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An Evaluation of Postemergence Weed Control Options in Herbicide Resistant Isolines of Corn, *(Zea mays)*

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Major professor

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AN EVALUATION OF POSTEMERGENCE WEED CONTROL OPTIONS IN HERBICIDE RESISTANT ISOLINES OF CORN, (*Zea mays*)

By

Karen A. Zuver

A THESIS

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ABSTRACT

AN EVALUATION OF POSTEMERGENCE WEED CONTROL OPTIONS IN HERBICIDE RESISTANT ISOLINES OF CORN, *(Zea mays)*

By

Karen A. Zuver

Herbicide resistant hybrids offer new options for weed control in corn. Growers need more information on the consistency of these new weed control strategies. Studies were conducted in 2000 and 2001 in Indiana, Illinois, Michigan, and Ohio to evaluate the consistency of weed control among typical herbicide strategies for imidazolinone-resistant, glufosinate-resistant, and glyphosate-resistant corn. Also, these strategies were compared to typical preemergence and postemergence programs for conventional corn. Near-isogenic hybrids were utilized to minimize variation in growth and yield potential among hybrids. The glyphosate-POST treatment had the least variability for weed control across weed species. The conventional-POST treatment was less consistent for control of giant foxtail and *Amaranthus* species than the preemergence treatment. The imidazolinone-POST treatment was less effective for the control of common ragweed than other postemergence treatments. Glufosinate-POST was similar to the glyphosate-POST treatment with exception of giant foxtail and common cocklebur where the glyphosate-POST treatment was superior. Corn yield varied among locations and years. The glyphosate-POST treatment had no instances of reduced yield compared to the weed free. The conventional-POST treatment had significantly lower yield than the weed free in three of eight locations. The imidazolinone-POST and glufosinate-POST strategies had one location of significantly lower yield compared to the weed free.

Dedicated to my husband, Greg, and our children, Anna and Garrett.

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Nomenclature and Abbreviations

Metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide; atrazine, 2-chloro-4-(ethylamino)-6-isopropylamino-*s*-triazine; nicosulfuron, 2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide;rimsulfuron, *N*((4,6-dimethoxypyrimidin-2-yl)aminocarbonyl)-3-(ethylsulfonyl)-2-pyradinesulfonamide;dicamba, 3,6-dichloro-2-methoxybenzoic acid; imazethapyr, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxilic acid; imazapyr, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid; glufosinate, 2-amino-4-(hydroxymethylphosphinyl) butanoic acid; glyphosate, *N*-(phosphonylmethyl) glycine; giant foxtail, *Setaria faberi* (L.) Herrm.#[1] SETFA; common lambsquarters, *Chenopodium album* L. # CHEAL; amaranthus species, *Amaranthus* spp.; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; giant ragweed, *Ambrosia trifida* L. # AMBTR; morningglory species, *Ipomea* spp. IPOSS; velvetleaf, *Abutilon theophrasti* Medicus # ABUTH; common cocklebur, *Xanthium strumarium* L. # XANST; corn, *Zea mays* L. # ZEAMX.

Additional index words: corn yield, herbicide-resistant crop, herbicide system, ABUTH, *Amaranthus* species, AMBEL, AMBTR, *Ipomea* species, SETFA, XANST, conventional corn, imidazolinone, glufosinate, glyphosate.

Abbreviations: ALS, acetolactate synthase; LSD, least significant difference; conventional-POST, conventional corn postemergence treatment; imi-POST, imidazolinone-resistant corn treatment; glufosinate-POST, glufosinate-resistant corn

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

treatment; glyphosate-POST, glyphosate-resistant corn treatment; IN, Indiana; IL, Illinois; MI, Michigan; OH, Ohio.

Introduction

Alternative plant breeding methods have led to the use of resistance crops in Michigan, but many factors need to be considered when using any available technology for crop production. Michigan crop producers have questions regarding the type of traits available, benefits and risks of using resistance corn, and factors to consider in making seed selection.

The Michigan State University Extension Service provides access to information on crop production methods through applied research in the form of extension bulletins. Additional information is needed that provides a guide for using resistance traits in corn. The information will need to outline the factors in questions noted above, and provides guidance in selecting corn seed for commercial corn production.

Alternative Pest Management Options In Commercial Corn Production

Considerations for Using Resistance Traits in Corn

Corn seed selection involves a number of variables, which are different for every farm operator. Traditional or conventional corn hybrids are usually selected based on yield potential and other agronomic characteristics. However, the availability of technology traits, such as insect and herbicide resistance, have brought additional considerations into the decision making process.

Commonly asked questions arise when reviewing these technologies.

1. What traits are available?
2. What are the benefits and risks of these technologies?
3. What are the considerations for adopting these traits?

What traits are available in corn?

- Insect resistance traits and herbicide resistance traits are available.
- Corn that is protected against European corn borer and several other insects is protected through the protein toxin derived from bacteria, called *Bacillus thuringiensis* (Bt).
- There are three main types of herbicide resistant corn:

    1. glyphosate-resistant (Roundup Ready® corn)
    2. glufosinate-resistant (LibertyLink® corn)
    3. imidazolinone-resistant (Clearfield® corn)

- Many **events** are used for resistance in the commercially available corn genetics. An event is the successful transformation of a selected gene or genes from one species into the genetic profile of a target crop such as corn. Different events integrate diverse sources of resistance, which are expressed at different levels and in various parts of the corn tissue(s). It is important to refer to the product use guide of the particular hybrid that you would choose to verify the means of resistance and the level of expression of the particular trait.
- Also available is a combination of the insect and herbicide resistance termed "stacked traits." An example of this would be herbicide resistance with Roundup Ready® stacked with insect resistance using YieldGard® as the event for insect resistance.

