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MESOTRIONE AND ATRAZINE COMBINATIONS AND INTERACTIONS APPLIED PREEMERGENCE

By

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ABSTRACT

MESOTRIONE AND ATRAZINE COMBINATIONS AND INTERACTIONS APPLIED PREEMERGENCE

By

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Field studies were conducted to determine the optimum rates of mesotrione (2-(4-mesyl-2-nitrobenzoyl)-3-hydroxycyclohex-2-enone) and atrazine (6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine) applied preemergence for control of broadleaf weeds. All rates of mesotrione controlled common lambsquarters (*Chenopodium album* L.), velvetleaf (*Abutilon theophrasti* Medicus), and Pennsylvania smartweed (*Polygonum pensylvanicum* L.). Control of common ragweed (*Ambrosia artemisiifolia* L.) required combinations of high rates of both mesotrione and atrazine. Combinations of mesotrione and atrazine did not effectively control, giant ragweed (*Ambrosia trifida* L.), common cocklebur (*Xanthium strumarium* L.), and ivyleaf morningglory (*Xanthium strumarium* L.).

Greenhouse studies were conducted to evaluate the response of three broadleaf weeds to mesotrione and atrazine applied preemergence and to determine the interaction of mesotrione and atrazine for velvetleaf and ivyleaf morningglory control. Sensitivity to mesotrione was as follows: velvetleaf > common cocklebur > ivyleaf morningglory. Sensitivity to atrazine was as follows: ivyleaf morningglory > common cocklebur > velvetleaf. Synergistic interactions between mesotrione and atrazine occurred frequently with velvetleaf and once with ivyleaf morningglory.

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CHAPTER 1

MESOTRIONE AND ATRAZINE COMBINATIONS APPLIED PREEMERGENCE IN CORN (*Zea mays* L.) IN FIVE MIDWEST STATES.

Abstract: Field trials were conducted in 2002 and 2003 at seven sites to determine the optimum rates of mesotrione and atrazine applied preemergence for control of common lambsquarters, velvetleaf, common ragweed, giant ragweed, ivyleaf morningglory, common cocklebur, and Pennsylvania smartweed. All rates of each herbicide controlled triazine-susceptible common lambsquarters greater than 95 percent. Triazine-resistant common lambsquarters was controlled by mesotrione, but was not controlled by atrazine at any rate tested. Control of common ragweed was 90 percent or greater from mesotrione at 158 g ha^{-1} in combination with atrazine at 280 g ha^{-1} or higher. In addition, mesotrione at 210 g ha^{-1} combined with any rate of atrazine provided at least 92 percent control of common ragweed. The only effective treatments for controlling giant ragweed were mesotrione at 210 g ha^{-1} in combination with atrazine at 1120 g ha^{-1} or higher. Treatments that resulted in the most consistent control of ivyleaf morningglory were treatments that included mesotrione at 210 g ha^{-1} in combination with any rate of atrazine, but still did not provide excellent control. Treatments that provided greatest control of common cocklebur were mesotrione at 158 g ha^{-1} or greater in combination with any rate of atrazine, but most observations were still below 90 percent control. Combinations of

mesotrione and atrazine only suppressed, and did not effectively control, giant ragweed, common cocklebur and ivyleaf morningglory. Mesotrione at 105 g ha^{-1} in combination with any rate of atrazine resulted in at least 99 percent control of Pennsylvania smartweed. Treatments that included mesotrione applied at least 158 g ha^{-1}, regardless of atrazine rate, increased corn yields at all sites except two.

Nomenclature: atrazine, 6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine; mesotrione, 2-(4-mesyl-2-nitrobenzoyl)-3-hydroxycyclohex-2-enone; s-metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide; common lambsquarters, *Chenopodium album* L. #[1] CHEAL; velvetleaf, *Abutilon theophrasti* Medicus # ABUTH; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; giant ragweed, *Ambrosia trifida* L. # AMBTR; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. # IPOHE; common cocklebur, *Xanthium strumarium* L. # XANST; Pennsylvania smartweed, *Polygonum pensylvanicum* L. # POLPY; corn, *Zea mays* L.

