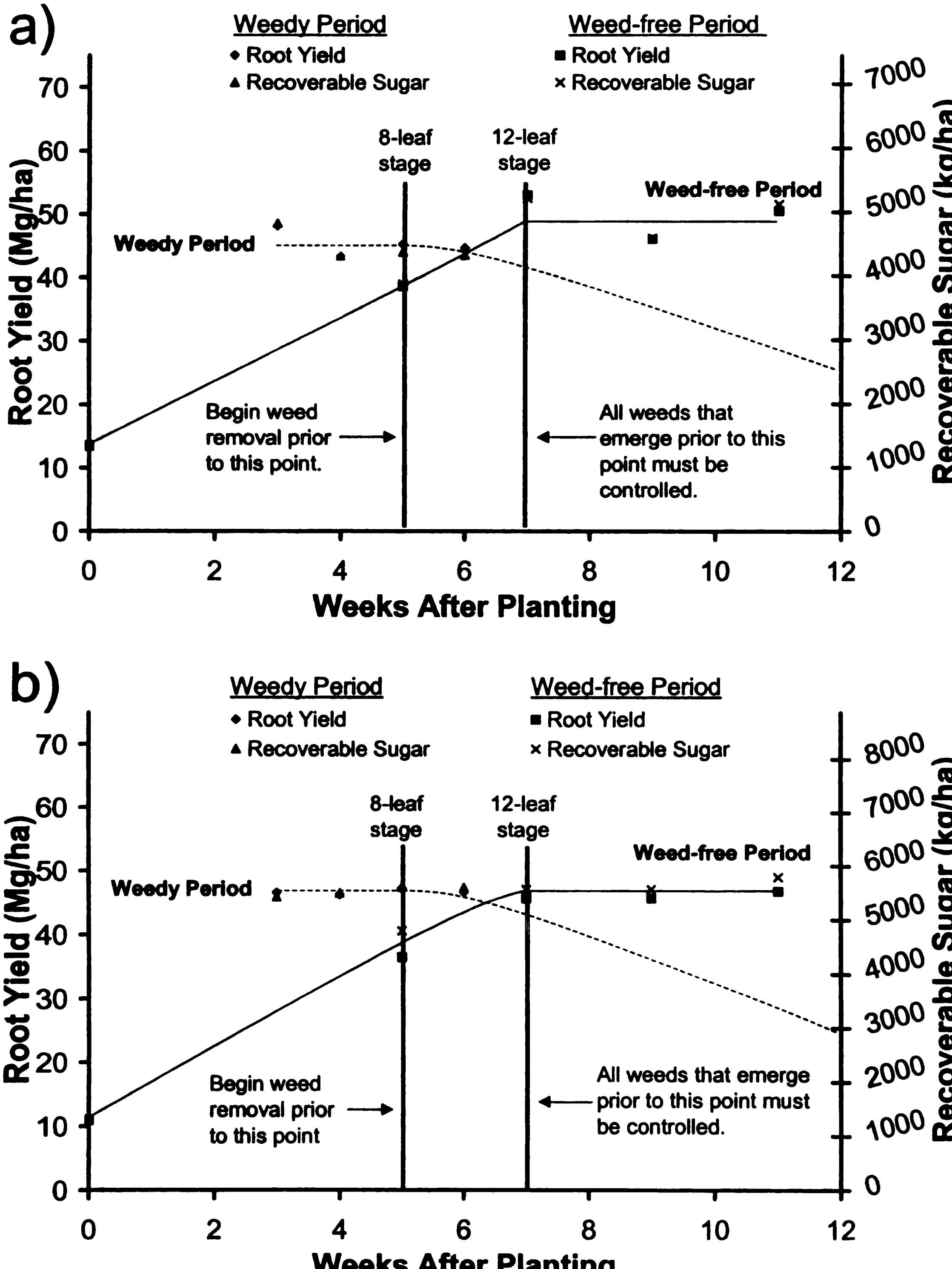
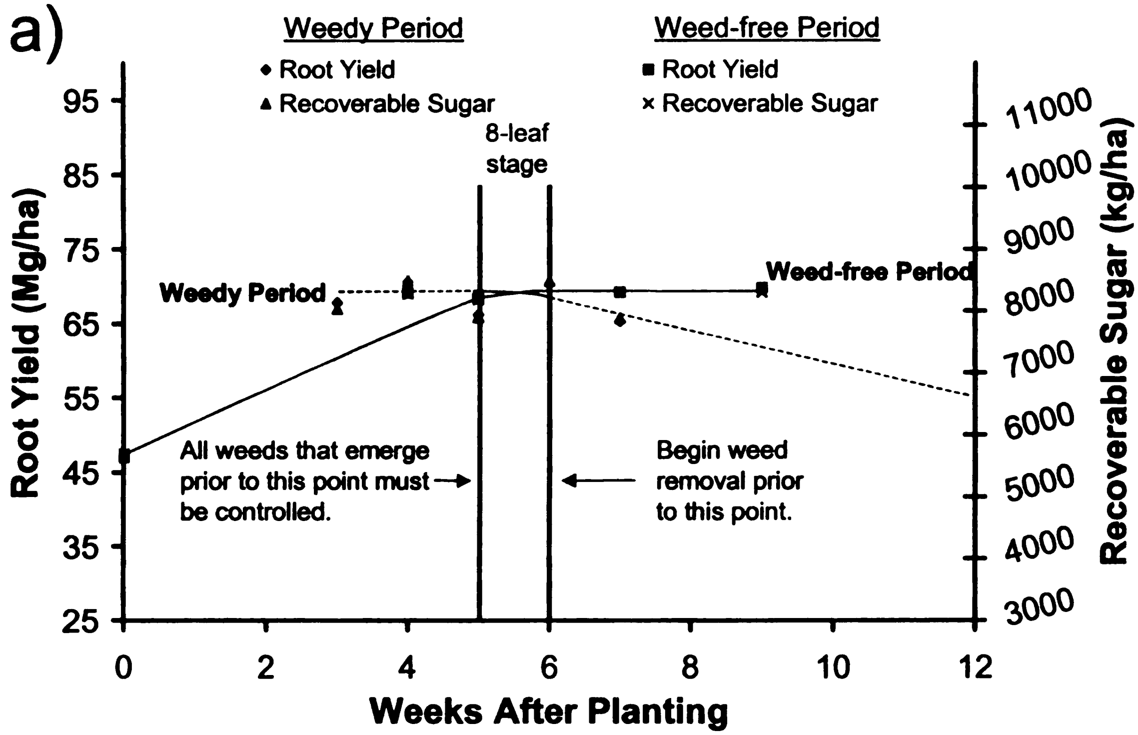


Figure 8 – Critical weed control period for a) glyphosate and b) glufosinate resistant sugarbeet in 1999.



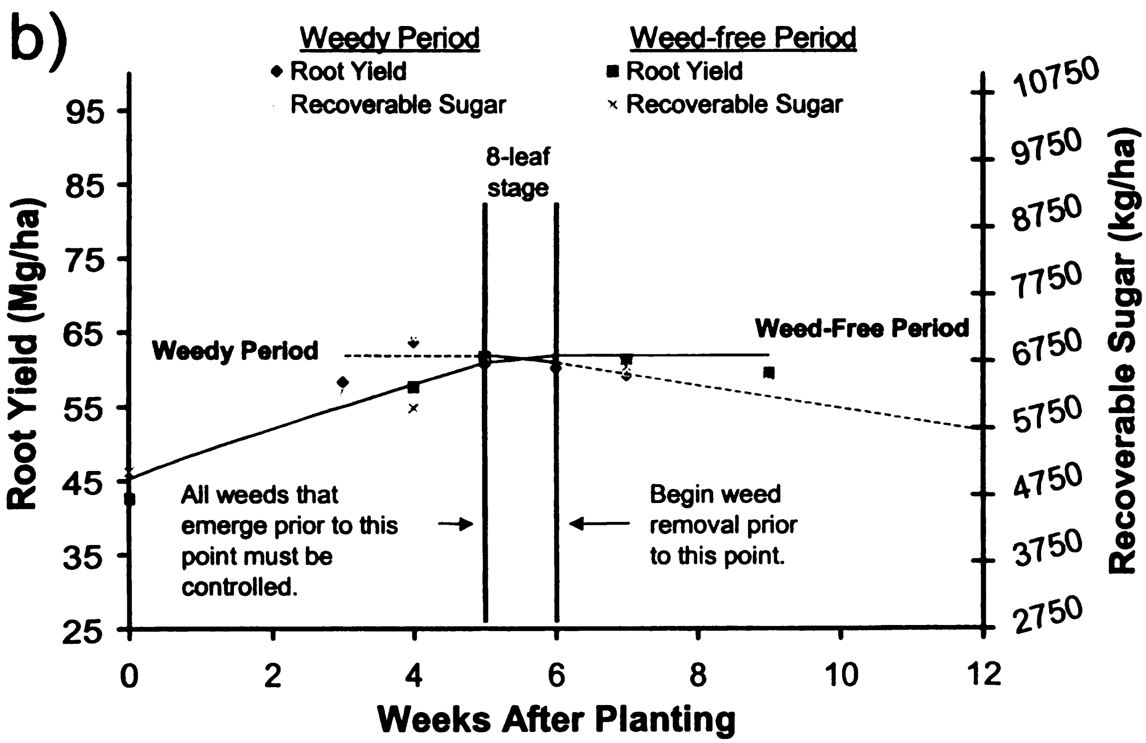
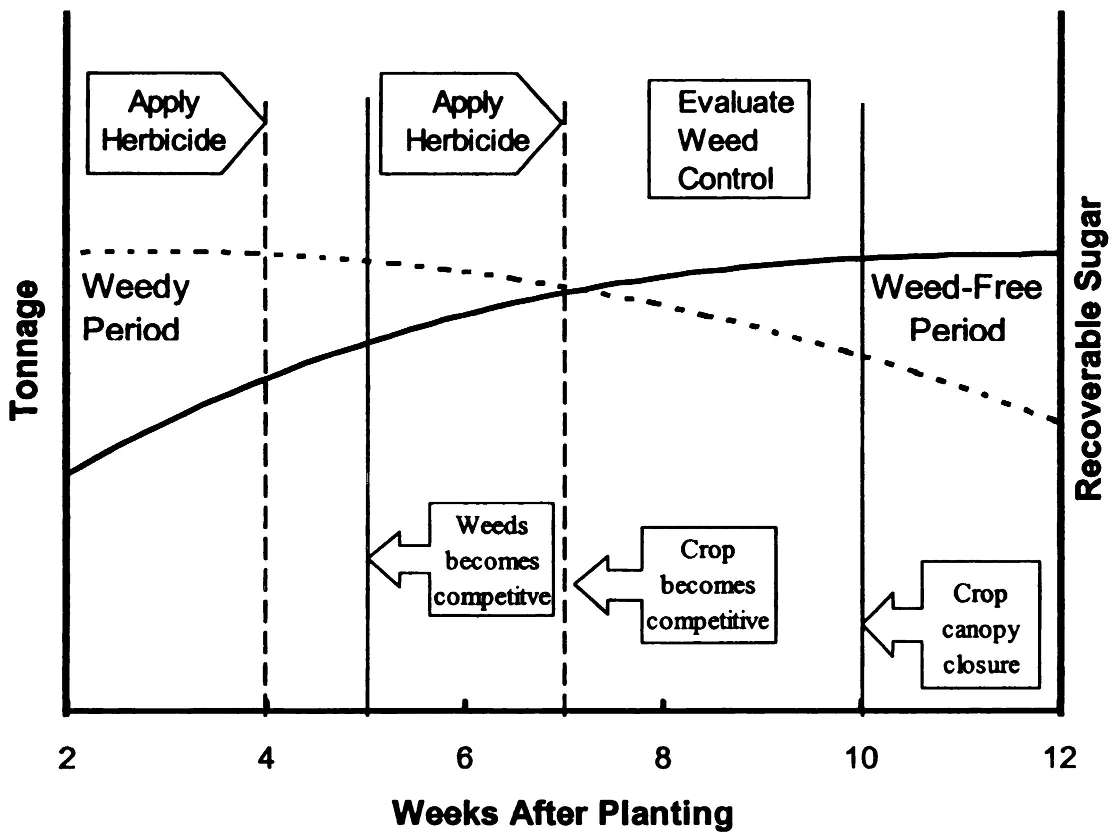


Figure 9 – Example of the timing for either glyphosate or glufosinate applications to prevent loss of root and sugar yield in sugarbeet. (The curved lines represent the effect weeds have on sugarbeet yield dependent on either the amount of time that weeds remain in the crop or the amount of time the crop remains weed-free. The dashed vertical lines represent when herbicide should be applied. The solid vertical lines represent when weeds begin to compete with sugarbeet and when the crop canopy closes.)



Chapter 3

Use of Preemergence Herbicides with Herbicide Resistant Sugarbeet

Abstract

Traditional weed management systems in sugarbeet follow a program approach. Herbicides such as cycloate, pyrazon, and ethofumesate are applied preemergence to provide residual control of annual weeds. Weeds not controlled with these 'residual' herbicides are removed using postemergence herbicides, cultivation, and hand-labor. The objective of this study was to evaluate the potential importance or effect of several PRE herbicide regimes in glufosinate and glyphosate resistant sugarbeet. Trials were conducted at three sites with both glufosinate resistant and glyphosate resistant sugarbeet in 1998 and 1999. Cycloate PPI, pyrazon PRE, ethofumesate PRE, or no PRE herbicides were applied at recommended rates followed by two or three applications of glufosinate POST at 0.29 to 0.4 kg ai/ha, or glyphosate POST at 0.63 kg ae/ha, or desmedipham and phenmedipham at 0.56 kg ai/ha plus triflusulfuron at 0.0174 kg ai/ha. Glufosinate and glyphosate were applied when weeds were two to four cm in height. Desmedipham and phenmedipham plus triflusulfuron were applied when weeds were one to two cm in height, and again with the addition of clopyralid at 0.105 kg ai/ha 7 to 14 days later. Weed control, root yield, and recoverable sugar were evaluated for each herbicide application regime.

Soil-applied preemergence herbicides delayed the necessity for the first application of glufosinate and glyphosate by three to nine days in six of 12 studies. PRE herbicides followed by glufosinate or glyphosate improved the control of common

lambsquarters or redroot pigweed at three out of 12 sites compared with POST only treatments. Common lambsquarters or redroot pigweed control increased at five out of six sites in 1999 when PRE herbicides were followed by desmedipham and phenmedipham plus triflusulfuron plus clopyralid compared with POST only treatments. Sugarbeet yield or quality did not increase when PRE herbicides were followed by either glufosinate, glyphosate, or desmedipham and phenmedipham plus triflusulfuron plus clopyralid POST compared with POST only treatments.

Introduction

The recent development of sugarbeet varieties that are resistant to either of the herbicides glyphosate or glufosinate has introduced the first major change in weed control programs for this crop in over 25 years. Nearly all of the herbicides currently used in sugarbeet production were developed in the late 1960's and have a narrow margin of selectivity. Non-optimal environmental conditions can alter herbicide phytotoxic effects, producing crop injury (Schweizer and Dexter 1987). Besides causing injury, traditional sugarbeet herbicides have the ability to control only very small weeds when applied postemergence (Wilson 1998). The precise timing required and the need for several reduced rate applications to avoid crop injury make current postemergence treatments less than ideal. Despite these limitations there has been a gradual shift towards the use of more postemergence herbicides (Griffith 1994). Unlike traditional postemergence sugarbeet herbicides, glyphosate and glufosinate do not injure the respective resistant crop cultivar and have the ability to control large weeds, making this technology the next step in the evolution of weed control programs.

Glyphosate and glufosinate have herbicidal activity on most species of plants and can be used for postemergence weed control in genetically altered, resistant crop varieties. Crops that are resistant to glyphosate are sold under the trademark Roundup Ready®, and glufosinate resistant crops are known as Liberty Link®. Each has a unique mode of action and can only be applied to the appropriate resistant variety.