What are the benefits and risks with these traits?

Insect-Resistant Corn -- Benefits

- Using insect-resistant corn for insect control greatly reduces the need for an over-the-top application of an insecticide for some corn-damaging insects.

- The use of Bt-corn will likely provide more consistent control of the targeted pests than insecticide, and is safer for the environment in terms of insecticide application.
- Insects such as European corn borer and corn earworm provide an entry point for disease as well. If boring-type insects are more consistently controlled, this may reduce pathogen infections.
- Lastly, the use of a corn with an integrated trait for insect resistance provides "insurance" against a possible pest infestation. Fields that may not be regularly scouted, or fields that are located in areas that are difficult to get to for in-season application, may benefit from an integrated trait to protect against possible insect damage.

Insect-Resistant Corn -- Risks

- The insect-resistance generally carries an additional cost on a per unit basis. If the added cost were $18 dollars per unit, then it would take nine extra bushels as compared to a non-Bt corn to break even on the investment at a market price for corn of $2 per bushel.
- Insect resistance management is necessary to maintain the effectiveness of integrated technology. Insect resistance management can be viewed as maintaining an area of refuge for insects to breed and populate in order to not overexpose an insect population to the Bt toxins and create resistant insects. Currently the Environmental Protection Agency mandates an 80-percent maximum for Bt-protected crops. That leaves a 20-percent minimum requirement

for conventional plants of the same crop species. There are several planting strategies available to achieve the 80:20 ratio.

- At this time, marketing of Bt-corn has no restrictions worldwide. However, if the Bt trait is stacked or integrated with another type of transgenic trait, such as herbicide resistance, there may be marketing restrictions. In the case of a stacked trait situation, there is a variable acceptance by foreign grain markets depending on the brand of the seed. It is important to contact a representative from the specific company to answer your marketing questions.

Herbicide-Resistant Corn – Benefits

- Competition from "hard-to-control" weeds can significantly affect yield.
- Rotation issues arise in specialty crop areas. Many herbicides have residual activity and therefore can carryover into sensitive crops. Use of non-residual herbicides, (that become inactive upon contact with the soil), for weed control can reduce that concern.
- Application of non-selective, broad spectrum, herbicides is easier than a tank-mix combination. Needing fewer herbicides in the tank mixture is easier for the handler and presents less opportunity for error.
- Crop safety is an important factor with weed management programs. With herbicide-resistant crops, labeled applications of the partnered herbicides on the proper hybrid provide less risk for herbicide injury than many selective herbicides on conventional crops.

Herbicide-Resistant Corn – Risks

- The issue of resistant weeds is already a problem throughout the Midwest and in Michigan. Continuous use of herbicide-resistant crops in a rotation can be a considerable problem if the same class of herbicides is routinely applied. Examples of this may include the use of STS® soybeans followed by the use of Clearfield® corn. Both herbicides inhibit the same enzyme (ALS) in an amino acid pathway. ALS-resistant ragweed has been found in Michigan and Ohio.
- Weed population shifts can occur. By routinely using one class of herbicides, the weeds that are not controlled by that type of herbicide will grow and produce seeds that will increase the population of that particular weed, creating a different weed problem. For example, by continuing to use ALS-inhibiting herbicides on field that has a small population of ALS-resistant common ragweed, the common ragweed that is susceptible will be controlled and the resistant species will then proliferate, creating a new weed problem.
- Controlling herbicide resistant crops in your rotation can also be a concern. If using glyphosate-resistant soybeans and then planting glyphosate-resistant corn, then the volunteer corn will be an herbicide resistant weed in the following crop of soybeans. It will be necessary to add other soybean herbicides to glyphosate to control the volunteer corn. This will increase the cost of the soybean weed control program.
- Management of herbicide-resistant crops is important to make sure the right herbicide is applied to the right herbicide-resistant corn. If glyphosate is applied to LibertyLink® corn, the corn will die!

- Rotation restrictions can also be a problem, as well as an advantage. Depending on the type of herbicide resistant corn used, (Clearfield®, Roundup Ready®, or LibertyLink®), the partnering herbicide may have rotational restrictions, or for residual control a tank-mix partner may need to be added, which may have rotational restrictions. Understanding rotational restrictions of all herbicides applied is necessary to avoid crop injury in the subsequent crops.
- The overall cost of the herbicide resistance strategy includes the cost of the herbicide(s) and any additional technology fees or costs. Currently, there are different programs associated with each herbicide resistance trait. However, as with the Bt-corn, the use of a cost analysis tool can help to determine if the benefit is worth the additional cost.
- The same concern of marketability exists in dealing with stacked traits for herbicide- and insect-resistance traits. Be sure to follow through with you seed supplier to ensure marketability of the grain.
- The lack of a residual herbicide component can be a concern for controlling your weed spectrum. Without the addition of residual components in the tank-mix, multiple applications will usually be necessary. This can be time consuming and increase the cost of the weed control program. Be sure to scout the fields in a timely manner, and follow through during the season to stay ahead of any severe weed infestation.

What factors would influence my adoption of any one of the traits?