Additional index words: herbicide combination, preemergence

Abbrevations: PRE, preemergence; POST, postemergence; HPPD, 4-hydroxyphenylpyruvate dioxygenase; DAT, days after treatment; TR, triazine-resistant.

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

INTRODUCTION

Over 31 million hectares of corn (*Zea mays* L.) are planted in the United States, more than any other crop (Anonymous 2001). Herbicides are applied to 98 percent of these hectares. Atrazine (6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine) is the most commonly used herbicide in those applications, applied to 75 percent of the corn hectares in 2001 (Anonymous 2001). Currently 65 weed species are resistant to triazine herbicides (Heap 2004). Atrazine is typically excellent at controlling common lambsquarters (*Chenopodium album* L.) and common ragweed (*Ambrosia artemisiifolia* L.) (Sprague et al. 2004), but resistant populations of both species are reported in Michigan (Heap 2004). Menbrene and Ritter (2001) reported that mesotrione (2-(4-mesyl-2-nitrobenzoyl)-3-hydroxycyclohex-2-enone) effectively controlled populations of triazine-resistant common lambsquarters. First confirmed in Michigan in 1975, triazine-resistant lambsquarters may now infest 40,000 hectares (Heap 2004). With atrazine becoming less effective, alternative modes of action are needed to control of these species.

Mesotrione is a new selective herbicide used for preemergence (PRE) and postemergence (POST) control of annual broadleaf weeds in field corn (Black et al. 1999). A member of the triketone family, mesotrione inhibits the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD). HPPD is involved in plastiquinone biosynthesis, which indirectly blocks carotenoid synthesis, resulting in bleaching of new growth followed by plant death (Lee 1997; Vencill 2002; Black et al.

1999). Corn exhibits excellent tolerance to mesotrione by rapidly metabolizing it into inactive metabolites (Vencill 2002). Along with excellent crop safety, mesotrione is also very environmentally safe.

When mesotrione was first released, it was primarily a POST broadleaf product applied at 100-150 g ai ha^{-1}. Previous research showed that mesotrione effectively controls velvetleaf (*Abutilon theophrasti* Medicus), *Ipomoea* spp., common ragweed, giant ragweed (*Ambrosia trifida* L.), common lambsquarters, and common cocklebur (*Xanthium strumarium* L.) (Armel et al. 2003; Getting et al. 2002; Johnson et al. 1999; Johnson et al. 2002; Ohmes et al. 2000; Smith and Beckett 1999; Waltz et al. 1999).

The potential of mesotrione may be greater as a PRE rather than a POST herbicide. Although it is applied at relatively low rates (200 g ha^{-1}), it provides season long residual activity with very little carryover (O'Sullivan et al. 2002). According to Rouchaud et al. (2000), mesotrione dissipates before the next growing season which allows for greater freedom in crop rotation strategies. This is particularly important in Michigan where growers may include sugarbeet, dry beans, or other vegetable crops into their rotations.

The introduction of mesotrione provides a new option for preemergence weed control in conventional and no-till corn. As with other selective herbicides, mesotrione may not provide complete weed control when used alone. Previous research showed that mesotrione applied PRE results in variable control of common ragweed, common cocklebur, and *Ipomoea* spp. (Armel et al. 2003; Johnson et al. 1999; Young et al. 1999). The use of a tank-mix partner, such as atrazine, could increase weed control and broaden the spectrum of weed species controlled.

Previous research showed the addition of atrazine at 253 g ha^{-1} to mesotrione POST increases broadleaf weed control (Johnson et al. 1999). Similar trends have been observed with other POST corn herbicides. Bradley et al. (2000) reported increased control of common cocklebur and *Ipomoea* spp. when atrazine was combined with other corn herbicides also applied POST. The current recommendations for mesotrione POST is to tank-mix mesotrione with atrazine at 280-560 g ha^{-1} for increased broadleaf control (Anonymous 2003, Sprague et al. 2004). Armel et al. (2003) showed that the addition of atrazine at 560 g ha^{-1} to mesotrione PRE increased control of common ragweed, common lambsquarters and *Ipomoea* spp.