The high cost of traditional sugarbeet herbicides such as desmedipham, pyrazon, and ethofumesate has led many growers to apply these products in a band over the row to reduce the amount of active ingredient (Schweizer and Dexter 1987). Weeds are only controlled within this band and cultivation between the rows controls the remaining weeds. Glyphosate and glufosinate are less expensive than traditional postemergence herbicides and could be applied as broadcast treatments. Therefor the entire field could be treated and cultivation would not be needed for weed control. Though the price of either herbicide is less, there are additional costs associated with a Roundup Ready or Liberty Link system. A technology fee would be assessed when seed is purchased (J. Kauffman, Monsanto, personal communication, August 1998). This additional cost for seed must be considered when the costs of weed control are evaluated.

Weed control in sugarbeet often follows a program approach where preemergence herbicides are applied at planting in combination with postemergence herbicides later in the season. Preemergence herbicides stay biologically active in the soil, controlling germinating weed seedlings. The pre-mixture of the postemergence herbicides phenmedipham and desmedipham controlled weeds more effectively when applied to areas previously treated with the preemergence herbicide cycloate (Dexter 1994). The greatest relative reduction in broadleaf weed density occurred when preemergence herbicides were applied at planting and followed with a postemergence herbicide treatment (Wilson 1992). The number of postemergence treatments and the need to include a preemergence herbicide to achieve the most cost-effective weed control varied according to weed density (Miller *et al.* 1997).

Neither glyphosate nor glufosinate remain active in the soil (WSSA 1994), and therefore have no residual effect on later emerging weed seedlings. Since glyphosate and glufosinate control only weeds that are emerged, preemergence herbicides would provide residual control of new weed seedlings.

The objective of this study was to evaluate weed control and yield of glyphosate or glufosinate resistant sugarbeet following either full or half of the recommended use rates of cycloate, pyrazon, ethofumesate, and mixtures thereof followed by postemergence applications of glyphosate or glufosinate. Treatments were also established to evaluate weed control when preemergence herbicides were applied as part of a traditional weed management system. We were interested in determining if preemergence herbicides would delay the first postemergence herbicide application, reduce the number of postemergence herbicide applications, give greater weed control, or affect sugarbeet yield and quality. We also were interested in evaluating the costs associated with the use of preemergence herbicides in glyphosate resistant and glufosinate resistant sugarbeet.

Materials and Methods

Research was conducted at three sites in Michigan in 1998 and 1999 in cooperation with Michigan and Monitor Sugar Companies (Table 7). Each of the locations consisted of one glyphosate resistant sugarbeet study and one glufosinate resistant sugarbeet study. The first site was established at the Michigan State University Saginaw Valley Bean and Beet Research Farm in Saginaw County. Michigan Sugar's sites were located in a grower's fields in Saginaw County, while Monitor Sugar's sites were located in Bay County. Each study at each site was arranged as a randomized complete block design with four replications. The dominant weeds at each site were redroot pigweed, *Amaranthus retroflexus*, and common lambsquarters, *Chenopodium album*.

In 1998 sugarbeet was planted in 71 cm or 76 cm wide rows with a seed spacing of 11 cm between the dates of April 28 and May 11 (Table 7). In 1999 sugarbeet was planted in 71 cm or 76 cm rows with a seed spacing of 6 cm, between the dates of April 28 and May 4. Sugarbeet was thinned to a spacing of 15 cm in 1999, approximately four weeks after planting. The glufosinate resistant sugarbeet variety, Beta 891LL, and the glyphosate resistant variety, HM RH3RR, were planted at each location. Plots were 9.1 m long and four rows (2.85 to 3.1 m) wide. Herbicides were broadcast with a tractor mounted compressed air sprayer. Cycloate was incorporated prior to planting using a Kongskilde Triple-K (Kongskilde Corp., Bowling Green, OH 43402). The preemergence herbicides pyrazon and ethofumesate were applied after planting at both full and half of the suggested use rates. The recommended use rates for cycloate are 3.36 to 5.04 kg ai/ha, pyrazon are 3.36 to 5.6 kg ai/ha, and ethofumesate are 1.68 to 2.24 kg ai/ha.

Prior to the first postemergence herbicide application, the number of weed seedlings in a 18 cm by 69 cm quadrant placed over the row was recorded. A standard postemergence treatment of desmedipham and phenmedipham at 0.56 kg ai/ha plus triflusulfuron at 0.0174 kg ai/ha was applied when weeds were 1.25 cm in height. This was followed seven to 14 days later with an application of desmedipham and phenmedipham plus triflusulfuron plus clopyralid at 0.105 kg ai/ha. Glyphosate and glufosinate were applied postemergence at 0.63 kg ae/ha and 0.29 to 0.4 kg ai/ha respectively when weeds were 2.5 cm tall (Table 8). A second postemergence application of glyphosate or glufosinate was made when weeds again reached 2.5 cm in height. Percent injury to the crop was visually rated, with values greater then zero representing severity of crop stunting. Weed control ratings were determined visually for each weed species two and four weeks after the second glyphosate and glufosinate application.

In 1998 the Michigan Sugar Co. site did not include a standard postemergence treatment. By request of the cooperator, a third application of glufosinate was made at this location to prevent weeds from going to seed. Standard postemergence treatments were not planned for the glyphosate resistant sugarbeet at the Monitor Sugar location, due to a shortage of sugarbeet seed. In 1999 two additional herbicide treatments were included to compare two versus three postemergence applications of glyphosate or glufosinate alone (Table 9).

In 1998 plots at both the Michigan Sugar Co. and Monitor Sugar Co. locations were machine harvested for yield October 5 through October 9. The third site at the Saginaw Valley Bean and Beet Research Farm was not harvested due to stand loss from disease. In 1999 sugarbeet was harvested from all locations October 5 through October 15. The glyphosate study at the Monitor Sugar location was not harvested because of inadequate stand due to poor crop emergence. In both years Michigan Sugar Company analyzed all sugarbeet samples for sugar content and purity (Michigan Sugar Co., Carrollton, MI 48724).

All data were recorded and initially subjected to analysis of variance using Pesticide Research Manager version 5 in 1998 and Agriculture Research Manager 6 in 1999 (Gylling Data Management, Brookings, SD), and means separated using Fisher's Least Significant Difference (LSD) at the 0.05 level (Appendix, Tables 16-27). Weed control data was arcsine transformed prior to further analysis. An F-max, Hartley's, test was used to determine if sites could be combined (Kirk 1982). Data could not be combined due to year by site by treatment interactions. Data from each study was again subjected to analysis of variance as a two factor randomized complete block designs using the general linear means procedure in SAS (SAS Institute, Cary, NC 27513). Pairwise comparisons were made using F-tests at the 0.05 level.

Results and Discussion

Full versus Half Rates

There was no difference in weed control when comparing full and half use rates of preemergence herbicides in 10 out of 12 studies. P-values for comparisons of each of these 10 studies ranged from 0.14 to 0.96. In the other two studies there was no biological significance to the difference between full and half rates. Weed control exceeded 97% for every treatment in the glufosinate study at the Michigan Sugar location in 1998, and the p-value for the full versus half rate comparison was greater than 0.05. In the glyphosate study at the Monitor Sugar location in 1998, replications of the half rate of ethofumesate were absent from the study, which resulted in this treatment being significantly different. We determined this to be due to human error and was not a result of a biological difference between full and half rate treatments. Weed control and yield data for all treatments can be found in the appendix. Data from treatments using full rates are therefore presented in this chapter.

Delay in Postemergence Applications

In 1998 preemergence herbicides delayed the first application of glyphosate or glufosinate by three to nine days in two out of the six trials (Table 8). This delay occurred in the glufosinate resistant sugarbeet at the Michigan State University and Michigan Sugar Company sites. In both instances this delay was seen in the two earliest planted studies (Table 7). Below average precipitation during the spring and summer of 1998 was a problem for many sugarbeet growers in Michigan. Sugarbeet planted prior to April 30, 1998 received adequate rainfall to activate preemergence herbicides in the soil. Glyphosate resistant sugarbeet was planted after May 2, 1998 at both sites and less then 2.6 cm of rain fell during the month of May. Therefore, preemergence herbicides in the glyphosate studies were not activated and weed emergence was not delayed.

In 1999 preemergence herbicides delayed postemergence applications of glyphosate and glufosinate in four out of six studies (Table 8). Preemergence herbicides did not delay postemergence application of glyphosate or glufosinate at the Michigan Sugar Company site because velvetleaf, *Abutilon theophrasti*, was not controlled by the preemergence herbicides and exceeded 1.25 cm in height when sugarbeet was at the cotyledon growth stage.

Need for Additional Postemergence Applications

Weed control and sugarbeet yield in treatments that included a preemergence application of cycloate, ethofumesate, or pyrazon followed by two postemergence applications of glyphosate or glufosinate were compared to no preemergence herbicide followed by two to three postemergence applications of glyphosate or glufosinate. The use of a preemergence herbicide could replace an additional postemergence application of glyphosate and glufosinate in one of four studies (Table 9). Preemergence herbicide followed by two postemergence applications of glyphosate improved the control of redroot pigweed compared with two postemergence applications of glyphosate at the Monitor Sugar site in 1999 (Tables 9 and 10). Glyphosate resistant sugarbeet at this site was not harvested due to a poor stand as a result of poor crop emergence. Weed control obtained from three applications of glyphosate or glufosinate or from a preemergence herbicide followed by two postemergence applications of glyphosate and glufosinate was not less than 96% in any other study. Thus, preemergence herbicides followed by two postemergence applications of glyphosate or glufosinate provided weed control equivalent to three applications of glyphosate or glufosinate. A third postemergence herbicide application was necessary only when the crop stand was inadequate.

Preemergence herbicides increased weed control in glyphosate resistant sugarbeet at the Monitor Sugar site in 1999 (Table 10) and in glufosinate resistant sugarbeet at the Michigan State University and Michigan Sugar Company sites in 1998 (Table 11). Benefits from preemergence herbicides were observed at the same sites where the first postemergence application of glufosinate was delayed. The use of cycloate, ethofumesate, or pyrazon followed by two applications of glufosinate provided better control of common lambsquarters then glufosinate alone at the Michigan State University site. Glufosinate was applied three times at the Michigan Sugar site; however, redroot pigweed control increased when cycloate plus pyrazon preceded postemergence applications compared with no preceding herbicide. The use of preemergence herbicides gave greater weed control compared with glyphosate and glufosinate alone in only three out of 12 studies in 1998 and 1999 (Tables 10 and 11). In 1998 greater weed control was seen in the earliest planted studies, while in 1999 preemergence herbicides increased weed control only in areas with poor crop stand.

Conventional Postemergence Programs

A split application of desmedipham and phenmedipham plus triflusulfuron plus clopyralid applied to glyphosate and glufosinate resistant sugarbeet provided 83% or greater control of common lambsquarters and redroot pigweed in 1998 at all sites (Table 12). Lack of precipitation in 1998 resulted in fewer weed flushes, and preemergence herbicides followed by postemergence herbicides did not provide better weed control then weed management programs using only postemergence herbicides. In contrast the use of preemergence herbicides in a conventional weed management system (desmedipham and phenmedipham plus triflusulfuron plus clopyralid) increased weed control in five of six studies in 1999 (Table 12). This supports conclusions by Wilson (1992) and Miller *et al.* (1997) where weed control increased when preemergence herbicides were followed by postemergence herbicides.

Sugarbeet Yield

Preemergence applications of cycloate, ethofumesate, and pyrazon followed by glyphosate or glufosinate did not affect sugarbeet root yield or recoverable sucrose compared with glyphosate or glufosinate alone (Tables 13 and 14). Similarly, preemergence herbicides did not affect the yield of glyphosate and glufosinate resistant sugarbeet treated with conventional postemergence herbicide regimes. P-values for these treatments ranged from 0.20 to 0.84 (data not shown). This supports research by Miller *et* *al.* (1997) where the use of preemergence herbicides decreased hoeing time, but did not increase sugarbeet yield.

Cost Comparison

The cost for each herbicide program was calculated using information provided by local agri-chemical dealers in 1998, and from the 1996 Doane's Agricultural Reports (DAR 1996). Because preemergence herbicide regimes were not associated with higher sugarbeet yield in any trial in this study, the least expensive herbicide combination was therefore be the most cost effective. Glyphosate applied twice provided 87% or more control of common lambsquarters and redroot pigweed in both 1998 and 1999. Herbicide prices show that an additional broadcast application of glyphosate ($26.25-$33.80/ha) is less expensive then a banded application of ethofumesate or pyrazon ($47.40-$79.60/ha) or a broadcast incorporated application of cycloate ($77.40-$103.75). Therefore the use of preemergence herbicides preceding glyphosate application in glyphosate resistant sugarbeet was not justified.

In glufosinate resistant sugarbeet one broadcast application of glufosinate would cost $56.50/ha in 1998 and 1999. The cost for an equivalent rate of this herbicide decreased to $40.30/ha in 2000. One application of cycloate ($77.40-$103.75) would be more expensive then one additional glufosinate application. Depending on which years prices are used, the cost for one application of glufosinate would be less than or equal to the cost of one application of either ethofumesate or pyrazon ($47.40-$79.60) applied in a band. Preemergence herbicides should be considered as weed control options when planting glufosinate resistant sugarbeet only if their application could be substituted for later postemergence applications of glufosinate. However, predicting the ability to substitute a preemergence herbicide for one or more postemergence applications of glufosinate is difficult. For example, dry growing conditions in 1998 resulted in decreased crop growth and poor herbicide performance. Regardless of whether preemergence herbicides were used, at one site additional glufosinate application were needed to maintain weed control resulting in higher herbicide cost. The use of preemergence herbicides improved annual weed control at a second site, where as weed control was not increased at a third location. Favorable weather conditions in 1999 resulted in rapid growth of sugarbeet. During this season, two postemergence applications of glufosinate alone were adequate for control of weeds and for protecting crop yield. Therefore, the decision to apply preemergence herbicides can not be made with any certainty of incurring a benefit because weed density, crop stand and vigor are unknown at the time. There is also less justification for using preemergence herbicides in glufosinate resistant sugarbeet as the price of glufosinate decreases.

Growers considering this weed management system should also consider the additional expenditure for technology fees associated with herbicide resistant sugarbeet varieties. Companies may chose to charge additional fees for transgenic material, in an effort to recover development costs. These fees are levied when growers purchase seed and must be paid regardless of whether glyphosate or glufosinate are applied. In the case of sugarbeet production the amount paid in technology fees could be larger then the actual cost for herbicides, since this crop does not have the many price competitive products that are available for corn or soybeans. Like any new product, technology fees will be set according to what the market will accept. The average expenditure for agricultural chemicals for sugarbeet production in the Great Lakes Region was $149.75

per hectare in 1996 (Ali 1999). When this cost is compared to the relatively low cost of glyphosate or glufosinate, it becomes apparent that these technology fees may become substantial. Estimates for the technology fees associated with glyphosate resistant sugarbeet are $80 per unit of seed. Typically growers plant 0.75 to 1.5 units of seed per hectare. This translates into an additional cost of $60 to $120 dollars per hectare (J. Kauffman, Monsanto, personal correspondence, August 1999).

Conclusion

Our studies show that weed control programs without preemergence herbicides will likely require two or three postemergence applications of glyphosate or glufosinate to provide full-season weed control. In some cases, preemergence herbicides such as cycloate, ethofumesate, and pyrazon did delay the need for the first postemergence herbicide application by three to nine days or did reduce the number of postemergence herbicide applications needed. This is advantageous when using traditional postemergence sugarbeet herbicides such as desmedipham and phenmedipham plus triflusulfuron plus clopyralid. Preemergence herbicides used prior to a traditional postemergence herbicide improved weed control at five out of six sites in 1999. The lower cost and greater effectiveness in controlling larger weeds associated with glyphosate or glufosinate negate these advantages.

In 1998 and 1999 there was no difference in weed control or sugarbeet yield in herbicide resistant sugarbeet treated with full compared with half rates of preemergence herbicides. Cycloate, ethofumesate, and pyrazon increased weed control in only 25% of the studies and did not improve root yield or recoverable sucrose. A third application of glyphosate or glufosinate provided excellent control of annual broadleaf weeds in the absence of the customary use of preemergence herbicide applications. Though preemergence herbicides should be considered as a useful tool for weed control in sugarbeet, glyphosate and glufosinate are each less expensive and offer greater crop safety with a wider spectrum of weed control.