- Prioritize seed selection criteria. Identify the most important factors for a successful crop and rank them in order. Yield performance and agronomic adaptability should be important considerations. The trait may be a novel way to control specific pests, however if the hybrid is not agronomically sound or able to produce an acceptable yield in your area, then the product does not fit in that situation.

- Have a rotation plan. In Michigan, there is the opportunity for diversity. To take advantage of the diversity in crop production and avoid potential crop injury from herbicide use, it is important to have a plan available when selecting crop management strategies each season.
- Identify the cost of production. Calculate the per acre costs and incorporate cost analysis tools for the return on additional resistance trait costs. It may be necessary to use some of the technology, but the added cost of the benefits may not pay on every acre.
- Know the limiting factors for yield. If pest management is a key reason for less than acceptable yield, then a technology trait may be a tool to reduce inputs and effectively manage that problem pest.
- Safety and the environment are important considerations. It is important to find ways to protect ourselves and the environment for the future. The Bt-corn is safe for the seed handler and safe for the environment by reducing pesticide applications. In the right situation, herbicide-resistant corn provides additional options for more environmentally sound herbicides without sacrificing control.
- Staying informed of available options can help for future crop management. With fast-changing technologies in the agricultural industry it is necessary to be aware

of available tools. Using technologies in a "field-test" situation provides the opportunity to observe the value of the trait without making a large investment.

Benefits and risks are associated with using any technology trait. Conventional weed control systems and insect management systems have been proven effective, and still are very effective. Having an understanding of potential limitations to crop yield, and prioritizing those factors can identify criteria for crop selection. It is important to stay informed about the new technologies in agriculture. Planting test plots with different traits can be a good evaluation and informative opportunity to learn about the different options. Close management is required for these types of plots to receive accurate information about the performance of the trait and hybrid. The end result in seed selection should be a hybrid that can maximize profitability on the farm. The final decision on using a resistance trait in crop production must be profitable for any additional cost to be economically justified.

Introduction

The goals and practices of corn production have changed dramatically over the past decade. Increasing overall production per hectare is necessary in order to maintain economic return on the investment for the commodity. In addition, there is increased awareness of environmental concerns among corn producers. Corn producers have sought out alternatives to preemergence herbicides and traditional weed control systems in order to increase productivity and decrease inputs, while being attentive to environmental constraints. Gene transfer technology has developed herbicide resistance for glyphosate and glufosinate (Comai et al. 1983; Rasche and Gadsby 1997). Through pollen mutagenesis the IT resistance for imidazolinone chemistries was developed for corn (Newhouse et al. 1991). Producers now have alternatives in crop protection with the use of herbicide resistant crops and this has broadened the options in weed control strategies. Traditional practices of chemical applications on non-resistant corn with and without mechanical weed control have proven effective in commercial corn production (Tharp et al, 2002). Question arises regarding the consistency of weed control in herbicide-resistant corn systems compared to traditional programs.

The weed management strategies that are available by using systems involving herbicide resistance corn hybrids include the use of glyphosate, glufosinate, and imidazolinone herbicides. Glyphosate and glufosinate are considered non-selective and have been used for vegetation management in the absence of a crop (Wilson et al. 1985). Glyphosate inhibits 5-enol-pyruvalshikimate-3-phosphate synthase enzyme (EPSPS), an enzyme of the aromatic amino acid biosynthetic pathway (Steinrucken and Amrhein, 1980). Glufosinate inhibits glutamine synthetase, an enzyme that catalyzes the conversion of glutamate plus ammonium to glutamine as part of nitrogen metabolism (Bellinder et al. 1985; Mersey et al. 1990; Wild et al. 1987). Imidazolinone herbicides inhibit acetolactate synthase, which is necessary for the synthesis of three essential amino acids; leucine, isoleucine, and valine (Shaner and Anderson, 1987). Though a broader spectrum of annual weed control is achieved with these herbicides (Steckel et al, 1997; Tharp et al, 1999), there are limitations for management of herbicide-resistant corn, (Burnside, 1996). They include mismatch of hybrids with the appropriate chemical, regulatory restrictions, potential for weed resistance, and customer acceptance.

A single postemergence treatment of glyphosate, glufosinate, or imazethapyr has been inconsistent in providing season-long weed control (Curran et al., 1999; Johnson et al, 2000; Krausz and Kapusta, 1998). Glufosinate plus atrazine was proven to provide greater weed control than glufosinate alone (Hamill et al. 2000). The addition of atrazine also increased weed control over glyphosate applied alone (Ciha and Cole, 1999; Johnson et al. 2000; Bradley et al. 2000). The imidazolinone herbicides also require an additional broadleaf herbicide for adequate control (Krausz and Kapusta, 1998). The previous information focused on one herbicide resistant trait at a time and did not use a comparative approach with several resistant hybrids in the same study, or comparing the performance across locations.

Performance of these herbicides is often influenced by environmental factors (Anderson et al. 1993a, 1993b; McWhorter et al. 1978; Stoller et al. 1993). Several studies showed that weeds must be controlled early in the growing season to prevent yield losses from weed interference. Mixed weed populations competing with corn until the weeds reached 20cm in height reduced corn grain yield by up to 20% (Fausey et al.

1997; Carey and Kells, 1995). The consistency of weed control strategies is variable and highly influenced by weed spectrum and environment. It is important to evaluate performance of the herbicide-resistant corn systems across weed spectrums and environments. The ideal method to test these herbicide resistant hybrids is to use a corn hybrid that contains all three of the herbicide-resistant traits. However, such hybrids are not available at this time. An alternative way is to identify near-isogenic hybrids, a corn hybrid that differs among its genotype by only one or very few genes (Anonymous, 1992).