Along with increased control, using tank-mixtures with multiple modes of action may reduce the selection for herbicide-resistant weeds (Shaner et al. 1997). Sutton et al. (2002) reported excellent control of triazine-resistant populations of common lambsquarters, redroot pigweed (*Amaranthus retroflexus* L.), black nightshade (*Solanum nigrum* L.) and acetolactase synthase (ALS)-resistant common cocklebur with combinations of mesotrione and atrazine. The blend of mesotrione and atrazine, as a potential alternative to current tank-mix combinations, may assist growers with present weed problems.

Currently, there is little understanding as to the amount of mesotrione and atrazine needed in a tank-mixture to control specific broadleaf weed species. The objective of this research was to determine the optimum rates of mesotrione and atrazine applied preemergence for consistent control of common lambsquarters, velvetleaf, common ragweed, giant ragweed, ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.), common cocklebur, and Pennsylvania smartweed (*Polygonum pensylvanicum* L.).

MATERIALS AND METHODS

Field studies were conducted at seven sites in 2002 and 2003. The locations included the experimental farms of Michigan State University (East Lansing, Clarksville), University of Illinois (Dekalb, Urbana), University of Kentucky (Lexington), Purdue University (West Lafayette), and The Ohio State University (South Charleston). Soil characteristics (Table 1) and rainfall (Table 2) varied among locations. Site preparation and corn hybrid selection were conducted according to traditional agronomic practices of each region (Table 3). Seeding population ranged from 69,000 to 74,100 depending upon location. Row number for all locations was four with 76-cm row spacing and plot length varied from 8.2 to 12.5 m among locations. All herbicides were applied in a spray volume of 140 to 224 L ha^{-1} and at a pressure of 207 to 345 kPa. To accommodate different plot sizes, sprayer type, nozzle type, and nozzle spacing varied to ensure uniform herbicide application.

The experimental design was a randomized complete block arranged in a 5 x 5 factorial including a weed free plot (hand weeded). Factor A, mesotrione, was applied at rates of 0, 53, 105, 158, and 210 g ha^{-1}. Factor B, atrazine, was applied at rates of 0, 280, 560, 1120, and 1780 g ha^{-1}. The typical use rate is 210 g ha^{-1} and 1120 g ha^{-1} for mesotrione and atrazine, respectively. Since broadleaf weed control was the focus of the study, a PRE application of s-metolachlor was made at the typical use rate for the soil type and region at each site to control annual grasses (Table 1). Treatments were replicated three or four times. Corn injury and weed control were evaluated visually 30, 45, and 60 days after treatment (DAT) using the rating scale of 0 (no injury) to 100 (completely killed). Weed density by species was determined 30, 45, and 60 DAT from three randomly placed 76 x 76-cm quadrats between the center two rows of each plot. The 30 DAT ratings and counts will be reported here because they best represent the weed control effects. The center two corn rows were mechanically harvested and weighed, and grain yields were corrected to 15.5 percent moisture.

Statistical Analysis

Weed species varied across location and year (Table 4). Weeds evaluated included triazine-susceptible common lambsquarters, present at five locations; triazine-resistant common lambsquarters, present at three locations; velvetleaf, present at ten locations; common ragweed, present at five locations; giant ragweed, present at six locations; ivyleaf morningglory, present at four locations; common cocklebur, present at two locations; and Pennsylvania smartweed, present at three locations. Weed control, weed densities, and corn yield at each site were subjected to analysis of variance. Means were separated using Fisher's Protected LSD test at the alpha=0.05 significance level and is reported in Tables A1-A14.

Treatment-by-location and treatment-by-year interactions were significant for all weed species, corn yields, and weed densities; thus the data from each location and year were considered separate sites. To illustrate weed control and weed densities, data are presented using boxplots to indicate the overall level and consistency of control for each weed species (Ott and Longnecker 2001). In each boxplot, the boxes represent 50 percent of the observations and the lines outside the boxes represent 90 percent of the observations. Shorter boxes and lines indicate greater consistency among the observations. Horizontal black bars across each boxplot indicate the mean of the observations. Corn yields are reported as a percentage of the weed free yield with an asterisk indicating treatments not significantly different from weed free plots.