Though glyphosate and glufosinate are each inexpensive when compared with the cost of traditional sugarbeet herbicides, their associated weed management systems should not be considered by the grower as less expensive. Technology fees added to the cost of seed must be considered as a part of the expenditure for weed control. These fees may negate the reduced cost of the herbicides.

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Table 7 – Soil series, type, organic matter, and planting dates for glufosinate and glyphosate resistant sugarbeet at each location in 1998 and 1999.

--------Site--------		--------------Soil--------------			--------------Planting--------------			
Location	Year	Series	Type	OM[a]	Gluf[b]	Glyt[c]	Row Width	Plant Spacing
				(%)	(date)	(date)	(cm)	(cm)
Michigan State Univ.	1998	Zilwaukee	Silty-clay loam	<3	4/27[d]	5/11[d]	71	11
Michigan Sugar Co.	1998	Sloan-Ceresco	Silt loam	>3	4/28	5/6	71	11
Monitor Sugar Co.	1998	Londo	Loam	<3	5/7	5/7	76	15[e]
Michigan State Univ.	1999	Zilwaukee Mistequay	Silty-clay	>3	4/28	4/28	71	15[e]
Michigan Sugar Co.	1999	Sloan	Silt loam	>3	4/30	4/30	71	15[e]
Monitor Sugar Co.	1999	Londo	Loam	<3	5/4	5/4[d]	76	15[e]

[a] OM – organic matter
[b] Gluf – glufosinate resistant sugarbeet
[c] Glyt – glyphosate resistant sugarbeet
[d] Trial could not be harvested due to stand loss.
[e] Trials were thinned from a 6 cm spacing.

Table 8 – Dates of first glyphosate and glufosinate application following preemergence applications of cycloate, ethofumesate, and pyrazon at the Michigan State University, Michigan Sugar Co., and Monitor Sugar Co. sites in 1998 and 1999.[a]

	1998						1999					
	M.S.U.		Michigan		Monitor		M.S.U.		Michigan		Monitor	
	Glyt	Gluf	Glyt	Gluf	Glyt	Gluf	Glyt	Gluf	Glyt	Gluf	Glyt	Gluf
No PRE	6/11	5/19	5/21	5/12	5/19	5/19	5/27	5/27	5/19	5/19	5/28	5/28
Cycl	6/11	5/22	5/21	5/21	-	-	6/1	6/1	5/19	5/19	-	-
Etho	6/11	5/19	-	-	5/19	5/19	6/1	6/1	-	-	6/3	6/3
Pyzn	6/11	5/22	5/21	5/21	5/19	5/19	5/27	5/27	5/19	5/19	5/28	5/28
Etho+Pyzn	6/11	5/22	5/21	5/21	5/19	5/19	6/1	6/1	5/19	5/19	6/3	6/3
Cycl+Pyzn	-	-	5/21	5/21	-	-	-	-	5/19	5/19	-	-

[a] No Pre – no preemergence herbicide, Cycl – cycloate, Etho – ethofumesate, Glyt – glyphosate, Gluf – glufosinate, Pyzn - pyrazon

Table 9 – Common lambsquarters and redroot pigweed[a] control and root yield of herbicide resistant sugarbeet following preemergence applications of cycloate, ethofumesate, pyrazon, or no preemergence herbicide followed by postemergence applications of glyphosate or glufosinate[b] at the Michigan State University and Monitor Sugar sites in 1999.

	Michigan State Univ.						Monitor Sugar Co.					
	Glyt			Gluf			Glyt			Gluf		
	Colq	Rrpw	Root Yield	Colq	Rrpw	Root Yield	Colq	Rrpw	Root Yield	Colq	Rrpw	Root Yield
	(%)	(%)	(Mg/ha)	(%)	(%)	(Mg/ha)	(%)	(%)	(Mg/ha)	(%)	(%)	(Mg/ha)
Untrt	-	-	51.9 b	-	-	49.3 c	-	-	-	-	-	35.0 c
2 Post[c]	100 a	100 a	85.5 a	100 a	99 a	73.6 ab	97 a	92 b	-	94 a	96 a	54.8 ab
3 Post[c]	100 a	100 a	79.3 a	100 a	100 a	72.2 ab	100 a	100 a	-	98 a	100 a	55.0 ab
Cycl fb 2 Post	100 a	100 a	78.4 a	100 a	100 a	77.8 a	-	-	-	-	-	-
Etho fb 2 Post	100 a	100 a	77.7 a	100 a	100 a	69.9 b	100 a	100 a	-	99 a	100 a	59.5 a
Pyzn fb 2 Post	100 a	100 a	80.6 a	100 a	97 a	69.8 b	99 a	100 a	-	96 a	99 a	56.8 ab
Etho+Pyzn fb 2 Post	100 a	100 a	78.7 a	100 a	100 a	73.7 ab	99 a	100 a	-	99 a	100 a	52.4 b
CV %	3.8	1.9	8.9	1.9	5.4	7.4	7.2	8.2	-	8.8	8.6	7.1

[a] Colq – common lambsquarters, Rrpw – redroot pigweed
[b] No Pre – no preemergence herbicide, Cycl – cycloate, Etho – ethofumesate, Glyt – glyphosate, Gluf – glufosinate, Pyzn – pyrazon
[c] 2 Post – glyphosate or glufosinate applied twice, 3 Post – glyphosate or glufosinate applied three times

Table 10 – Control of common lambsquarters and redroot pigweed[a] at the Michigan State University, Michigan Sugar, and Monitor Sugar sites in 1998 and 1999 from cycloate, ethofumesate, pyrazon, or no herbicide preemergence[b] each followed by glyphosate.

	1998						1999					
	M.S.U.		Michigan		Monitor		M.S.U.		Michigan		Monitor	
	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
No PRE	100	100	98	87	90	97	100	100	100	100	97	92
Cycl	95	98	100	99	-	-	100	100	-	-	-	-
Etho	100	100	-	-	93	100	100	100	-	-	100	100*
Pyzn	100	100	96	96	94	100	100	100	-	-	99	100*
Etho+Pyzn	100	100	98	100	95	95	100	100	99	100	99	100*
Cycl+Pyzn	-	-	100	99	-	-	-	-	-	-	-	-
p-value	0.70	0.34	0.30	0.32	0.51	0.47	-	-	-	-	0.49	0.03
CV %	9.1	3.9	7.9	13.8	9.8	8.5	-	-	-	-	5.8	6.8

* weed control was significantly increased at the 0.05 level
[a] Colq – common lambsquarters, Rrpw – redroot pigweed
[b] No Pre – no preemergence herbicide, Cycl – cycloate, Etho – ethofumesate, Pyzn - pyrazon

Table 11 – Control of common lambsquarters and redroot pigweed[a] at the Michigan State University, Michigan Sugar, and Monitor Sugar sites in 1998 and 1999 from cycloate, ethofumesate, pyrazon, or no herbicide preemergence[b] each followed by glufosinate.

	1998						1999					
	M.S.U.		Michigan		Monitor		M.S.U.		Michigan		Monitor	
	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
No PRE	67	92	88	94	88	98	100	99	95	90	98	100
Cycl	96*	100	82	97	-	-	100	100	-	-	-	-
Etho	91*	100	-	-	92	100	100	100	-	-	99	100
Pyzn	95*	97	76	95	92	94	100	97	-	-	96	100
Etho+Pyzn	100*	100	91	97	89	99	100	100	98	90	99	100
Cycl+Pyzn	-	-	93	100*	-	-	-	-	-	-	-	-
p-value	0.001	0.60	0.24	0.04	0.81	0.51	-	0.14	-	-	0.43	-
CV %	6.2	6.9	13.7	7.0	17.5	8.4	-	3.4	-	-	8.4	-

* weed control was significantly increased at the 0.05 level
[a] Colq – common lambsquarters, Rrpw – redroot pigweed
[b] No Pre – no preemergence herbicide, Cycl – cycloate, Etho – ethofumesate, Pyzn - pyrazon

Table 12 – Control of common lambsquarters and redroot pigweed[a] at the Michigan State University and Monitor Sugar sites in 1998 and the Michigan State University, Michigan Sugar, and Monitor Sugar sites in 1999 from cycloate, ethofumesate, pyrazon, or no preemergence herbicide[b] followed by desmedipham and phenmedipham plus triflusulfuron plus clopyralid applied to glyphosate[c] and glufosinate[d] resistant sugarbeet.

	1998						1999											
	M.S.U.				Monitor		M.S.U.				Michigan				Monitor			
	Glyt		Gluf		Gluf		Glyt		Gluf		Glyt		Gluf		Glyt		Gluf	
	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw	Colq	Rrpw
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
No PRE	100	97	92	100	86	99	99	79	99	94	76	76	46	47	89	80	80	94
Cycl	100	100	100	100	-	-	100	98*	100	99*	90	91	92*	79*	-	-	-	-
Etho	93	95	100	100	87	94	100	100*	100	100*	-	-	-	-	98	100*	100*	100
Pyzn	100	100	100	100	92	98	100	100*	100	99*	85	81	81*	78*	97	94*	94*	92
Etho+Pyzn	83	93	100	100	93	96	100	98*	100	99*	85	90	93*	85*	97	97*	100*	100
Cycl+Pyzn	-	-	-	-	-	-	-	-	-	-	95	91	95*	90*	-	-	-	-
p-value	0.09	0.48	0.41	-	0.81	0.76	0.43	0.001	0.44	0.04	0.19	0.16	0.05	0.02	0.55	0.002	0.001	0.38
CV %	8.0	8.6	7.5	-	17.5	11.8	3.3	7.1	3.2	5.9	15.7	16.6	30.4	19.6	11.9	8.5	8.2	11.9

* weed control was significantly increased at the 0.05 level.
[a] Colq – common lambsquarters, Rrpw – redroot pigweed
[b] No Pre – no preemergence herbicide, Cycl – cycloate, Etho – ethofumesate, Pyzn - pyrazon
[c] Glyt – glyphosate resistant sugarbeet
[d] Gluf – glufosinate resistant sugarbeet

Table 13 – Root yield and recoverable sucrose of sugarbeet following application of cycloate, ethofumesate, pyrazon, or no preemergence herbicide[a] followed by glyphosate at the Michigan Sugar and Monitor Sugar sites in 1998 and the Michigan State University site in 1999.

	1998						1999					
	M.S.U.		Michigan		Monitor		M.S.U.		Michigan		Monitor	
	Root Yield	Sucrose	Root Yield	Sucrose	Root Yield	Sucrose	Root Yield	Sucrose	Root Yield	Sucrose	Root Yield	Sucrose
	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)
No PRE	-	-	50.7	4614	52.7	6104	85.5	9952	49.2	6202	-	-
Cycl	-	-	57.4	5442	-	-	78.4	9174	-	-	-	-
Etho	-	-	-	-	51.4	6111	77.7	8992	-	-	-	-
Pyzn	-	-	53.0	5019	48.3	5460	80.6	9444	-	-	-	-
Etho+Pyzn	-	-	57.7	5233	54.4	6509	78.7	9111	56.6	7050	-	-
Cycl+Pyzn	-	-	56.5	5286	-	-	-	-	-	-	-	-
p-value	-	-	0.61	0.82	0.52	0.35	0.21	0.19	-	-	-	-
CV %	-	-	15.75	22.99	10.81	11.91	7.55	7.54	-	-	-	-

[a] No Pre – no preemergence herbicide, Cycl – cycloate, Etho – ethofumesate, Pyzn - pyrazon

Table 14 – Root yield and recoverable sucrose of sugarbeet following application of cycloate, ethofumesate, pyrazon, or no preemergence herbicide[a] followed by glufosinate at the Michigan Sugar and Monitor Sugar sites in 1998 and the Michigan State University and Monitor Sugar sites in 1999.

	1998						1999					
	M.S.U.		Michigan		Monitor		M.S.U.		Michigan		Monitor	
	Root Yield	Sucrose	Root Yield	Sucrose	Root Yield	Sucrose	Root Yield	Sucrose	Root Yield	Sucrose	Root Yield	Sucrose
	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)	(Mg/ha)	(kg/ha)
No PRE	-	-	46.9	5156	45.1	5755	73.6	9687	57.6	7245	54.8	7127
Cycl	-	-	43.1	4695	-	-	77.8	10485	-	-	-	-
Etho	-	-	-	-	51.6	6498	69.9	9470	-	-	59.5	7730
Pyzn	-	-	41.5	4691	51.6	6374	69.8	9421	-	-	56.8	7413
Etho+Pyzn	-	-	44.2	5003	48.7	6049	73.7	10092	54.1	6780	52.4	6967
Cycl+Pyzn	-	-	52.5	5942	-	-	-	-	-	-	-	-
p-value	-	-	0.32	0.40	0.95	0.94	0.44	0.33	-	-	0.88	0.98
CV %	-	-	14.21	18.86	11.79	12.43	6.74	47.17	-	-	7.83	8.49

[a] No Pre – no preemergence herbicide, Cycl – cycloate, Etho – ethofumesate, Pyzn - pyrazon

Chapter 4

Effect of Cultivation on Weed Emergence In Glufosinate Resistant Sugarbeet

Abstract

Weed control in sugarbeet involves banded applications of herbicides combined with cultivation. Cultivation as a weed control strategy is not needed with the introduction of herbicide resistant sugarbeet. Growers have expressed an interest in continuing to cultivate sugarbeet. The purpose of this study was to evaluate the effect of cultivation timing and the number of cultivation(s) on annual weed emergence in glufosinate resistant sugarbeet. Glufosinate was applied three times at 400 g ai/ha in all treatments. The number and species of weeds in a 25 cm by 76 cm quadrant were counted prior to each glufosinate application or cultivation, and every 10 to 14 days afterwards. The dominant weed species were giant foxtail, common lambsquarters, redroot pigweed, and Pennsylvania smartweed.

In 1998 weed emergence increased in August and September where treatments were cultivated after the final glufosinate application. Cultivation prior to a POST application of glufosinate did not result in greater late season weed emergence. In 1999 weed emergence between June 24 and July 14 was greater in treatments where plots were cultivated prior to the first glufosinate application. Cultivation did not produce greater weed emergence in August and September compared to treatments with no cultivation. Precipitation and sugarbeet growth rate differed between 1998 and 1999. Emergence of small-seeded broadleaf weeds such as common lambsquarters was affected by cultivation. There was no difference in the number of weed seedlings present at the end

of the season in cultivated plots compared with non-cultivated plots in which glufosinate was applied two to three weeks after the final cultivation.

Introduction

Cultivation between the rows of the crop is a common technique for weed control in sugarbeet. With the introduction of sugarbeet varieties that are resistant to herbicides such as glufosinate or glyphosate, cultivation as a weed control strategy may no longer be required. This is because these herbicides may be applied broadcast, providing excellent weed control at a competitive cost. In spite of this new technology, growers have expressed an interest in continuing to cultivate sugarbeet. Many growers employ a "cutaway" cultivation early in the season to aerate and loosen the soil allowing young sugarbeet plants to get established. In addition to weed control, cultivation may be used to loosen the soil, push soil around the sugarbeet plants to aid in harvest, and to enhance the aesthetics of the crop in the field.

One argument against using cultivation with herbicide resistant crops is that tilling the soil may increase the emergence of new weed seedlings (Egley and Williams 1990). Neither glufosinate nor glyphosate have residual soil activity and thus only control emerged weeds (WSSA 1994). New weed emergence after herbicide application could translate into decreased control. Seed germination and dormancy is complicated and can be influenced by many factors including soil temperature, soil moisture, and exposure to light (Baskin and Baskin 1990, Alm *et al.* 1993, Salisbury and Ross 1992, Taiz and Zeiger 1998). Cultivation can affect the distribution of seeds or the environment needed for germination (Egley 1986, Egley and Williams 1990), thereby influencing the emergence of weeds.