Questions arise regarding yield of herbicide-resistant hybrids across environments and over years in comparison to the conventional hybrids. Published reports comparing near-isogenic hybrids with the individual resistance traits have shown no differences (Kells and Dysinger, 1996; Shaner et al., 1987), however these comparisons are limited to one herbicide-resistant hybrid with the susceptible near-isogenic hybrid, not all resistance traits. Similar research by Hillger et al. in 2002 addressed the economic effects of using herbicide-resistant corn hybrids, however the information did not report weed control between the different systems or use the near-isogenic hybrids for all treatments. Hillger stated that there was no significant difference in yield, however economic return varied due to the cost of the herbicide treatment. Though environment will play a role in efficacy of weed control, (Anderson et al. 1993a, 1993b; McWhorter et al. 1980; Stoller et al. 1993), research from Boerboom and Lauer in 1997 suggested that yield from resistant hybrids should not differ between application of traditional herbicides or the herbicide specific to the resistance trait. Previous research compared the traditional herbicide strategies to the herbicide-resistant corn strategy. However, this has not been done across the different herbicide-resistant strategies in a single study using near-isogenic hybrids. There is a need for information addressing the effectiveness of herbicide strategies using herbicide-resistant corn hybrids and the partnered herbicides compared to the traditional options.

The objectives of this research were (a) to compare the consistency of weed control with herbicide-resistant corn strategies to the traditional weed control strategies; and (b) to compare the consistency of corn yield among herbicide-resistant hybrids to the conventional hybrid.

Materials and Methods

Field experiments were conducted at four locations in 2000 and 2001. The locations included the campus experimental farms of Michigan State University, the University of Illinois, Purdue University, and The Ohio State University. Near-isogenic corn hybrids of proper maturity were used at each location. The Michigan hybrids were 97 comparative relative maturity (crm) and 108 crm hybrids were used for the Illinois, Indiana, and Ohio locations. Soil characteristics varied among locations. Fertilizer form and applications, tillage operations, and planting methods were conducted in accordance with the customary practices of each region (Table 1). Seeding rate also varied between locations from 67,900 seeds/ha to 74,130 seeds per hectare (Table 1). Replications and row number per plot varied between locations, with 4 to 6 replications and 4 to 6 rows per main plot (Table 2); row width was 76 cm at all locations. Sprayer, nozzle type, and nozzle spacing were selected to accommodate plot size and proper herbicide distribution.

The corn was planted in strips with four randomized treatments within the near-isogenic hybrid strip. Four postemergence herbicide treatments were evaluated on the appropriate hybrid, in addition to a standard preemergence treatment which was applied to each hybrid (Table 3). The preemergence treatment was metolachlor plus atrazine (standard PRE) , at the recommended rate for that region and soil type. The postemergence treatments were tankmix applications of nicosulfuron plus rimsulfuron plus atrazine (Basis Gold®) plus dicamba (Clarity®) applied to the conventional hybrid (conventional-POST); imazethapyr plus imazapyr (Lightning®) plus dicamba (Clarity®) applied to the imidazolinone-resistant near-isogenic hybrid (imi-POST); glufosinate (Liberty®) plus atrazine applied to the glufosinate-resistant near-isogenic hybrid (glufosinate-POST); and glyphosate (Roundup Ultra®) plus atrazine applied to the glyphosate-resistant near-isogenic hybrid (glyphosate-POST) (Table 3). All postemergence treatments also included proper rates of adjuvants. The postemergence treatments at each location were applied to 5- to 10-cm tall annual grass and broadleaf weeds.

Statistical Analysis

The trials were arranged in a split-plot design, with corn hybrid as the main effect and herbicide treatment as the subplot. Untreated and weed-free plots were included for comparisons. Weed species varied across locations and years (Table 4). Weeds evaluated include giant foxtail, (*Setaria faberi*), present at eight locations; velvetleaf, (*Abutilon theophrasti*) and common lambsquarter, (*Chenopodium album*), present at six locations; morningglory species, (*Ipomea sp.*), and mixed populations of tall waterhemp, smooth, and redroot pigweed, (*Amaranthus sp.*), present at four locations; and giant ragweed, (*Ambrosia trifida*), common ragweed, (*Ambrosia artimissifolia*), and common cocklebur, (*Xanthimum strumarium*), which were each present at two locations (Table 4). Weed control data are expressed on a 0 (no effect) to 100% (complete plant death) scale. Weed control was evaluated visually by species at 7, 14, and 28 days after postemergence (DAP) application. The 28 DAP rating provided the best representation for weed control effects.

Corn yields were determined by harvesting the center two rows of each plot with a mechanical harvester at each location. The weight data are expressed by hybrid as a percentage of the mean yield of the weed-free treatment for each location each year, and corrected to 15.5-percent moisture.

Boxplot diagrams are used to illustrate the level and consistency of data for each weed control strategy across locations and years. In each boxplot, the boxes represent 50% of the observations and the lines outside the box represent 90% of the observations. Shorter boxes indicate greater consistency among the observations. Means are listed below each figure, with the treatment indicated along the horizontal axis. Corn yields were subjected to ANOVA procedures, and the means were separated using Fisher's Protected LSD procedure at the 0.10 level of significance.