RESULTS AND DISCUSSION

Crop Response.

No crop injury was observed from any treatments at all locations (data not reported). Therefore, corn yield loss was attributed to weed competition, not crop injury.

Weed Control.

Triazine-susceptible common lambsquarters control.

All treatments were consistently effective for control of common lambsquarters (Figure 1). Treatments including atrazine resulted in at least 83 percent control, regardless of rate. Only atrazine at 280 g ha^{-1} had an average density of greater than five plants m^{-2} while all other atrazine treatments reduced populations to one or two plant m^{-2}. When mesotrione was applied alone, at least 90 percent control of common lambsquarters was observed, regardless of rate, across all locations. Treatments that included mesotrione, regardless of atrazine rate, reduced populations to zero or one plant m^{-2}. Therefore, common lambsquarters is easily controlled by mesotrione or atrazine.

Triazine-resistant (TR) common lambsquarters control.

TR-common lambsquarters control from treatments containing only atrazine were lower and more variable than treatments which included any rate of mesotrione (Figure 2). Treatments including only atrazine resulted in control ranging from 30 to 90 percent. In these treatments, average weed densities were greater than 25 plants m^{-2}. Control of TR-common lambsquarters increased as mesotrione rate was increased. Mesotrione applied alone at 158 g ha^{-1} or greater resulted in at least 90 percent control. When any rate of mesotrione was applied, average weed density dropped below 10 plants m^{-2} and in many cases was zero. Combinations of mesotrione and atrazine did not increase control of TR-common lambsquarters as compared to mesotrione alone. Treatments receiving 158 g ha^{-1} or greater of mesotrione resulted in the greatest control. Average control of these treatments was above 95 percent, regardless of atrazine application, at all locations. Mesotrione applied at 158 g ha^{-1} or greater, regardless of atrazine application, removed all TR-common lambsquarters plants. Thus, TR-common lambsquarters is easily controlled by mesotrione and atrazine was not effective.

Velvetleaf control.

Control of velvetleaf from treatments that included only atrazine was inconsistent, ranging from 42 to 78 percent control (Figure 3). Velvetleaf control increased with increasing rates of atrazine, but average control was less than 80 percent. These results agree with Wax and Maxwell (1998), Waltz et al. (1999), and Hasty et al. (2003) who reported poor control of velvetleaf with atrazine. Reduction of velvetleaf density was also inconsistent from treatments receiving only atrazine. As atrazine rate increased from 0 to 1780 g ha^{-1}, velvetleaf density decreased from about eight plants to four plants m^{-2}. When mesotrione was applied alone at 105 g ha^{-1} or greater, control was 90 percent or greater.

Treatments containing any rate of mesotrione resulted in velvetleaf densities at or below five plants m^{-2} and in many treatments average densities were below one plant m^{-2}. When mesotrione was applied at 53 g ha^{-1} in combination with increasing rates of atrazine, velvetleaf control increased. When mesotrione was applied at 105 g ha^{-1} or greater, no increase in control was observed when atrazine was applied, regardless of rate. This high level of velvetleaf control with mesotrione applied PRE agrees with reports by Ohmes et al. (2000), Johnson et al. (1999), Sprague et al. (1999), and Waltz et al. (1999). Treatments which included any rate of mesotrione were more consistent for velvetleaf control and reducing plant populations of velvetleaf as compared to atrazine treatments.

Common Ragweed.