One way in which tillage may influence seedling emergence is by affecting soil temperature and moisture. Research has shown a relationship between weed growth and soil temperature and moisture (Wiese and Binning 1987). Less tillage can result in lower soil temperature and greater soil moisture (Oryokot *et al.* 1997c). Reducing tillage concentrates weed seeds near the soil surface (Clements *et al.* 1996). As temperature increases above a minimum threshold the rate of seed germination and shoot elongation is increased. For some weed species there is a temperature above which germination and elongation decrease (Oryokot *et al.* 1997b & 1997c). Temperature and moisture are also known to influence secondary dormancy of some annual weeds. Low soil temperature may break seed dormancy, while high temperatures induce dormancy (Forcella *et al.* 1997). The actual effect of tillage on soil moisture, temperature, and therefore weed emergence is somewhat limited. As an example, *Amaranthus retroflexus* seedlings are physiologically restricted to germination depths of less then 2.5 cm. At shallow depths heat and moisture transfer between the soil and atmosphere is rapid and reduces the affect of tillage on seed germination (Oryokot *et al.* 1997a). These criteria may also limit the effect of tillage on annual grasses such as *Setaria faberi*, which has its greatest emergence from depths less then 1 cm (Fausey and Renner 1997).

Exposure to light is another seed emergence variable affected by tillage (Wesson and Wareing 1969, Buhler 1997, Gallagher and Cardina 1998). Exposure to light can break seed dormancy in many plant species. This requirement for light would keep propagules that are buried more then a few centimeters from germinating, which is an advantage for plant species with small seeds (Salisbury and Ross 1992, Buhler 1997). Phytochrome which exists in two forms, phytochrome red (Pr), and phytochrome far red

(Pfr), mediates the response of seeds to light (Ascard 1994). Phytochrome in the buried seeds is in the inactive red-light absorbing form (Pr). Exposure to sunlight converts Pr to Pfr, which results in a series of physiological events that lead to germination (Gallagher and Cardina 1998, Taiz & Zeiger 1998). In research by Buhler (1997), emergence of small seeded weeds such as *Chenopodium album* and *Polygonum pennsylvanicum* was less when tillage was performed in the dark. The light environment during tillage did not have an affect on the emergence of annual grasses such as *Setaria faberi,* or large seeded broadleaf weeds such as *Abutilon theophrasti*. Similar results were reported by Ascard (1994) in which the germination of some weed species was less where tillage implements excluded light. Unlike Buhler however, Ascard's experiments did not show lower *C. album* germination when tillage was performed at night. Gallagher and Cardina (1998) reported differences in emergence of some weed species when tillage was performed at night versus during the day; however, these differences varied considerably. Though the microclimate variable that accounted for the most variation in the emergence of *C. album* was temperature, exposure to light prolonged non-dormancy (Forcella *et al.* 1997). Thus the interaction between temperature, light requirement, and soil moisture on seed germination is complex and varies by weed species.

The effect of cultivation on weed emergence may vary according to the time of the year. When soil is cultivated there is a small proportion of the total seed bank which is released from dormancy (Roberts 1984). Weeds such as *C. album* tend to appear more frequently after spring tillage, and continue to appear whenever the soil is disturbed. Temperature largely determines this seasonal pattern of emergence, however soil moisture is an important factor required for germination (Roberts 1984).

The purpose of this study was to evaluate the effects of cultivation on the emergence of annual weeds in sugarbeet. This information can then be used in developing cultivation and herbicide programs to manage weeds in herbicide resistant sugarbeet.

Materials and Methods

This study was conducted at the Michigan State University Agronomy Research Farm at East Lansing, Michigan in 1998 and 1999. The field was of a Capac (series) sandy loam (55% sand, 30% silt, & 15% clay), with a pH that ranged from 6.9 to 7.2. Organic matter ranged from 1.8 in 1998 to 2.7 in 1999. The field was chisel plowed the previous fall and smoothed with a soil finisher. The soil was tilled again with a Kongskilde Triple-K (Kongskilde Corp., Bowling Green, OH 43402) immediately prior to planting. Beta variety 890LL was planted to stand in 76 cm rows on May 7, 1998 and May 4, 1999. Fertilizer (336 kg/ha of 19-19-19) was applied at planting. Plots were 18.3 m long and four rows in width.

Trials consisted of six treatments replicated three times. The study was designed as a randomized complete block with repeated measures. The six treatments varied according to the timing and frequency of cultivation (Table 15). All treatments received broadcast applications of 400 g/ha of glufosinate plus 2.8 kg/ha ammonium sulfate. In 1998 the dates for these postemergence applications were June 8, June 18, and July 10. In 1999 glufosinate was applied postemergence to sugarbeet on June 9, June 22, and July 12. The first herbicide application was made five days after the initial cultivation. The first cultivation or cutaway was delayed in order to allow sugarbeet plants to grow beyond the cotyledon stage. This was necessary in order to minimize crop damage with the available cultivation equipment. Subsequent herbicide applications were made when newly emerged weeds were two to five cm in height or if previously treated weeds were not controlled.

Weed species were counted in a 25 by 76 cm quadrant placed randomly within the plots. The position of the quadrant was marked with a flag in order for subsequent weed counts to be taken from the same area. Weeds were counted between the crop rows prior to each herbicide application or cultivation. Weeds were counted every 10 to 14 days until the end of September. Weed species include *Setaria faberi* (giant foxtail), *Chenopodium album* (common lambquarters), *Polygonum spp.* (Pennsylvania & ladysthumb smartweed), *Amaranthus retroflexus* (redroot pigweed), *Abutilon theophrasti* (velvetleaf), *Ambrosia artemisiifolia* (common ragweed), annual grasses, and broadleaf weeds in the family Brassicaceae. In 1998, *C. album* accounted for approximately 20% and *S. faberi* for approximately 60% of the emerged annual weeds. In 1999 approximately 10% of the emerged weeds were *C. album* and 65% *S. faberi.*

In 1998 weed density was recorded from June 2 until September 30. In 1999 densities were recorded from June 6 until September 24. The density of each individual weed species on a specified date were subjected to analysis of variance using PRM 5 in 1998 and ARM 6 in 1999 (Gylling Data Management, Brookings, SD 57006). Separate analysis for each date was required since this study contained repeated measures, and experimental units were not independent from one another. Means were separated by a least significant difference at the 0.05 level. The average number of seedlings from species displaying a significant difference in emergence as a result of cultivation was then graphed as a scatter plot using a Microsoft Excel spreadsheet (Microsoft, Buffalo, NY 14207). Graphing the data in this manner gave a visual representation of the change in weed emergence over time.

Results and Discussion

The 1998 growing season was poor throughout much of Michigan. Below average rainfall resulted in drought conditions which affected the growth of both sugarbeet and annual weeds. Many sugarbeet growers experienced inconsistent crop emergence, slow crop growth, and lack of canopy development. In contrast the 1999 season began with adequate rainfall and warm temperatures. Sugarbeet emergence and growth was rapid, though the incidence of disease was more frequent. Control of annual weeds with glufosinate was excellent.

In 1998 total weed emergence was greater in plots where the final cultivation followed the last postemergence application of glufosinate (timings C & A+C, Figure 10). Differences in weed emergence were evident three to four weeks after the final cultivation. *C. album* emergence increased at the end of the season where plots were cultivated after the final glufosinate application (timings C & A+C, Figure 11). However, cultivation did not influence (P=0.05) the emergence of *S. faberi* (Figure 12), *Abutilon theophrasti,* or *Amaranthus artemisiifolia* at any time during the season. Tillage is reported to have inconsistent effects on the emergence of annual grass species such as *S. faberi* (Buhler 1997). Soil temperatures above 17° C may induce secondary dormancy in *S. faberi* (Forcella *et al.* 1997).

Early season weed densities did not reflect differences due to cultivation, because frequent cultivation and herbicide applications removed seedlings. Cultivation prior to a postemergence application of glufosinate did not increase weed emergence in August and September when compared with no cultivation (timings A, B, & A+B).

Similar results were seen during the 1999 season. Weed emergence between June 24 and July 14 increased when plots were cultivated prior to the first herbicide application (timings A & A+C, Figure 13). Treatments that included the second cultivation had fewer emerged weeds due to seedlings being removed at a later date (timings B & A+B, Figure 13). Most of the newly emerged weeds were annual grasses, including *S. faberi* (Figure 15). Moist soil conditions in 1999 may have resulted in cool soil temperatures, allowing grasses to germinate. In contrast to 1998, the emergence of *C. album* did not increase after the final cultivation (Figure 14). In 1999 the sugarbeet canopy completely covered the soil area between the rows. This shading may have influenced weed germination by affecting soil moisture, solar radiation reaching the soil, and temperature (Anderson and Nielsen 1996). The only weed that emerged after the final cultivation was *Polygonum spp.* (timing C & A+C, Figure 16). This was unexpected since smartweeds emerge at low temperatures and are considered an early emerging species (Buhler *et al.* 1997)

Conclusions

Literature suggests that cultivation may affect the emergence of several weed species. Similar to research published by Buhler (1997), cultivation affected the emergence of small seeded broadleaves such a *C. album* and *Polygonum spp.*, and had inconsistent effects on the emergence of annual grass, including *S. faberi*. In our studies it took three to four weeks after the final cultivation to see differences in weed emergence. Cultivation did not affect late season weed emergence if glufosinate was applied after the final cultivation. This coincides well with an observation by Roberts (1984), in which the rate of appearance for new seedlings returned to a "background" level after soil cultivation released a flush of weeds.

Cultivation may continue to be used in herbicide resistant sugarbeet. Growers who plan on cultivating herbicide resistant sugarbeet varieties need to be aware that glufosinate should be broadcast-applied approximately two to three weeks after the last cultivation.

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Table 15 – Description of cultivation treatments and timings in 1998 and 1999.

Treatment Description	Timing	1998	1999
No Cultivation	None	N/A	N/A
One cultivation prior to the first glufosinate application.	A	June 3rd	June 4th
One cultivation one week after the second glufosinate application.	B	June 25th	June 30th
One cultivation one week after the final glufosinate application.	C	July 17th	July 23rd
Two cultivations; once prior to the first glufosinate application and one week after the second glufosinate application.	A + B	June 3rd & June 25th	June 4th & June 30th
Two cultivations; once prior to the first glufosinate application and one week after the final glufosinate application.	A + C	June 3rd & July 17th	June 4th & July 23rd

Figure 10 – Effect of cultivation timing on the emergence of annual weeds in glufosinate resistant sugarbeet in 1998. (Error bars represent differences at the 0.05 levels)

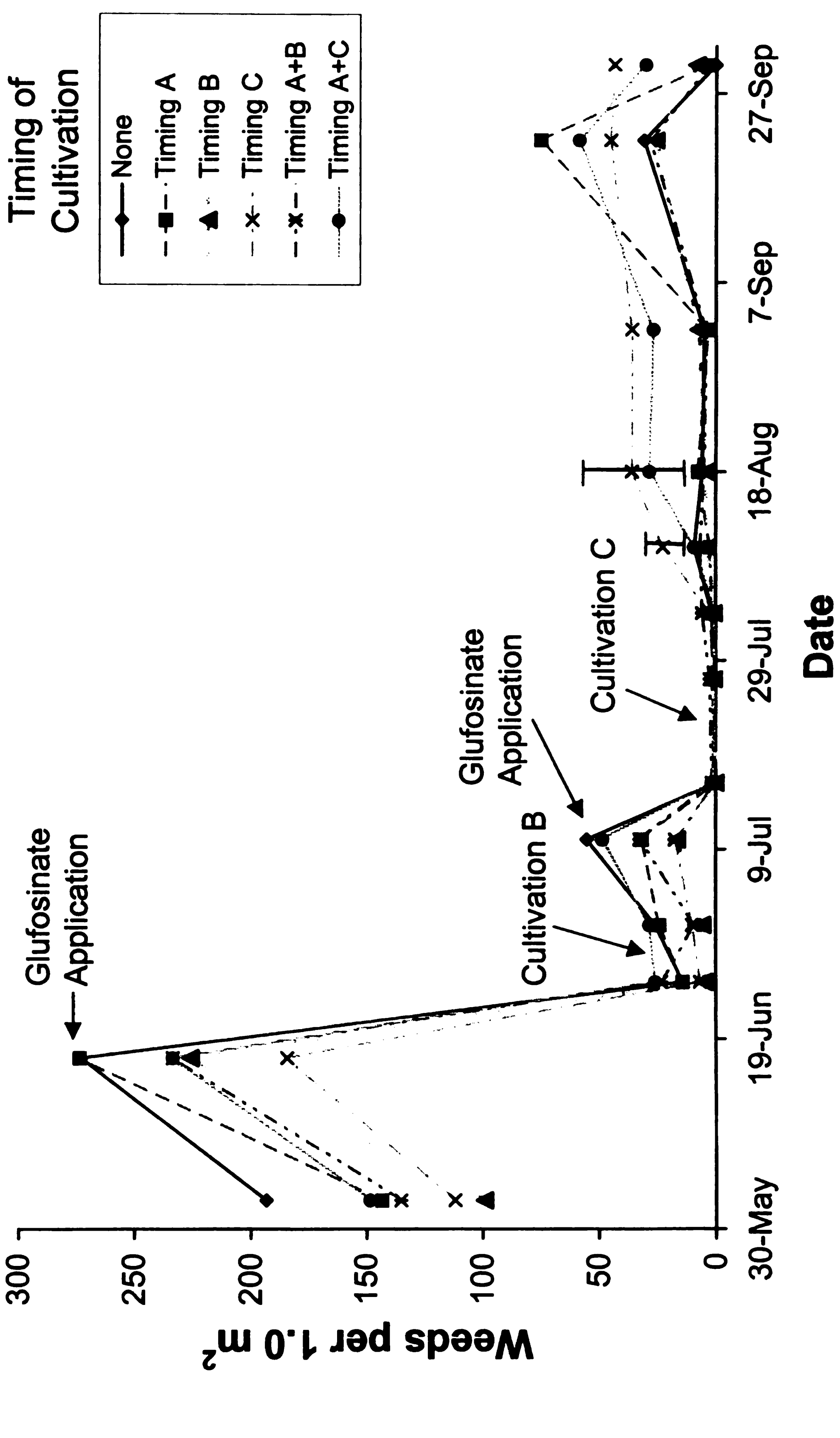
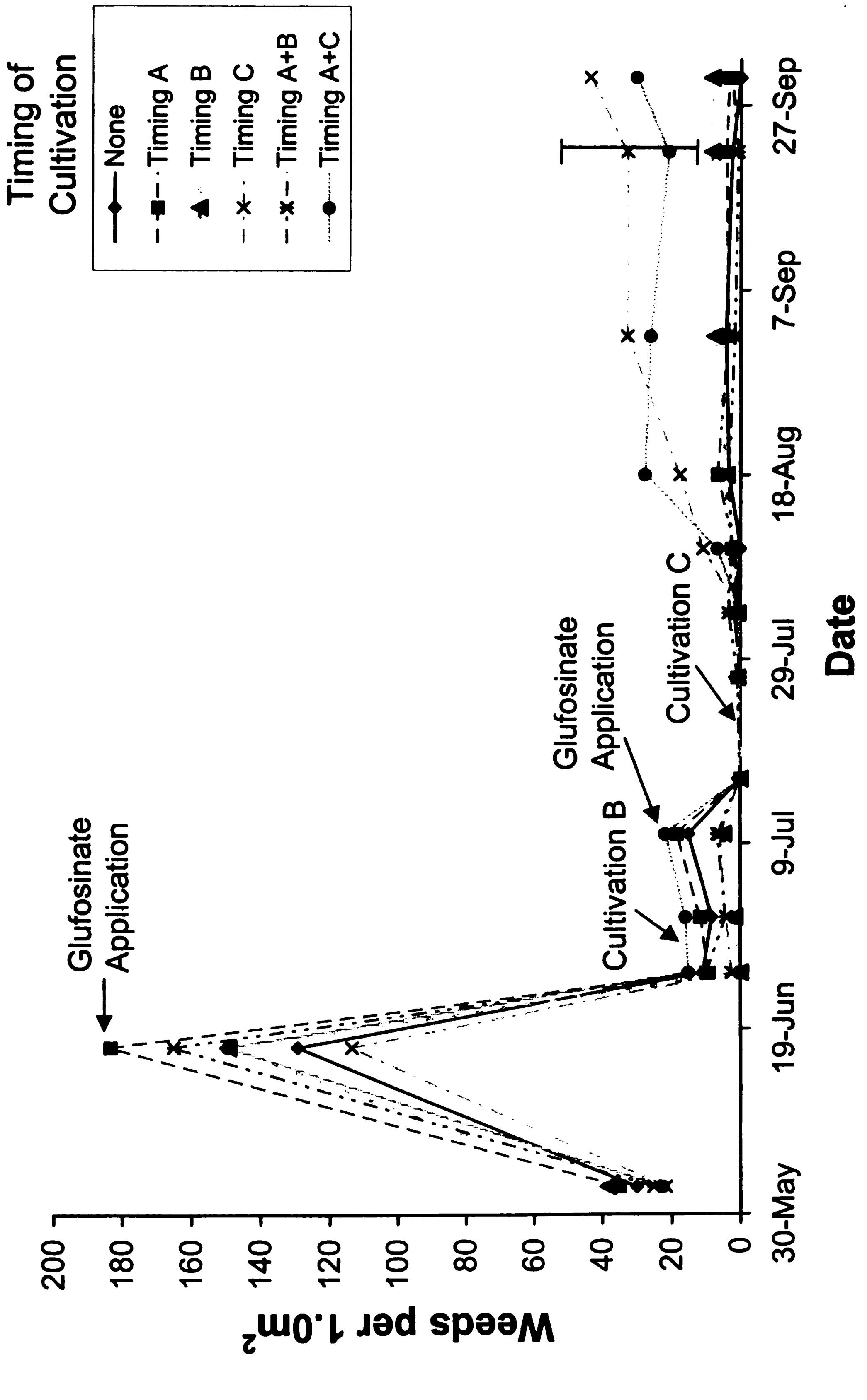