Location	Soil Texture		Organic Matter		Soil pH		Tillage Practices	Hybrid Maturity	Seeding Rate (seeds/ha)
	2000	2001	2000	2001	2000	2001	2000 & 2001	2000 & 2001	2000 & 2001
Illinois University of Illinois Agronomy Research Farm Champaign, IL	silty clay loam	silty clay loam	4.7%	4.8%	6.6	6.6	fall chisel fby[1] spring cultivation	108 crm[2]	72,900 seeds/ha
Indiana Purdue University Agronomy Research Farm West Lafayette, IN	silty clay loam	silty clay loam	2.6%	2.7%	6.1	6.2	disk tillage after harvest fby 2 passes with field cultivator	108 crm	74,130 seeds/ha
Michigan Michigan State University Agronomy Research Farm; East Lansing, MI	sandy loam	sandy loam	2.3%	1.43%	7.2	6.4	fall chisel plow and spring field cultivation	97 crm	67,9000 seeds/ha
Ohio The Ohio State University Agronomy Research Farm Columbus, OH	silty clay loam	silty clay loam	3.9%	5.6%	6.24	6.8	fall chisel fby spring disk and cultipacker	108 crm	74,130 seeds/ha

[1] fby = "followed by"

[2] crm = comparative relative maturity

Table 1. Soil characteristics, field preparation practices, and planting rate at each location in 2000 and 2001.

Location	Plot Size (m x m)		Number of Replications		Planting Date		Preemergence Application		Postemergence Application		Pressure (kPa)	Volume (L/ha)
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000 & 2001	2000 & 2001
Illinois University of Illinois Agronomy Research Farm Champaign, IL	2.3 x 13.7	2.3 x 6.8	6	6	04/30	04/24	04/26	04/25	05/30	05/24	221 kPa	187 L/ha
Indiana Purdue University Agronomy Research Farm West Lafayette, IN	4.56 x 9.12	4.56 x 9.12	4	6	04/27	04/22	04/28	04/04	06/07	05/30	193 kPa	140 L/ha
Michigan Michigan State University Agronomy Research Farm; East Lansing, MI	4.56 x 9.12	4.56 x 9.12	6	4	05/15	05/09	05/15	05/09	06/15	06/11	207 kPa	187 L/ha
Ohio The Ohio State University Agronomy Research Farm Columbus, OH	3 x 12	3 x 12	6	6	05/01	05/14	05/01	05/14	05/30	06/13	290 kPa	187 L/ha

Table 2. Plot description, and application date at each location in 2000 and 2001.

Herbicide Treatment	Hybrid	Rate	Timing
Handweed	All	--	through season
Untreated	All	--	through season
metolachlor + atrazine	All	recommended rate for soil type	PRE
rimsulfuron + nicosulfuron + atrazine + dicamba[1]	Conventional	13.4 g/ha + 13.4 g/ha+851 g/ha+8.8 g/ha	POST
imazethapyr + imazapyr + dicamba[2]	Imidazolinone-resistant	47 g/ha+16 g/ha+8.8 g/ha	POST
glufosinate + atrazine[3]	Glufosinate-resistant	351 g/ha+1,120 g/ha	POST
glyphosate + atrazine[4]	Glyphosate-resistant	628 g/ha+1,120 g/ha	POST

[1]additives include: crop oil concentrate 1% (v/v)+spray grade ammonium sulfate 2.24 kg/ha.
[2]additives include: surfactant 0.25% (v/v)+spray grade ammonium sulfate 2.8 kg/ha.
[3]additives include: spray grade ammonium sulfate (3.36 kg/ha).
[4]additives include: spray grade ammonium sulfate 2% w/v.

Table 3. Herbicide treatments, rates, and application timing for all locations in 2000 and 2001.

	Illionois		Indiana		Michigan		Ohio	
Weeds	2000	2001	2000	2001	2000	2001	2000	2001
ABUTH[a]	■	■	■	■	■	■		
AMASP	■	■			■	■		
AMBEL					■	■		
AMBTR							■	■
CHEAL	■	■	■		■	■	■	
DATST		■						
IPOSP	■	■	■	■				
SETFA	■	■	■	■	■	■	■	■
XANST	■						■	

[a] Abbreviations: ABUTH, velvetleaf; AMASP, pigweed and waterhemp species; AMBEL, common ragweed; AMBTR, giant ragweed; CHEAL, common lambsquarters; DATST, jimsonweed; IPOSP, morningglory species; SETFA, giant foxtail; XANST, common cocklebur.

Table 4. Weeds present (■) by location and years.

Results and Discussion

Crop Response. No severe corn injury was observed among locations and years (data not reported). Therefore, herbicide injury was not a factor in corn yield.

Weed Control.

Giant foxtail control. The preemergence treatment had a range of 64 to 100 percent control of giant foxtail, and the conventional-POST treatment ranged from 70 to 98 percent control (Figure 1). These results are similar to previous research that demonstrated greater control of giant foxtail with the postemergence treatment than the preemergence treatment (Tapia et al. 1997). The imi-POST treatment ranged from 72 to 99 percent giant foxtail control with the glufosinate-POST treatment ranging from 63 to 98 percent, and glyphosate-POST treatment ranging from 82 to 100 percent control.

Common lambsquarters control. All treatments were consistently high for control of common lambsquarters (Figure 1). The preemergence strategy ranged from 88 to 99 percent and the conventional-POST treatment was consistently above 90 percent control of common lambsquarters. Imi-POST treatment ranged from 93 to 100 percent control. Glufosinate-POST and the glyphosate-POST strategies were consistently above 95 percent control of common lambsquarters. This is contrary to previous research (Higgens et al. 1991), which showed more consistent control of common lambsquarters with glufosinate as compared to glyphosate.