Control of common ragweed increased as atrazine rate increased (Figure 4). Average control increased from about 50 percent to 90 percent as atrazine rate increased from 280 g ha^{-1} to 1780 g ha^{-1}. Common ragweed densities followed the same trend. As atrazine rate increased, density decreased from 30 to 5 plants m^{-2}. Control of common ragweed increased from about 62 percent to over 90 percent when mesotrione rate increased from 53 to 210 g ha^{-1}, respectively. When mesotrione and atrazine were applied in combination, an increase in control and reduction in weed density were observed as atrazine rate increased. As increasing rates of atrazine were applied in combination with 53 or 105 g ha^{-1} of mesotrione, control increased with the greatest control always occurring at the highest rate of atrazine. The most consistent control of common ragweed occurred with treatments of mesotrione at 158 g ha^{-1} in combination with atrazine at 560 g ha^{-1} or greater or mesotrione at 210 g ha^{-1} in combination with atrazine at any rate. These treatments controlled common ragweed above 90 percent in nearly all observations. These results agree with those of Armel et al. (2003) who reported increased control of common ragweed with mesotrione when applied in combination with 560 g ha^{-1} of atrazine. Densities were reduced the most when 105 g ha^{-1} or greater of mesotrione was applied in combination with 560 g ha^{-1} or greater of atrazine. Therefore, the combinations of the two herbicides were most effective at reducing common ragweed populations resulting in greatest control.

Giant Ragweed.

Control of giant ragweed was inconsistent, but average control increased from 28 percent to 77 percent and plant density was reduced from 20 to 10 plants m^{-2}, when atrazine rate was increased from 280 to 1780 g ha^{-1} (Figure 5). An increase in control from mesotrione was only observed when the rate increased from 53 to 105 g ha^{-1}; no further increase in control was observed from 158 or 210 g ha^{-1}. Similar to atrazine, when mesotrione rate increased from 53 to 210 g ha^{-1}, giant ragweed population dropped from 20 to 8 plant m^{-2}. When any rate of mesotrione was applied, the greatest control was always observed when applied in combination with the highest rate of atrazine. Combinations of these two herbicides were more effective and consistent than either herbicide alone, but none of the treatments completely controlled giant ragweed. Unlike the weed species discussed above, an increase in observed control did not always result in a reduction in plant population. Giant ragweed plants may have only been suppressed and not killed, as compared to plant death with the weeds discussed previously.

Ivyleaf Morningglory.

Control of ivyleaf morningglory ranged from 17 to 63 percent when atrazine was applied alone. (Figure 6). As atrazine rate increased, control increased, but atrazine was consistently ineffective in controlling ivyleaf morningglory alone. Treatments that included only mesotrione were generally more effective than atrazine, but control was variable and averaged only about 82 percent with mesotrione at 210 g ha^{-1}. Although control increased, treatments with either atrazine or mesotrione alone did not effectively reduce ivyleaf morningglory density. Treatments including mesotrione at 210 g ha^{-1}, regardless of atrazine rate, resulted in the most consistent control of ivyleaf morningglory, but in many cases did not provide greater than 90 percent control. The greatest control was obtained when the combination of the highest rates of both mesotrione and atrazine were applied. However, control was still inconsistent and ranged from 80 to 100 percent. The combination of the two herbicides reduced populations, only slightly. As with giant ragweed, the greater control of ivyleaf morningglory, evaluated visually, is likely due the suppression of plants, not a reduction in plant population.

Common Cocklebur.

As atrazine rate increased from 280 to 1780 g ha^{-1}, control of common cocklebur control increases from 12 to 70 percent, but was inconsistent across all sites (Figure 7). Treatments that included atrazine alone did not effectively reduce common cocklebur density. Control with mesotrione was also inconsistent, but was more effective as compared to atrazine. When mesotrione was applied alone at 158 or 210 g ha^{-1}, common cocklebur densities were reduced, but mesotrione did not effectively remove all plants. When the combination of mesotrione and atrazine were applied, control of common cocklebur was more consistent, but the tank mixture did not provide greater than 90 percent control. When mesotrione was applied at 53 g ha^{-1} in combination with increasing rates of atrazine, control increased from 42 to 70 percent. However, data suggests that at high rates of mesotrione, the addition of atrazine did not increase control. The treatments that provided the greatest control were treatments that included mesotrione at 158 or 210 g ha^{-1} in combination with any rate of atrazine. Although these treatments resulted in the greatest control, most observations were still below 90 percent. Therefore, these data suggest that the combination of mesotrione and atrazine resulted in only partial control of common cocklebur PRE. For complete control, a POST application may be necessary.