Timing of Cultivation
None
Timing A
Timing B
Timing C
Timing A+B
Timing A+C
Glufosinate Application
Glufosinate Application
Cultivation B
Cultivation C
Weeds per 1.0 m²
0
50
100
150
200
250
300
30-May
19-Jun
9-Jul
29-Jul
18-Aug
7-Sep
27-Sep
Date

Figure 11 – Effect of cultivation timing on the emergence of common lambsquarters in glufosinate resistant sugarbeet in 1998. (Error bars represent differences at the 0.05 levels)



Timing of Cultivation
None
Timing A
Timing B
Timing C
Timing A+B
Timing A+C
Glufosinate Application
Cultivation B
Glufosinate Application
Cultivation C
Weeds per 1.0m2
200
180
160
140
120
100
80
60
40
20
0
30-May
19-Jun
9-Jul
29-Jul
18-Aug
7-Sep
27-Sep
Date

Figure 12 – Effect of cultivation timing on the emergence of annual grass in glufosinate resistant sugarbeet in 1998. (Error bars represent differences at the 0.05 levels)

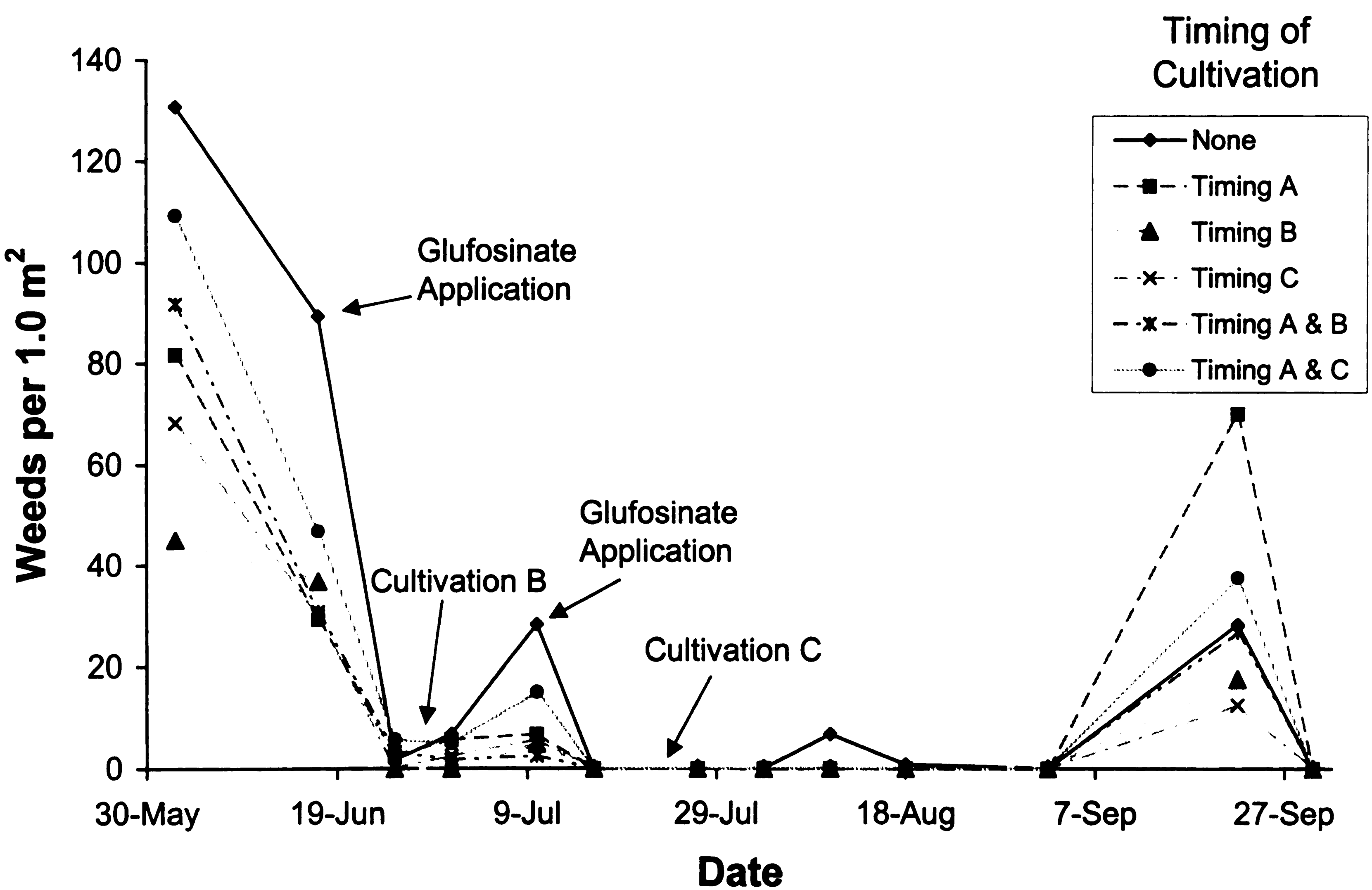

Weeds per 1.0 m2
140
120
100
80
60
40
20
0
30-May
19-Jun
9-Jul
29-Jul
18-Aug
7-Sep
27-Sep
Date
Glufosinate Application
Cultivation B
Glufosinate Application
Cultivation C
Timing of Cultivation
None
Timing A
Timing B
Timing C
Timing A & B
Timing A & C

Figure 13 – Effect of cultivation timing on the emergence of annual weeds in glufosinate resistant sugarbeet in 1999. (Error bars represent differences at the 0.05 levels)

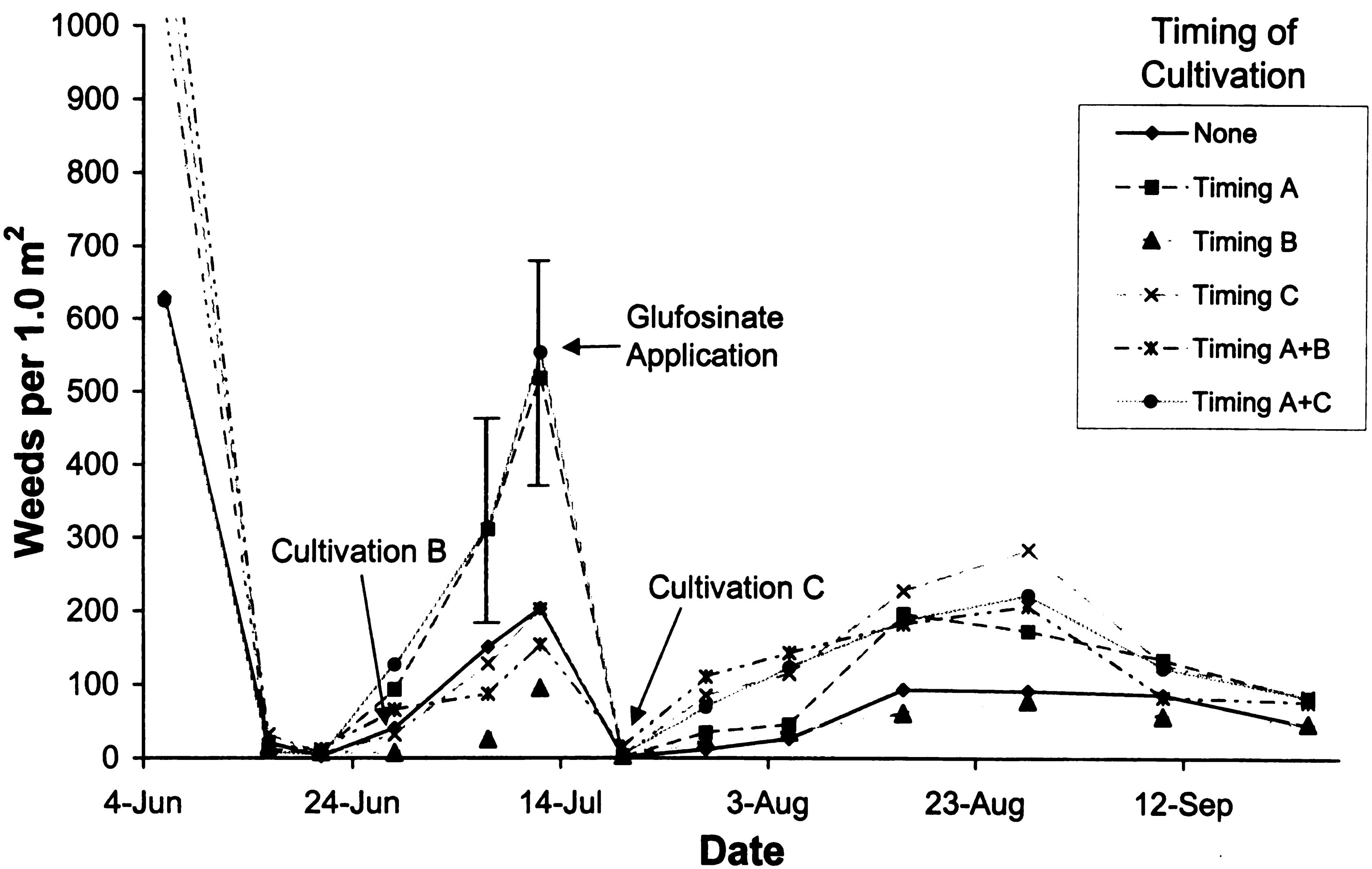
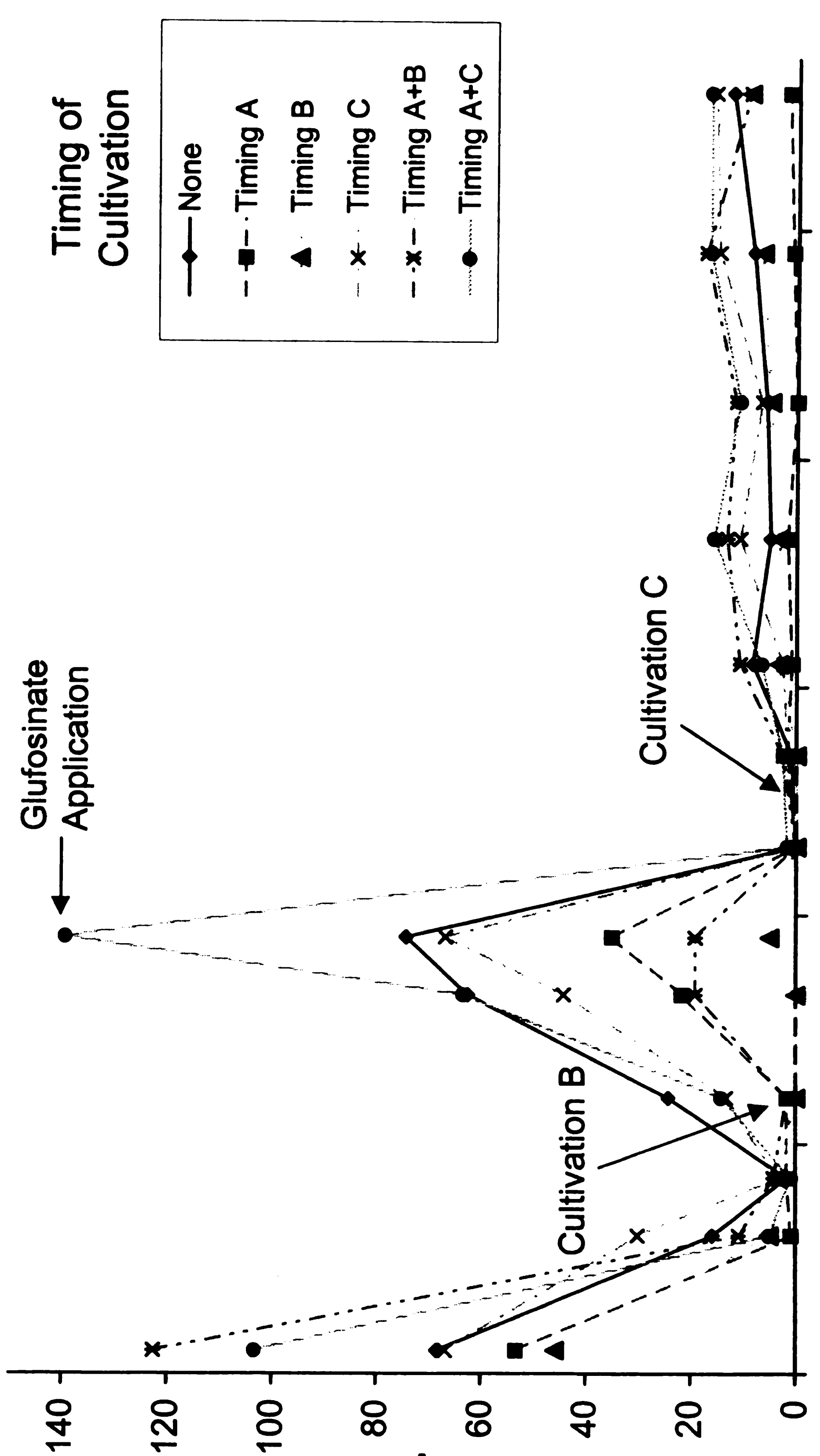

Weeds per 1.0 m²
1000
900
800
700
600
500
400
300
200
100
0
4-Jun
24-Jun
14-Jul
3-Aug
23-Aug
12-Sep
Date
Glufosinate Application
Cultivation B
Cultivation C
Timing of Cultivation
None
Timing A
Timing B
Timing C
Timing A+B
Timing A+C

Figure 14 – Effect of cultivation timing on the emergence of common lambsquarters in glufosinate resistant sugarbeet in 1999.