Amaranthus species control. The preemergence treatment was more consistent than the postemergence strategies with a range of 95 to 100 percent control (Figure 1). Conventional-POST and imi-POST both had a range of control from 60 to 100 percent. This may be explained by previous research identifying amaranthus populations having a level of tolerance to ALS-inhibiting herbicides, (Sprague et al.1997). The two non-selective herbicide treatments of glufosinate and glyphosate averaged over 90 percent control. The glufosinate-POST strategy ranged from 70 to 100 percent control, although the glyphosate-POST treatment was more consistent ranging from 90 to 100 percent control of the amaranthus species.

Common ragweed control. Preemergence control of common ragweed was inconsistent ranging from 58 to 100 percent and the conventional-POST strategy was effective with 100 percent control (Figure 1). Imi-POST treatment was ineffective with a range of 70 to 89 percent. This may reflect the ability of common ragweed to recover after application of imazethapyr, (Ballard et al. 1996). The glufosinate-POST treatment was highly effective with 100 percent control of common ragweed and glyphosate-POST treatment ranged from 97 to 100 percent control.

Giant ragweed control. The preemergence treatment was consistently ineffective from 20 to 75 percent, (Figure 2). All postemergence treatments were similar in the control of giant ragweed and more consistent than the preemergence treatment. The conventional-POST treatment ranged from 75 to 100 percent control. The imi-POST treatment ranged from 75 to 100 percent control. Giant ragweed control ranged from 70 to 100 percent with the glufosinate-POST and glyphosate-POST treatments.

Morningglory species control. Control of morningglory species ranged from 50 to 100 percent with preemergence treatment and 75 to 100 percent with the conventional-POST treatment (Figure 2). This may be explained by previous research showing that morningglory species emerge later into the growing season and emerge over a prolonged period of time. The imi-POST treatment ranged from 85 to 100 percent control.

Glufosinate-POST and the glyphosate-POST treatments each ranged from 90 to 100 percent control.

Velvetleaf control. The preemergence treatment was more variable than all postemergence treatments ranging from 50 to 100 percent control of velvetleaf (Figure 2). All postemergence treatments were consistently above 93 percent control for velvetleaf. The conventional-POST ranged from 94 to 100 percent velvetleaf control and imi-POST control ranged from 95 to 100 percent. Glufosinate-POST treatment ranged from 93 to 100 percent control of velvetleaf and the glyphosate-POST ranged from 97 to 100 percent. This is consistent with previous research on velvetleaf showing better control with postemergence treatments than with standard preemergence treatments (Tharp, 1999; Bradley, 2000).

Common cocklebur control. Preemergence control of common cocklebur was extremely inconsistent with control ranging from 30 to 99 percent (Figure 2). The conventional-POST and imi-POST treatments each ranged from 85 to 100 percent control. The glufosinate-POST and glyphosate-POST treatments ranged from 60 to 99 percent and 85 to 100 percent, respectively. The control of common cocklebur is a similar trend as the other larger seeded broadleaf weeds. All postemergence treatments were more consistent for common cocklebur control than the preemergence treatment. Bradley et al. reported similar findings in 2000, with the postemergence application of glufosinate plus atrazine providing better control than the preemergence treatment.

Comparison of herbicides.

Application method comparison on conventional corn. The conventional-POST strategy was more consistent for the control of all weed species, except the amaranthus species, compared to the preemergence treatment (Figures 1 and 2). Other research has shown similar results for the larger seeded broadleaf weeds, as seeding depth is generally greater than the smaller seeded weeds such as the amaranthus species, and germination occurs throughout the growing season, (Johnson et al. 2000). The preemergence strategy maintained consistently high control of the pigweed and waterhemp species. The inconsistency in controlling amaranthus species by the conventional-POST treatment may be explained by tolerance to ALS-inhibiting herbicides. Lovell et al. (1996) reported a population of waterhemp species which showed cross-resistance to sulfonylurea herbicides.

Postemergence strategy comparison. The conventional-POST strategy was the most consistent treatment for the control of common ragweed, morningglory species, and common cocklebur (Figures 1 and 2). The imi-POST strategy was comparable to the other postemergence treatments for all weeds except common ragweed where it was the least effective treatment. Previous research by Ballard et al. (1996) showed a recovery of common ragweed when imidazolinone herbicides were applied. The glufosinate-POST strategy was equal to the conventional-POST treatment for the control of common ragweed, and comparable to all other postemergence treatments with the exception of common cocklebur. All other postemergence treatments averaged greater than 95 percent control, with the glufosinate-POST treatment averaging 89 percent. The glyphosate-POST strategy was consistently effective for control of each weed species, with the exception of giant ragweed where it was equal to the glufosinate-POST strategy and lower than the conventional-POST and imi-POST treatments.

Corn Yield.

The data for corn yield among locations and years have significant interactions, therefore these data are reported for each location and separated by year (Table 5). Yields expressed as percent of the weed free showed variation within each location among years. The conventional-POST strategy ranged from 76 to 112 percent of the conventional-POST weed free yield. Among the eight locations, three instances showed significantly lower yields than the weed free. This may be due to severe weed densities causing competition prior to postemergence herbicide application. The imi-POST yield ranged from 71 to 106 percent of the imi-POST weed free yield. There was one instance in which the yield was significantly lower than the yield of the imi-POST weed free check. Glufosinate-POST treatment yield ranged from 86 to 113 percent of the glufosinate-POST weed free yield, and had one instance in which the yield was significantly lower. The glyphosate-POST strategy corn yield ranged from 91 to 104 percent of the glyphosate-POST weed free yield, and had no instances where yield was significantly lower than the weed free.

Postemergence treatments generally offered more consistent control than the preemergence treatment for giant foxtail, common lambsquarters, common ragweed, and the large-seeded broadleaf weeds. The most consistent treatment among all postemergence strategies for the control of giant foxtail was the glyphosate-POST treatment. The conventional-POST treatment provided the most consistent control for all large-seeded broadleaf weeds, however exhibited the most instances of reduced yield as compared to the weed free check. This may be due to early-season weed competition at the specific locations or other factors. The imi-POST treatment performed similar to the conventional-POST treatment with the exception of common ragweed where control was less effective with the imi-POST strategy. The glufosinate-POST and glyphosate-POST treatments also performed similarly for several of the weed species. However, for control of giant foxtail and common cocklebur, the glyphosate-POST treatment was more effective.

Corn yield was variable among weed control strategies, as well as locations and years. This indicates that environmental conditions as well as other factors, possibly involving weed competition, can play a role in final yield with weed control strategies. Each herbicide strategy provided consistent control for a specific weed spectrum. Herbicide-resistant corn hybrids do offer additional options for effective and consistent weed control. The best herbicide-resistant corn strategy to select in any given situation is dependent on the weed spectrum and adaptability of the hybrid for the region.

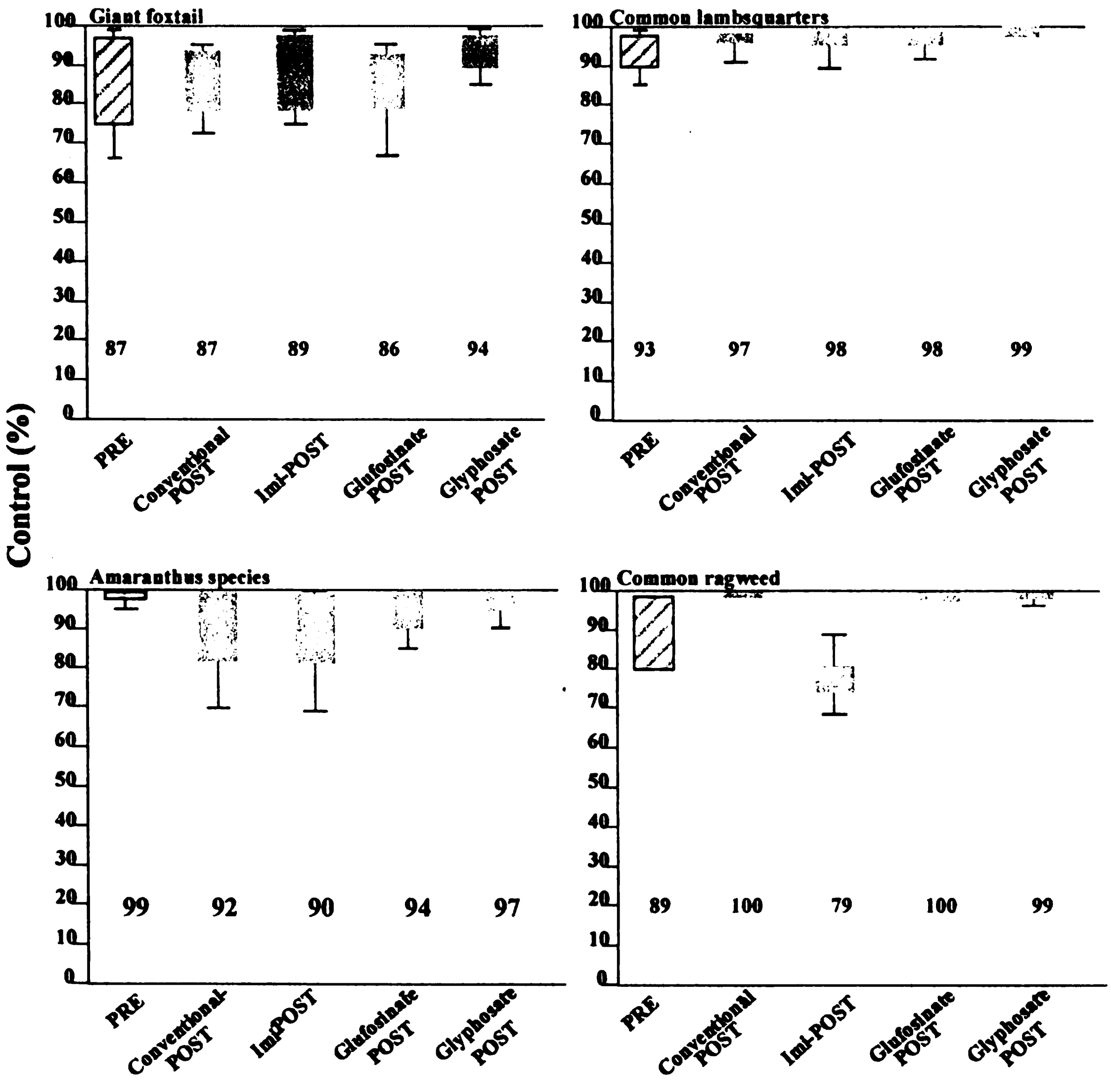

Figure 1. Boxplot figures represent control of giant foxtail, common lambsquarters, amaranthus species, and common ragweed. Data summarized from 2000 and 2001. Data collected from one study each year in each of the following states: Illinois, Indiana, Michigan, Ohio. Means of each treatment are located along the horizontal axis.