Weeds per 1.0 m²
140
120
100
80
60
40
20
0
4-Jun
24-Jun
14-Jul
3-Aug
23-Aug
12-Sep
Date
Glufosinate Application
Cultivation B
Cultivation C
Timing of Cultivation
None
Timing A
Timing B
Timing C
Timing A+B
Timing A+C

Figure 15 – Effect of cultivation timing on the emergence of annual grass in glufosinate resistant sugarbeet in 1999. (Error bars represent differences at the 0.05 levels)

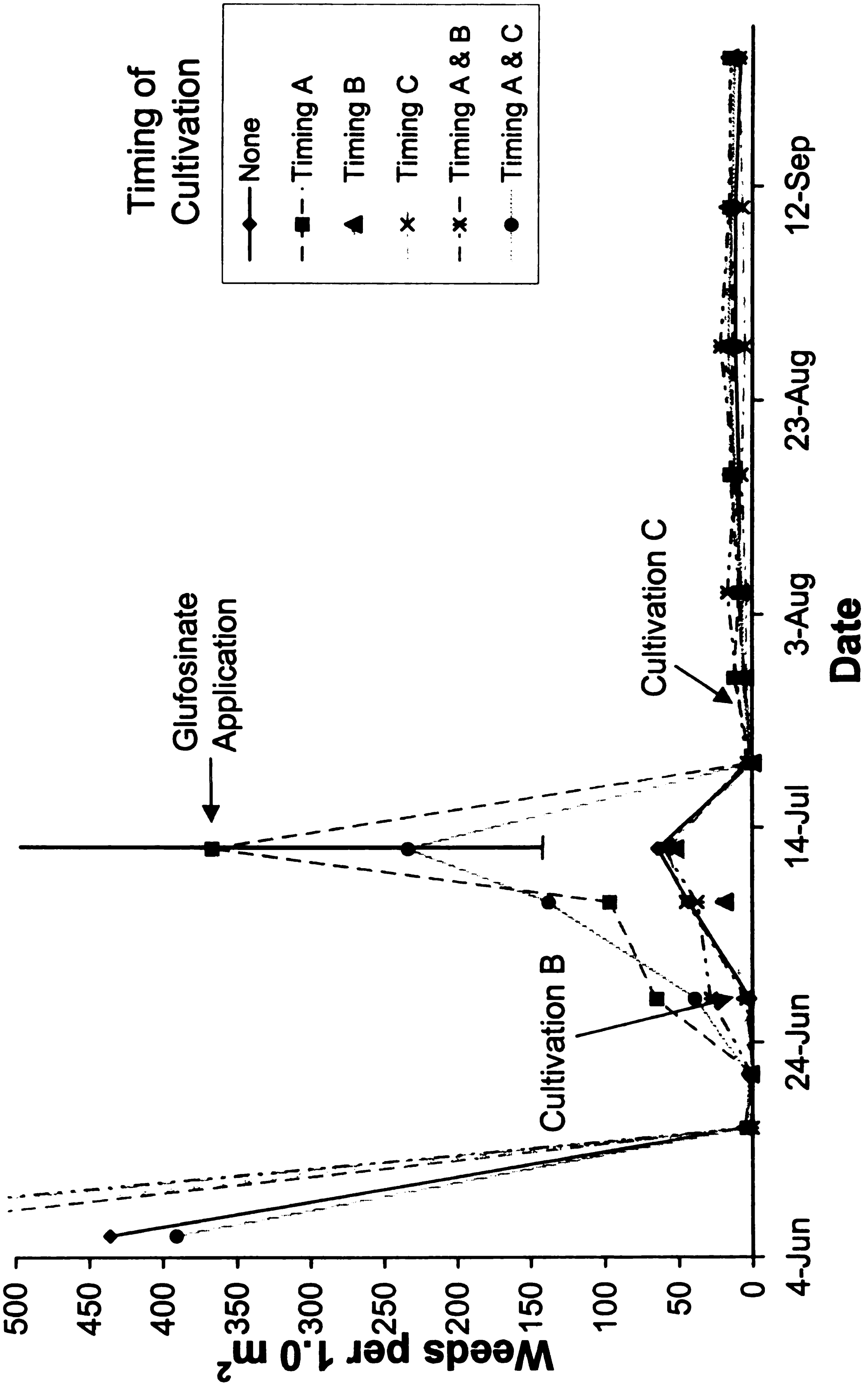
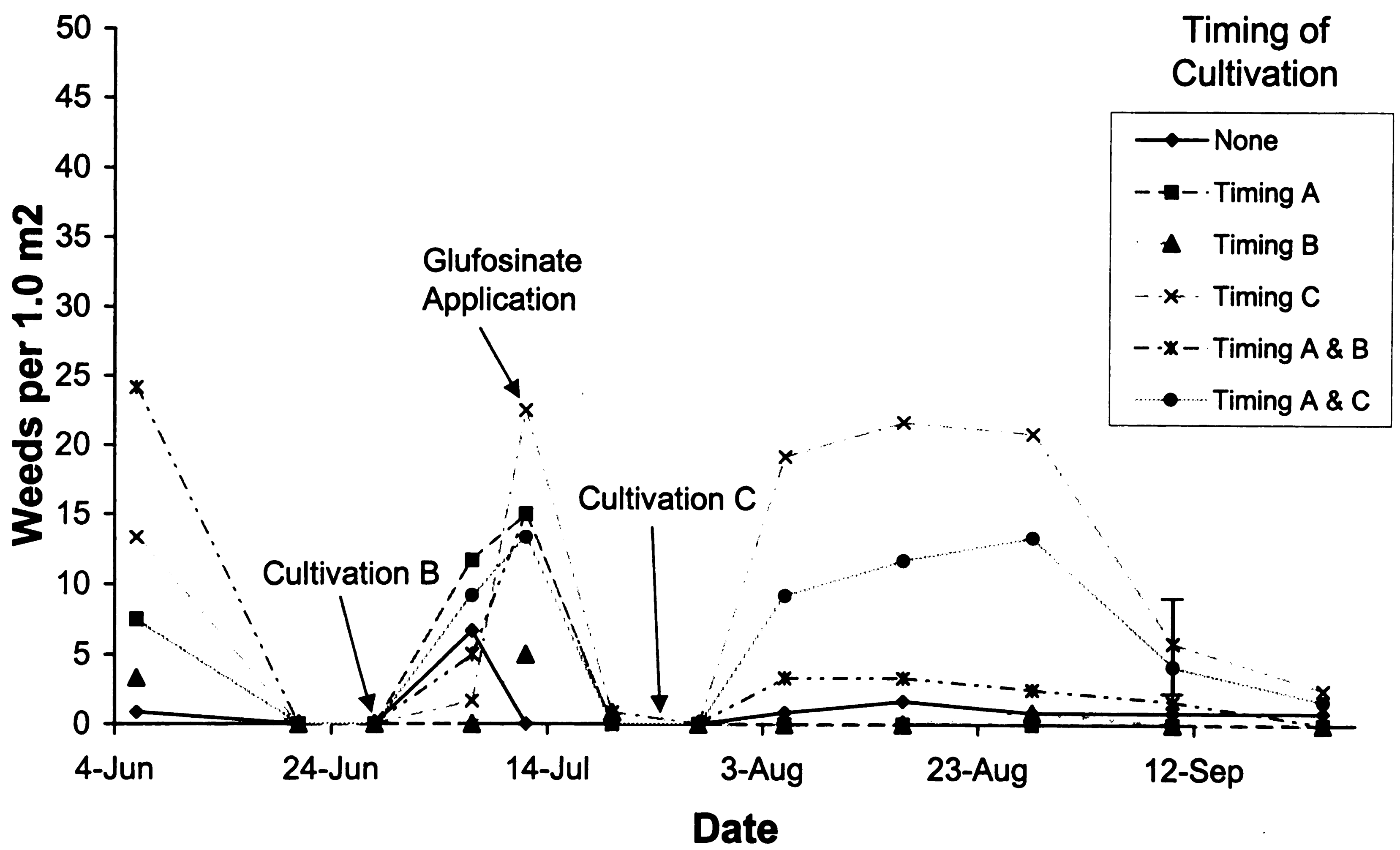

Weeds per 1.0 m2
500
450
400
350
300
250
200
150
100
50
0
4-Jun
24-Jun
14-Jul
3-Aug
23-Aug
12-Sep
Date
Cultivation B
Glufosinate Application
Cultivation C
Timing of Cultivation
None
Timing A
Timing B
Timing C
Timing A & B
Timing A & C

Figure 16 – Effect of cultivation timing on the emergence of annual smartweeds in glufosinate resistant sugarbeet in 1999. (Error bars represent differences at the 0.05 levels)


Weeds per 1.0 m2
50
45
40
35
30
25
20
15
10
5
0
4-Jun
24-Jun
14-Jul
3-Aug
23-Aug
12-Sep
Date
Glufosinate Application
Cultivation B
Cultivation C
Timing of Cultivation
None
Timing A
Timing B
Timing C
Timing A & B
Timing A & C

Appendices

Table 16 – Yield[a] and control of common lambsquarters, redroot pigweed, and velvetleaf[b] with pyrazon, ethofumesate, or cycloate followed by postemergence applications of glyphosate[c] to sugarbeet at the Michigan Sugar Co. site in 1998.

--- Program---		Rate	Applied	------ % Control ------			Yield	--Recov. Sugar[d]--		Cost[e]
#	Herbicide	Kg/ha	Date	Colq	Rrpw	Vele	Mg/ha	Kg/T	Kg/ha	$/ha
1	None	N/A	N/A	0	0	0	20.6	88	1821 b	$ 0
2	Glyt	0.63	5/21	98	87	98	50.7	91	4614 a	$ 55
	Glyt	0.63	6/22							
3	Cycl	4.48	5/6	100	99	100	57.4	95	5442 a	$ 155
	Glyt	0.63	5/21							
	Glyt	0.63	6/22							
4	Pyzn	5.04	5/6	100	99	100	56.5	93	5286 a	$ 410
	Cycl	4.48	5/6							
	Glyt	0.63	5/21							
	Glyt	0.63	6/22							
5	Pyzn	5.04	5/6	96	96	98	50.9	94	4790 a	$ 305
	Glyt	0.63	5/21							
	Glyt	0.63	6/22							
6	Pyzn	2.52	5/6	97	92	96	53.0	95	5019 a	$ 180
	Glyt	0.63	5/21							
	Glyt	0.63	6/22							
7	Etho	2.24	5/6	98	100	100	57.7	91	5233 a	$ 540
	Pyzn	5.04	5/6							
	Glyt	0.63	5/21							
	Glyt	0.63	6/22							
8	Etho	1.12	5/6	97	95	99	54.7	89	4853 a	$ 300
	Pyzn	2.52	5/6							
	Glyt	0.63	5/21							
	Glyt	0.63	6/22							
	$LSD_{0.05}$			4.1	13.5	4.6	16.3	N/S		
	CV%			3.2	11.1	3.7	22.2	8.8		

[a]Yield represents the weight of sugarbeet root from the field in Mg/ha on October 5, 1998.

[b]Weed control rated July 27, 1998. Colq – common lambsquarters, Rrpw – redroot pigweed, Vele - velvetleaf

[c]Cycl – cycloate, Etho – ethofumesate, Glyt – glyphosate, Pyzn – pyrazon

[d]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[e]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 17 – Yield[a] and control of common lambsquarters, redroot pigweed, and velvetleaf[b] with pyrazon, ethofumesate, or cycloate followed by postemergence applications of glufosinate[c] to sugarbeet at the Michigan Sugar Co. site in 1998.

--- Program---		Rate	Applied	------	% Control	------	Yield	Recov. Sugar[d]		Cost[e]
#	Herbicide	Kg/ha	Date	Colq	Rrpw	Vele	Mg/ha	Kg/T	Kg/ha	$/ha
1	None	N/A	N/A	0	0	0	13.7	112	1537 c	$ 0
2	Gluf	0.29	5/12	88	94	100	46.9	110	5156 ab	$ 140
	Gluf	0.29	6/5							
	Gluf	0.4	6/15							
3	Cycl	4.48	4/28	82	97	100	43.1	109	4695 b	$ 245
	Gluf	0.29	5/21							
	Gluf	0.29	5/27							
	Gluf	0.4	6/15							
4	Cycl	4.48	4/28	93	100	100	52.5	113	5942 a	$ 495
	Pyzn	5.04	4/28							
	Gluf	0.29	5/21							
	Gluf	0.29	5/27							
	Gluf	0.4	6/15							
5	Pyzn	5.04	4/28	76	95	100	41.5	113	4691 b	$ 390
	Gluf	0.29	5/21							
	Gluf	0.29	5/27							
	Gluf	0.4	6/15							
6	Pyzn	2.52	4/28	78	98	100	42.2	111	4697 b	$ 265
	Gluf	0.29	5/21							
	Gluf	0.29	5/27							
	Gluf	0.4	6/15							
7	Etho	2.24	4/28	91	97	100	44.2	113	5003 ab	$ 585
	Pyzn	5.04	4/28							
	Gluf	0.29	5/21							
	Gluf	0.29	5/27							
	Gluf	0.4	6/15							
8	Etho	1.12	4/28	80	100	100	47.4	113	5373 ab	$ 365
	Pyzn	2.52	4/28							
	Gluf	0.29	5/21							
	Gluf	0.29	5/27							
	Gluf	0.4	6/15							
	$LSD_{0.05}$			16.9	5	-	9.2	N/S		
	CV%			15.7	4.1	-	15.3	4.1		

[a]Yield represents the weight of sugarbeet root from the field in Mg/ha harvested October 5, 1998.

[b]Weed control rated July 27, 1998. Colq – common lamsquarters, Rrpw – redroot pigweed, Vele - velvetleaf

[c]Cycl – cycloate, Etho – ethofumesate, Gluf - glufosinate, Pyzn – pyrazon

[d]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[e]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 18 – Yield[a] and control[b] of common lambsquarters and redroot pigweed with pyrazon or ethofumesate followed by postemergence applications of glyphosate[c] to sugarbeet at the Monitor Sugar Co. site in 1998.

--- Program--- #	Herbicide	Rate Kg/ha	Applied Date	% Weed Control Colq	Rrpw	Yield T/ha	Recov. Sugar[d] Kg/T	Kg/ha	Cost[e] $/ha
1	None	N/A	N/A	0	0	25.8	119	3062 b	$ 0
2	Glyt	0.63	5/19	90	97	52.7	116	6104 a	$ 55
	Glyt	0.63	6/4						
3	Etho	1.68	5/8	93	100	51.4	119	6111 a	$ 235
	Glyt	0.63	5/19						
	Glyt	0.63	6/4						
4	Etho	0.84	5/8	83	95	49.8	118	5901 a	$ 145
	Glyt	0.63	5/19						
	Glyt	0.63	6/4						
5	Pyzn	4.48	5/8	94	100	48.3	113	5460 a	$ 285
	Glyt	0.63	5/19						
	Glyt	0.63	6/4						
6	Pyzn	2.24	5/8	91	97	56.5	115	6477 a	$ 170
	Glyt	0.63	5/19						
	Glyt	0.63	6/4						
7	Pyzn	1.68	5/8	95	95	54.4	120	6509 a	$ 350
	Etho	1.68	5/8						
	Glyt	0.63	5/19						
	Glyt	0.63	6/4						
8	Pyzn	1.68	5/8	90	100	51.6	118	6107 a	$ 240
	Etho	0.84	5/8						
	Glyt	0.63	5/19						
	Glyt	0.63	6/4						
9	Hand-weed	N/A	N/A	100	100	52.3	120	6256 a	-
	$LSD_{0.05}$			8.5	6.2	9.3	N/S		
	CV%			7.1	4.87	12.9	5.4		

[a]Yield represents the weight of sugarbeet root from the field in Mg/ha harvested October 9, 1998.

[b]Weed control rated July 9, 1998. Colq – common lambsquarters, Rrpw – redroot pigweed

[c]Cycl – cycloate, Etho – ethofumesate, Glyt – glyphosate, Pyzn – pyrazon

[d]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[e]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 19 – Yield[a] and control of common lambsquarters and redroot pigweed[b] with pyrazon or ethofumesate followed by postemergence applications of glufosinate or desmedipham and phenmedipham plus triflusulfuron plus clopyralid[c] to sugarbeet at the Monitor Sugar Co. site in 1998.

---- Program-----		Rate	Applied	%Weed Control		Yield	Recov. Sugar[d]		Cost[e]
#	Herbicide	Kg/ha	Date	Colq	Rrpw	T/ha	Kg/T	Kg/ha	$/ha
1	None	N/A	N/A	0	0	24.0	126	3021 b	$ 0
2	Gluf	0.29	5/19	88	98	45.1	128	5755 a	$ 85
	Gluf	0.29	6/4						
3	Etho	1.68	5/8	92	100	51.6	126	6498 a	$ 265
	Gluf	0.29	5/19						
	Gluf	0.29	6/4						
4	Etho	0.84	5/8	94	97	49.2	127	6242 a	$ 175
	Gluf	0.29	5/19						
	Gluf	0.29	6/4						
5	Pyzn	4.48	5/8	92	94	51.6	124	6374 a	$ 315
	Gluf	0.29	5/19						
	Gluf	0.29	6/4						
6	Pyzn	2.24	5/8	93	98	48.9	124	6064 a	$ 200
	Gluf	0.29	5/19						
	Gluf	0.29	6/4						
7	Pyzn	1.68	5/8	89	99	48.7	124	6049 a	$ 380
	Etho	1.68	5/8						
	Gluf	0.29	5/19						
	Gluf	0.29	6/4						
8	Pyzn	1.68	5/8	89	99	56.8	131	7464 a	$ 290
	Etho	0.84	5/8						
	Gluf	0.29	5/19						
	Gluf	0.29	6/4						
9	Desm&phen	0.56	5/15	86	99	43.4	125	5435 a	$ 350
	Tfsu	0.0174	5/15						
	Desm&phen	0.56	6/1						
	Tfsu	0.0174	6/1						
	Clpy	0.105	6/1						
10	Etho	1.68	5/8	87	94	47.4	127	6003 a	$ 535
	Desm&phen	0.56	5/15						
	Tfsu	0.0174	5/15						
	Desm&phen	0.56	6/1						
	Tfsu	0.0174	6/1						
	Clpy	0.105	6/1						
11	Pyzn	4.48	5/8	92	98	47.2	128	6026 a	$ 585
	Desm&phen	0.56	5/15						
	Tfsu	0.0174	5/15						
	Desm&phen	0.56	6/1						
	Tfsu	0.0174	6/1						
	Clyp	0.105	6/1						

12	Pyzn	3.36	5/8	93	96	47.8	131	6242 a	$ 710
	Etho	1.68	5/8						
	Desm&phen	0.56	5/15						
	Tfsu	0.0174	5/15						
	Desm&phen	0.56	6/1						
	Tfsu	0.0174	6/1						
	Clpy	0.105	6/1						
	$LSD_{0.05}$			13	6.1	14.0	N/S		
	CV%			10.8	4.75	20.7	4.4		

[a]Yield represents the weight of sugarbeet root from the field in Mg/ha.harvested October 9, 1998.

[b]Weed control was rated July 9, 1998. Colq – common lambsquarters, Rrpw – redroot pigweed

[c]Clpy – clopyralid, Cycl – cycloate, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate, Gluf - glufosinate, Pyzn – pyrazon, Tfsu - triflusulfuron

[d]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[e]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 20 – Control of common lambsquarters, redroot pigweed, and Pennsylvania smartweed[a] in glyphosate resistant sugarbeet at the Saginaw Valley Bean & Beet Farm in 1998.

----- Program-----		Rate	Applied	---------- % Control ----------			Cost[c]
#	Herbicide[b]	Kg/ha	Date	Colq	Rrpw	Pesw	$/ha
1	None	N/A	N/A	0	0	0	$ 0
2	Glyt	0.63	6/11/98	100	100	100	$ 55
	Glyt	0.63	6/25/98				
3	Etho	1.68	5/11/98	100	100	100	$ 235
	Glyt	0.63	6/11/98				
	Glyt	0.63	6/25/98				
4	Etho	0.84	5/11/98	96	100	100	$ 145
	Glyt	0.63	6/11/98				
	Glyt	0.63	6/25/98				
5	Pyzn	4.48	5/11/98	100	100	100	$ 285
	Glyt	0.63	6/11/98				
	Glyt	0.63	6/25/98				
6	Pyzn	2.24	5/11/98	97.5	100	100	$ 170
	Glyt	0.63	6/11/98				
	Glyt	0.63	6/25/98				
7	Pyzn	3.36	5/11/98	100	100	100	$ 410
	Etho	1.68	5/11/98				
	Glyt	0.63	6/11/98				
	Glyt	0.63	6/25/98				
8	Pyzn	1.68	5/11/98	100	100	100	$ 235
	Etho	0.84	5/11/98				
	Glyt	0.63	6/11/98				
	Glyt	0.63	6/25/98				
9	Cycl	3.36	5/11/98	95	97.5	100	$ 160
	Glyt	0.63	6/11/98				
	Glyt	0.63	6/25/98				
10	Desm&Phen	0.56	6/11/98	100	97.5	82.5	$ 350
	Tfsu	0.0174	6/11/98				
	Desm&Phen	0.56	6/17/98				
	Tfsu	0.0174	6/17/98				
	Clpy	0.105	6/17/98				
11	Etho	1.68	5/11/98	92.5	95	100	$ 535
	Desm&Phen	0.56	6/11/98				
	Tfsu	0.0174	6/11/98				
	Desm&Phen	0.56	6/17/98				
	Tfsu	0.0174	6/17/98				
	Clpy	0.105	6/17/98				
12	Pyzn	4.48	5/11/98	100	100	95	$ 585
	Desm&Phen	0.56	6/11/98				
	Tfsu	0.0174	6/11/98				
	Desm&Phen	0.56	6/17/98				
	Tfsu	0.0174	6/17/98				
	Clpy	0.105	6/17/98				

13	Pyzn	3.36	5/11/98	82.5	92.5	85	$ 710
	Etho	1.68	5/11/98				
	Desm&Phen	0.56	6/11/98				
	Tfsu	0.0174	6/11/98				
	Desm&Phen	0.56	6/17/98				
	Triflusulfuron	0.0174	6/17/98				
14	Cycl	3.36	5/11/98	100	100	95	$ 460
	Desm&Phen	0.56	6/11/98				
	Tfsu	0.0174	6/11/98				
	Clpy	0.105	6/17/98				
	Desm&Phen	0.56	6/17/98				
	Triflusulfuron	0.0174	6/17/98				
	$LSD_{0.05}$			9.5	7.3	13.1	
	CV%			4.9	3.7	6.9	

[a]Weed control was rated July 27, 1998. Colq – common lambsquarters, Rrpw – redroot pigweed, Pesw – Pennsylvania smartweed

[b]Clpy – clopyralid, Cycl – cycloate, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate, Glyt – glyphosate, Pyzn – pyrazon, Tfsu - triflusulfuron

[c]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 21 – Control of common lambsquarters, redroot pigweed, velvetleaf, and Pennsylvania smartweed[a] in glufosinate resistant sugarbeet at the Saginaw Valley Bean & Beet Farm in 1998.

----- Program-----		Rate	Applied	-------- % Weed	Control --------			Cost[c]
#	Herbicide[b]	Kg/ha	Date	Colq	Rrpw	Vele	Pesw	$/ha
1	None	N/A	N/A	0	0	0	0	$ 0
2	Gluf	0.29	5/19/98	67	92	100	92	$ 85
	Gluf	0.29	6/4/98					
3	Etho	1.68	4/27/98	91	100	90	100	$ 265
	Gluf	0.29	5/19/98					
	Gluf	0.29	6/4/98					
4	Etho	0.84	4/27/98	91	100	100	92	$ 175
	Gluf	0.29	5/19/98					
	Gluf	0.29	6/4/98					
5	Pyzn	4.48	4/27/98	95	97	97	100	$ 315
	Gluf	0.29	5/22/98					
	Gluf	0.29	6/11/98					
6	Pyzn	2.24	4/27/98	91	100	97	100	$ 200
	Gluf	0.29	5/19/98					
	Gluf	0.29	6/4/98					
7	Pyzn	3.36	4/27/98	100	100	97	100	$ 440
	Etho	1.68	4/27/98					
	Gluf	0.29	5/22/98					
	Gluf	0.29	6/11/98					
8	Pyzn	1.68	4/27/98	100	92	99	100	$ 265
	Etho	0.84	4/27/98					
	Gluf	0.29	5/19/98					
	Gluf	0.29	6/11/98					
9	Cycl	3.36	4/27/98	96	100	100	98	$ 190
	Gluf	0.29	5/22/98					
	Gluf	0.29	6/11/98					
10	Desm&Phen	0.56	5/15/98	92	100	85	85	$ 350
	Tfsu	0.0174	5/15/98					
	Desm&Phen	0.56	5/22/98					
	Tfsu	0.0174	5/22/98					
	Clpy	0.105	5/22/98					
11	Etho	1.68	4/27/98	100	100	87	100	$ 535
	Desm&Phen	0.56	5/15/98					
	Tfsu	0.0174	5/15/98					
	Desm&Phen	0.56	5/22/98					
	Tfsu	0.0174	5/22/98					
	Clpy	0.105	5/22/98					

12	Pyzn	4.48	4/27/98	100	100	80	90	$ 585
	Desm&Phen	0.56	5/15/98					
	Tfsu	0.0174	5/15/98					
	Desm&Phen	0.56	5/22/98					
	Tfsu	0.0174	5/22/98					
	Clpy	0.105	5/22/98					
13	Pyzn	3.36	4/27/98	100	100	78	100	$ 710
	Etho	1.68	4/27/98					
	Desm&Phen	0.56	5/15/98					
	Tfsu	0.0174	5/15/98					
	Desm&Phen	0.56	5/22/98					
	Tfsu	0.0174	5/22/98					
	Clpy	0.105	5/22/98					
14	Cycl	3.36	4/27/98	100	100	100	100	$ 460
	Desm&Phen	0.56	5/15/98					
	Tfsu	0.0174	5/15/98					
	Clpy	0.105	5/22/98					
	Desm&Phen	0.56	5/22/98					
	Tfsu	0.0174	5/22/98					
	$LSD_{0.05}$			6.9	8.5	18.5	12.7	
	CV%			3.7	4.3	10	6.7	

[a]Weed control was rated July 9, 1998. Colq – common lambsquarters, Rrpw – redroot pigweed

[b]Clpy – clopyralid, Cycl – cycloate, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate,
Gluf - glufosinate, Pyzn – pyrazon, Tfsu - triflusulfuron

[c]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 22 – Sugarbeet injury[a], yield[b], and control of common lambsquarters and redroot pigweed[c] with pyrazon, ethofumesate, or cycloate followed by postemergence applications of glyphosate or desmedipham and phenmedipham plus triflusulfuron plus clopyralid[d] to sugarbeet at the Michigan Sugar Co. site in 1999.

---- Program----		Rate	Applied	Injury	------ % Control ------			Yield	Recov.	Sugar[e]	Cost[f]
#	Herbicide	kg/ha	Date	%	Colq	Rrpw	Vele	T/ha	kg/T	kg/ha	$/ha
1	None	N/A	N/A	3	0	0	0	35.0	131	4538 d	$ 0
2	Glyt	0.63	5/19	3	100	100	100	49.2	126	6202 a-c	$ 55
	Glyt	0.63	6/18								
3	Cycl	4.48	4/30	7	92	91	100	48.3	129	6223 a-c	$ 270
	Glyt	0.63	5/19								
	Glyt	0.63	6/18								
4	Cycl	4.48	4/30	6	98	98	100	47.7	132	6289 a-c	$ 550
	Pyzn	5.04	5/1								
	Glyt	0.63	5/19								
	Glyt	0.63	6/18								
	Glyt	0.63	7/13								
5	Cycl	2.24	4/30	4	98	91	100	46.8	131	6128 a-c	$ 190
	Glyt	0.63	5/19								
	Glyt	0.63	6/18								
	Glyt	0.63	7/13								
6	Cycl	2.24	4/13	6	100	100	100	47.8	127	6062 a-c	$ 315
	Pyzn	2.52	5/1								
	Glyt	0.63	5/19								
	Glyt	0.63	6/18								
	Glyt	0.63	7/13								
7	Pyzn	5.04	5/1	6	100	100	100	48.2	132	6352 a-c	$ 330
	Glyt	0.63	5/19								
	Glyt	0.63	6/18								
	Glyt	0.63	7/13								
8	Pyzn	2.52	5/1	6	100	100	99	49.7	131	6459 ab	$ 205
	Glyt	0.63	5/19								
	Glyt	0.63	6/18								
	Glyt	0.63	7/13								
9	Etho	2.24	5/1	5	99	100	100	56.6	127	7050 a	$ 545
	Pyzn	5.04	5/1								
	Glyt	0.63	5/19								
	Glyt	0.63	6/18								
10	Etho	1.12	5/1	5	85	89	100	52.1	125	6522 ab	$ 300
	Pyzn	2.52	5/1								
	Glyt	0.63	5/19								
	Glyt	0.63	6/18								
11	Glyt	0.63	5/19	3	76	79	87	47.8	128	6041 a-c	$ 305
	Glyt	0.63	6/18								
	Pyzn	5.04	6/18								

12	Desm&Phen	0.56	5/19	29	76	76	100	43.5	124	5367 b-d	$ 355
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
13	Cycl	4.48	4/30	32	90	91	100	44.7	123	5450 b-d	$ 455
	Desm&Phen	0.56	5/19								
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
14	Cycl	4.48	4/30	32	95	91	93	43.7	122	5329 b-d	$ 705
	Pyzn	5.04	5/1								
	Desm&Phen	0.56	5/19								
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
15	Pyzn	5.04	5/1	34	85	81	86	41.2	124	5056 cd	$ 605
	Desm&Phen	0.56	5/19								
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
16	Pyzn	5.04	5/1	38	85	90	87	37.1	120	4419 d	$ 845
	Etho	2.24	5/1								
	Desm&Phen	0.56	5/19								
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
	$LSD_{0.05}$			10	16.2	16.9	14.2	12.6	N/S		
	CV %			51.3	13.1	13.7	11	19.1	5.24		

[a]Injury was recorded on June 11, 1999.

[b]Yield represents the weight of sugarbeet root from the field in Mg/ha.harvested October 5, 1998.

[c]Weed control was rated July 20, 1999. Colq – common lambsquarters, Rrpw – redroot pigweed

[d]Clpy – clopyralid, Cycl – cycloate, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate, Glyt - glyfosate, Pyzn – pyrazon, Tfsu - triflusulfuron

[e]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[f]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 23 – Sugarbeet injury[a], yield[b], and control of common lambsquarters and redroot pigweed[c] with pyrazon, ethofumesate, or cycloate followed by postemergence applications of glufosinate or desmedipham and phenmedipham plus triflusulfuron plus clopyralid[d] to sugarbeet at the Michigan Sugar Co. site in 1999.

---- Program----		Rate	Applied	Injury	----- % Control -----			Yield	Recov. Sugar[e]		Cost[f]
#	Herbicide	kg/ha	Date	%	Colq	Rrpw	Vele	T/ha	kg/T	kg/ha	$/ha
1	None	N/A	N/A	1	0	0	0	42.0	126	5307 e	$ 0
2	Gluf	0.4	5/19	5	98	89	100	62.2	123	7673 ab	$ 170
	Gluf	0.4	6/10								
	Gluf	0.4	6/18								
3	Gluf	0.4	5/19	0	95	90	93	57.6	126	7245 a-c	$ 115
	Gluf	0.4	6/10								
4	Cycl	4.48	4/30	1	100	82	100	61.4	122	7469 a	$ 215
	Gluf	0.4	5/19								
	Gluf	0.4	6/18								
5	Cycl	4.48	4/30	3	100	98	100	56.8	124	7015 a-d	$ 470
	Pyzn	5.04	5/1								
	Gluf	0.4	5/19								
	Gluf	0.4	6/18								
	Gluf	0.4	7/13								
6	Cycl	2.24	4/30	3	100	97	100	60.5	122	7355 ab	$ 220
	Gluf	0.4	5/19								
	Gluf	0.4	6/18								
	Gluf	0.4	7/13								
7	Cycl	2.24	4/13	1	99	96	97	57.6	127	7308 ab	$ 320
	Pyzn	2.52	5/1								
	Gluf	0.4	5/19								
	Gluf	0.4	6/10								
	Gluf	0.4	7/13								
8	Pyzn	5.04	5/1	1	100	100	99	61.4	131	8049 a	$ 420
	Gluf	0.4	5/19								
	Gluf	0.4	6/10								
	Gluf	0.4	7/13								
9	Pyzn	2.52	5/1	0	100	100	100	62.6	127	7935 a	$ 295
	Gluf	0.4	5/19								
	Gluf	0.4	6/10								
	Gluf	0.4	7/13								
10	Etho	2.24	5/1	6	98	90	100	54.1	126	6780 a-d	$ 605
	Pyzn	5.04	5/1								
	Gluf	0.4	5/19								
	Gluf	0.4	6/18								
11	Etho	1.12	5/1	6	100	81	100	57.1	127	7249 a-c	$ 360
	Pyzn	2.52	5/1								
	Gluf	0.4	5/19								
	Gluf	0.4	6/18								

12	Desm&Phen	0.56	5/19	13	46	47	62	45.5	124	5765 de	$ 350
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
13	Cycl	4.48	4/30	20	92	79	90	52.9	129	6803 a-d	$ 455
	Desm&Phen	0.56	5/19								
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
14	Cycl	4.48	4/30	20	95	90	80	53.1	123	6678 a-e	$ 705
	Pyzn	5.04	5/1								
	Desm&Phen	0.56	5/19								
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
15	Pyzn	5.04	5/1	12	81	78	87	47.1	124	5895 c-e	$ 605
	Desm&Phen	0.56	5/19								
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
16	Pyzn	5.04	5/1	20	93	85	82	51.0	123	6295 b-e	$ 845
	Etho	2.24	5/1								
	Desm&Phen	0.56	5/19								
	Tfsu	0.0174	5/19								
	Desm&Phen	0.56	5/27								
	Tfsu	0.0174	5/27								
	Clpy	0.105	5/27								
	$LSD_{0.05}$			9.3	18.2	17	24.4	10.9	N/S		
	CV %			94.3	14.5	14.6	19.6	13.8	5.8		

[a]Injury was recorded on June 11, 1999.