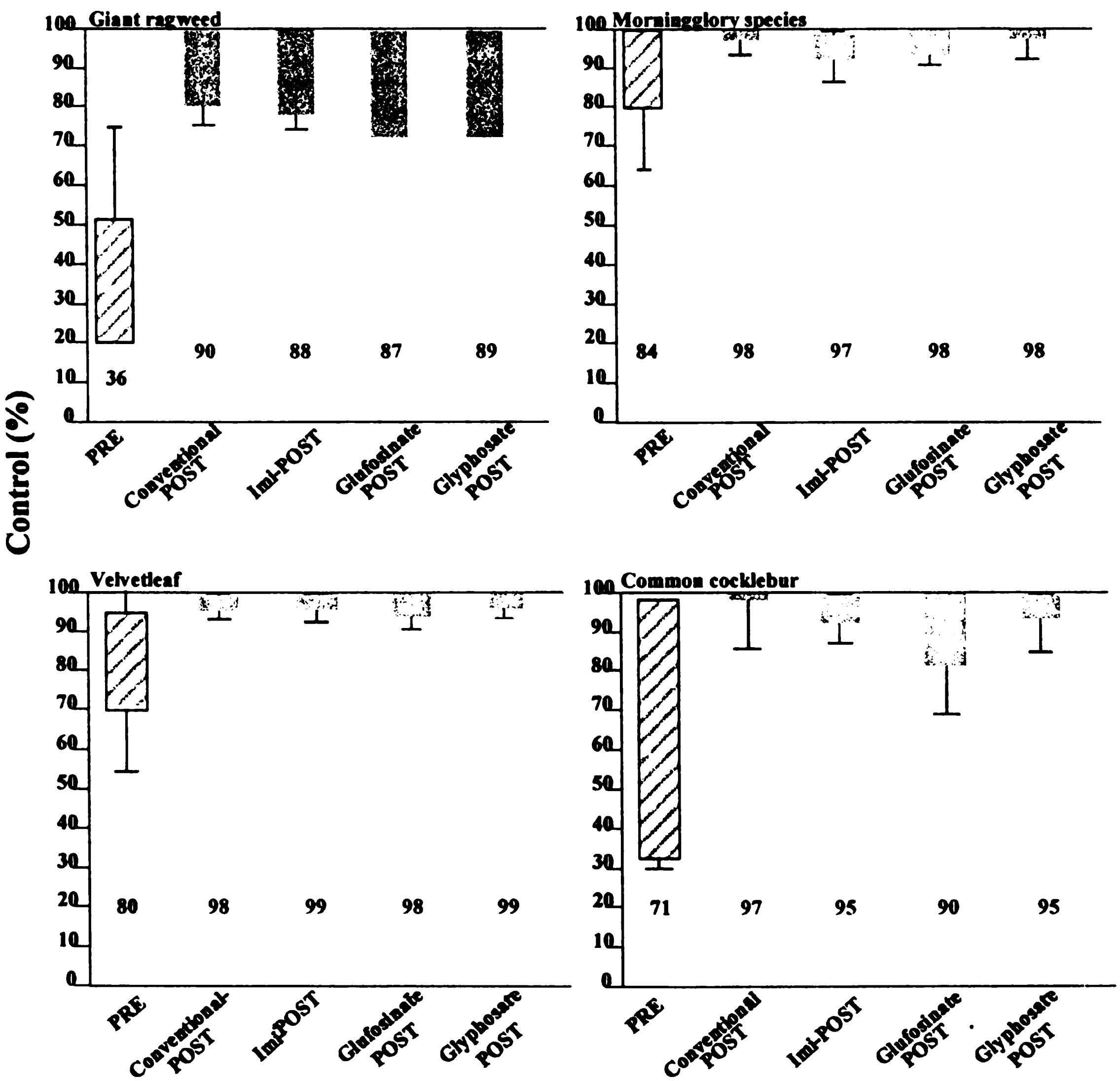

Figure 2. Boxplot figures represent control of giant ragweed, morningglory species, velvetleaf, and common cocklebur. Data summarized from 2000 and 2001. Data collected from one study each year in each of the following states: Illinois, Indiana, Michigan, Ohio. Means of each treatment are located along the horizontal axis.

Weed Control Strategy	IN[1]		IL		MI		OH		Reduced Yield[2]
	2000	2001	2000	2001	2000	2001	2000	2001	Number
Conventional-POST	90*[3]	112	94	95	94	115	96*	76*	3
Imi-POST	98	106	93	95	98	96	100	71*	1
Glufosinate-POST	113	92	98	111	86*	98	100	86	1
Glyphosate-POST	103	99	104	101	96	101	101	91	0
$LSD_{0.10}$	7.33	10.0	7.5	8.0	13.2	11.2	2.9	16.4	
Weedy Check	89	91	82	44	44	8	17	1	

[1]Indiana, Illinois, Michigan, Ohio locations by year.
[2]Total number of instances that the postemergence treatment was significantly lower than the weed free check.
[3]Asterisks indicate a significantly lower yield as compared to the weed free check.

Table 5. Corn yield reported as a percentage of the weed free within each location and year.

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