[b]Yield represents the weight of sugarbeet root from the field in Mg/ha.harvested October 5, 1998.

[c]Weed control was rated July 20, 1999. Colq – common lambsquarters, Rrpw – redroot pigweed

[d]Clpy – clopyralid, Cycl – cycloate, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate, Gluf – glufosinate, Pyzn – pyrazon, Tfsu - triflusulfuron

[e]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[f]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 24 – Sugarbeet injury[a] and control of annual grass, common lambsquarters, and redroot pigweed[b] with ethofumesate or pyrazon followed by glyphosate or desmedipham and phenmedipham plus triflusulfuron plus clopyralid[c] in sugarbeet at Monitor Sugar Co. site in 1999.

---- Program----		Rate	Applied	Injury	-------- % Control --------			Cost[d]
#	Herbicide	kg/ha	Date	%	ANGR	Colq	Rrpw	$/ha
1	None	N/A	N/A	1	0	0	0	$ 0
2	Glyt	0.63	5/28	3	100	100	100	$ 80
	Glyt	0.63	6/10					
	Glyt	0.63	7/9					
3	Glyt	0.63	5/28	2	97	97	92	$ 55
	Glyt	0.63	6/10					
4	Desm&phen	0.56	5/20	24	44	89	80	$ 350
	Tfsu	0.0174	5/20					
	Desm&phen	0.56	6/3					
	Tfsu	0.0174	6/3					
	Clpy	0.105	6/3					
5	Pyzn	4.48	5/4	4	99	99	100	$ 285
	Glyt	0.63	5/28					
	Glyt	0.63	6/23					
6	Pyzn	2.24	5/4	4	97	99	99	$ 170
	Glyt	0.63	5/28					
	Glyt	0.63	6/10					
7	Pyzn	4.48	5/4	17	51	97	94	$ 585
	Desm&phen	0.56	5/20					
	Tfsu	0.0174	5/20					
	Desm&phen	0.56	6/3					
	Tfsu	0.0174	6/3					
	Clpy	0.105	6/3					
8	Etho	1.68	5/4	4	100	100	100	$ 295
	Glyt	0.63	6/3					
	Glyt	0.63	6/23					
9	Etho	1.68	5/4	22	96	98	100	$ 535
	Desm&phen	0.56	5/20					
	Tfsu	0.0174	5/20					
	Desm&phen	0.56	6/3					
	Tfsu	0.0174	6/3					
	Clpy	0.105	6/3					
10	Pyzn	3.36	5/4	1	100	99	100	$ 410
	Etho	1.68	5/4					
	Glyt	0.63	6/3					
	Glyt	0.63	6/23					
11	Pyzn	1.68	5/4	6	100	98	100	$ 235
	Etho	0.84	5/4					
	Glyt	0.63	6/3					
	Glyt	0.63	6/23					

12	Pyzn	3.36	5/4	19	89	97	97	$ 710
	Etho	1.68	5/4					
	Desm&phen	0.56	5/20					
	Tfsu	0.0174	5/20					
	Desm&phen	0.56	6/3					
	Tfsu	0.0174	6/3					
	Clpy	0.105	6/3					
	$LSD_{0.05}$			3.7	14.3	7.3	7.3	
	CV %			28.2	12.2	5.6	5.7	

[a]Injury was recorded on June 11, 1999.

[b]Weed control was rated July 20, 1999. Angr – annual grass, Colq – common lambsquarters, Rrpw – redroot pigweed

[c]Clpy – clopyralid, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate, Glyt - glyfosate, Pyzn – pyrazon, Tfsu - triflusulfuron

[d]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 25 – Sugarbeet injury[a], yield[b], and control of annual grass, common lambsquarters and redroot pigweed[c] with ethofumesate or pyrazon followed by postemergence applications of glufosinate or desmedipham and phenmedipham plus triflusulfuron plus clopyralid[d] to sugarbeet at the Monitor Sugar Co. site in 1999.

--- Program----		Rate	Applied	Injury	------- % Control ------			Yield	Sugar[e]	Cost[f]
#	Herbicide	kg/ha	Date	%	ANGR	Colq	Rrpw	T/ha	kg/ha	$/ha
1	None	N/A	N/A	1	0	0	0	35.0	4583 b	$ 0
2	Gluf	0.4	5/28	0	100	98	100	55.0	7054 a	$ 170
	Gluf	0.4	6/10							
	Gluf	0.4	7/9							
3	Gluf	0.4	5/28	1	97	94	96	54.8	7127 a	$ 115
	Gluf	0.4	6/10							
4	Desm&phen	0.56	5/20	10	51	80	94	51.6	6618 a	$ 350
	Tfsu	0.0174	5/20							
	Desm&phen	0.56	6/3							
	Tfsu	0.0174	6/3							
	Clpy	0.105	6/3							
5	Pyzn	4.48	5/4	0	99	96	99	56.8	7413 a	$ 345
	Gluf	0.4	5/28							
	Gluf	0.4	6/23							
6	Pyzn	2.24	5/4	0	97	98	98	53.0	6605 a	$ 205
	Gluf	0.4	5/28							
	Gluf	0.4	6/10							
7	Pyzn	4.48	5/4	13	79	94	92	53.5	6698 a	$ 585
	Desm&phen	0.56	5/20							
	Tfsu	0.0174	5/20							
	Desm&phen	0.56	6/3							
	Tfsu	0.0174	6/3							
	Clpy	0.105	6/3							
8	Etho	1.68	5/4	3	99	99	100	59.5	7730 a	$ 295
	Gluf	0.4	6/3							
	Gluf	0.4	6/23							
9	Etho	1.68	5/4	11	89	100	100	50.6	6479 ab	$ 535
	Desm&phen	0.56	5/20							
	Tfsu	0.0174	5/20							
	Desm&phen	0.56	6/3							
	Tfsu	0.0174	6/3							
	Clpy	0.105	6/3							
10	Pyzn	3.36	5/4	0	97	99	100	52.4	6967 a	$ 470
	Etho	1.68	5/4							
	Gluf	0.4	6/3							
	Gluf	0.4	6/23							
11	Pyzn	1.68	5/4	3	99	99	100	53.7	7106 a	$ 295
	Etho	0.84	5/4							
	Gluf	0.4	6/3							
	Gluf	0.4	6/23							

12	Pyzn	3.36	5/4	12	92	100	100	56.4	6447 ab	$ 710
	Etho	1.68	5/4							
	Desm&phen	0.56	5/20							
	Tfsu	0.0174	5/20							
	Desm&phen	0.56	6/3							
	Tfsu	0.0174	6/3							
	Clpy	0.105	6/3							
	$LSD_{0.05}$			3.3	19.7	6.8	7.8	5.0		
	CV %			51.2	16.3	5.3	6.0	6.9		

[a]Injury was recorded on June 11, 1999.

[b]Yield represents the weight of sugarbeet root from the field in Mg/ha.harvested October 15, 1999.

[c]Weed control was rated July 20, 1999. Angr – annual grass, Colq – common lambsquarters, Rrpw – redroot pigweed

[d]Clpy – clopyralid, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate, Gluf – glufosinate, Pyzn – pyrazon, Tfsu - triflusulfuron

[e]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[f]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 26 – Sugarbeet injury[a], yield[b], and control of common lambsquarters and redroot pigweed[c] with pyrazon, ethofumesate, or cycloate followed by postemergence applications of glyphosate or desmedipham and phenmedipham plus triflusulfuron plus clopyralid[d] to sugarbeet at the Saginaw Valley Bean and Beet Farm in 1999.

----- Program-----		Rate	Applied	Injury	% Weed Control		Yield	Recov. Sugar[e]		Cost[f]
#	Herbicide	kg/ha	Date	%	Colq	Rrpw	T/ha	kg/T	Kg/ha	$/ha
1	None	N/A	N/A	0	0	0	51.9	117	5841 f	$ 0
2	Glyt	0.63	5/27	0	100	100	79.3	115	9128 a-d	$ 80
	Glyt	0.63	6/17							
	Glyt	0.63	7/7							
3	Glyt	0.63	5/27	1	100	100	85.5	116	9952 ab	$ 55
	Glyt	0.63	6/17							
4	Desm&phen	0.56	5/19	19	52	79	77.3	115	8858 b-e	$ 350
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
5	Pyzn	4.48	4/28	4	100	100	80.6	117	9444 a-d	$ 285
	Glyt	0.63	5/27							
	Glyt	0.63	6/17							
6	Pyzn	2.24	4/28	6	100	100	76.7	117	8984 a-e	$ 170
	Glyt	0.63	5/27							
	Glyt	0.63	6/17							
7	Pyzn	4.48	4/28	21	100	100	69.8	113	7899 e	$ 585
	Desm&phen	0.56	5/19							
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
8	Etho	1.68	4/28	1	100	100	77.7	116	8992 a-e	$ 235
	Glyt	0.63	6/1							
	Glyt	0.63	6/24							
9	Etho	0.84	4/28	3	100	100	81.1	117	9484 a-c	$ 145
	Glyt	0.63	6/1							
	Glyt	0.63	6/24							
10	Etho	1.68	4/28	24	100	100	74.3	117	8681 c-e	$ 535
	Desm&phen	0.56	5/19							
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
11	Pyzn	3.36	4/28	0	100	100	78.7	116	9111 a-d	$ 410
	Etho	1.68	4/28							
	Glyt	0.63	6/1							
	Glyt	0.63	6/24							

12	Pyzn	1.68	4/28	4	100	100	86.9	117	10171 a	$ 235
	Etho	0.84	4/28							
	Glyt	0.63	6/1							
	Glyt	0.63	6/24							
13	Pyzn	3.36	4/28	24	100	98	71.7	115	8258 de	$ 710
	Etho	1.68	4/28							
	Desm&phen	0.56	5/19							
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
14	Cycl	3.36	4/27	1	100	100	78.4	117	9174 a-d	$ 130
	Glyt	0.63	6/1							
	Glyt	0.63	6/24							
15	Cycl	3.36	4/27	26	100	98	73.5	119	8789 b-e	$ 430
	Desm&phen	0.56	5/19							
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
16	Cycl	3.36	4/27	4	100	100	82.8	119	9868 a-c	$ 105
	Glyt	0.63	6/17							
	$LSD_{0.05}$			3.9	0.9	2.9	10.3	N/S		
	CV%			31.7	0.7	2.2	9.4	3.3		

[a]Injury was recorded on June 11, 1999.

[b]Yield represents the weight of sugarbeet root from the field in Mg/ha.harvested October 11, 1999.

[c]Weed control was rated July 20, 1999. Colq – common lambsquarters, Rrpw – redroot pigweed

[d]Clpy – clopyralid, Cycl – cycloate, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate, Glyt - glyfosate, Pyzn – pyrazon, Tfsu - triflusulfuron

[e]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[f]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.

Table 27 – Sugarbeet injury[a], yield[b], and control of common lambsquarters and redroot pigweed[c] with pyrazon, ethofumesate, or cycloate followed by postemergence applications of glufosinate or desmedipham and phenmedipham plus triflusulfuron plus clopyralid[d] to sugarbeet at the Saginaw Valley Bean and Beet Farm in 1999.

---- Program----		Rate	Applied	Injury	% Weed Control		Yield	Recov. Sugar[e]		Cost[f]
#	Herbicide	kg/ha	Date	%	Colq	Rrpw	T/ha	kg/T	kg/ha	$/ha
1	None	N/A	N/A	0	0	0	49.3	130	6410 e	$ 0
2	Gluf	0.4	5/27	1	100	100	72.2	135	9782 a-d	$ 170
	Gluf	0.4	6/17							
	Gluf	0.4	7/7							
3	Gluf	0.4	5/27	0	100	99	73.6	132	9687 a-d	$ 115
	Gluf	0.4	6/17							
4	Desm&phen	0.56	5/19	10	99	94	66.5	133	8855 d	$ 350
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
5	Pyzn	4.48	4/28	1	100	97	69.8	135	9421 a-d	$ 345
	Gluf	0.4	5/27							
	Gluf	0.4	6/17							
6	Pyzn	2.24	4/28	3	100	100	75.1	136	10174 ab	$ 230
	Gluf	0.4	5/27							
	Gluf	0.4	6/17							
7	Pyzn	4.48	4/28	11	100	99	69.2	133	9234 b-d	$ 585
	Desm&phen	0.56	5/19							
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
8	Etho	1.68	4/28	1	100	100	69.9	135	9470 a-d	$ 295
	Gluf	0.4	6/1							
	Gluf	0.4	6/24							
9	Etho	0.84	4/28	0	100	100	70.7	134	9470 a-d	$ 205
	Gluf	0.4	6/1							
	Gluf	0.4	6/24							
10	Etho	1.68	4/28	11	100	100	70.7	131	8976 cd	$ 535
	Desm&phen	0.56	5/19							
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
11	Pyzn	3.36	4/28	3	100	100	73.7	137	10092 a-c	$ 525
	Etho	1.68	4/28							
	Gluf	0.4	6/1							
	Gluf	0.4	6/24							

12	Pyzn	1.68	4/28	0	100	100	73.2	134	9830 a-d	$ 320
	Etho	0.84	4/28							
	Gluf	0.4	6/1							
	Gluf	0.4	6/24							
13	Pyzn	3.36	4/28	14	100	99	69.9	134	9405 a-d	$ 710
	Etho	1.68	4/28							
	Desm&phen	0.56	5/19							
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
14	Cycl	3.36	4/27	0	100	100	77.8	135	10485 a	$ 190
	Gluf	0.4	6/1							
	Gluf	0.4	6/24							
15	Cycl	3.36	4/27	10	100	99	69.4	133	9236 b-d	$ 430
	Desm&phen	0.56	5/19							
	Tfsu	0.0174	5/19							
	Desm&phen	0.56	6/4							
	Tfsu	0.0174	6/4							
	Clpy	0.105	6/4							
16	Cycl	3.36	4/27	0	100	97	69.0	132	9087 b-d	$ 135
	Gluf	0.4	6/17							
	$LSD_{0.05}$			2.9	0.9	2.9	8.4	N/S		
	CV %			50.7	0.7	2.2	8.3	2.7		

[a]Injury was recorded on June 11, 1999.

[b]Yield represents the weight of sugarbeet root from the field in Mg/ha.harvested October 11, 1999.

[c]Weed control was rated July 20, 1999. Colq – common lambsquarters, Rrpw – redroot pigweed

[d]Clpy – clopyralid, Cycl – cycloate, Desm&phen – desmedipham and phenmedipham, Etho – ethofumesate, Gluf – glufosinate, Pyzn – pyrazon, Tfsu - triflusulfuron

[e]Recoverable sugar is the amount of white sugar that can be obtained from the processing of sugarbeet roots, and is calculated using the yield, percent sucrose in the beet, and approximate purity of the juice.

[f]All prices in the tables reflect the cost of product, fuel, maintenance, repair, and labor associated with broadcast application of each herbicide program. Prices only reflect operating costs and do not include the cost of purchasing, owning, or storing equipment.