Pennsylvania Smartweed.

Control of Pennsylvania smartweed increased on average from 39 percent to 98 percent when atrazine rate increased from 280 to 1780 g ha^{-1} (Figure 8). When mesotrione was applied alone at 105 g ha^{-1} or greater, control was 97 percent or greater, regardless of rate. Mesotrione at 105 g ha^{-1} or greater in combination with any rate of atrazine resulted in at least 99 percent control in all observations.

Pennsylvania smartweed densities were reduced as atrazine rate increased. Treatments that included any rate of mesotrione, with or without atrazine, effectively reduced weed populations below 1 plant m^{-2}. Thus, Pennsylvania smartweed is easily controlled by both mesotrione and atrazine.

Corn Yield.

Corn yields are expressed as percent of weed free yield to show variation of particular treatments across all sites (Figure 9). In treatments that included only atrazine, yields increased as rates increased, but on average, yields did not exceed 75 percent of the weed free yield. Corn yields increased with increasing rates of both mesotrione and atrazine. However, a greater increase in yield was observed from mesotrione as compared to atrazine, but yields were still below 85 percent of the weed free. Highest corn yields were often observed in treatments that included mesotrione at 158 g ha^{-1} or greater, regardless of atrazine treatment.

At 13 out of 14 sites, when no herbicide application was made, yield was significantly reduced as compared to the weed free control (Table 4). As atrazine rate increased, the instances of reduced yield decreased, but weed competition still reduced yield at six sites with the highest two rates of atrazine. When mesotrione was applied alone, the number of instances of reduced yield was 9 and 2 from application rates of 53 and 210 g ha^{-1}, respectively. Treatments that consistently reduced weed competition across all but two sites were: atrazine at 1780 g ha^{-1} in combination with mesotrione, regardless of rate, and all treatments that included mesotrione at 158 g ha^{-1} or higher, regardless of atrazine application. Mesotrione at 158 g ha^{-1} in combination with 1780 g ha^{-1} allowed weeds to reduce yields only once. Corn yields in 2003 at Dekalb and Lexington were very low because of high giant ragweed pressure (Tables A3, A8). Because of these high giant ragweed populations, nearly all of the corn yields from these two sites were significantly lower than the weed free control. Low corn yields in 2002 at Lexington were due to severe drought late in the growing season (data not shown).

The combination of mesotrione and atrazine can be an effective strategy for controlling several broadleaf weed species PRE. Control of triazine-susceptible common lambsquarters can be obtained from treatments that include atrazine or mesotrione or the combination of the two herbicides (Table 6). Atrazine and mesotrione are both very effective for control of triazine-susceptible common lambsquarters. Control of TR-common lambsquarters was only obtained from treatments that included mesotrione. When mesotrione was applied at low rates, data was inconsistent between common lambsquarters populations (Figures 1 and 2). Differences in control of common lambsquarters populations with low rates of mesotrione could be attributed to very little rainfall in East Lansing in 2003, which resulted in reduced control of TR-common lambsquarters (Table 2). Similar results were observed by Armel et al. (2003) who reported mesotrione PRE did not control common lambsquarters under low rainfall conditions. Previous research showed that weed control with mesotrione varied with rainfall pattern after herbicide application (Simmons et al. 2000). As with TR-common lambsquarters, velvetleaf was easily controlled by treatments that included mesotrione (Table 6). All treatments that included at least 105 g ha^{-1} of mesotrione resulted in excellent velvetleaf control. However, for control of common ragweed, a combination of high rates of mesotrione and atrazine was needed. Only partial control of giant ragweed, common cocklebur, and ivyleaf morningglory occurred when the highest rates of the two herbicides were applied in combination.

Yields from treatments that included mesotrione at 158 g ha^{-1} or greater, regardless of atrazine application, were not significantly different from the yield of the weed free at all sites, except for two (Table 5). The yields from the 1780 g ha^{-1} of atrazine required at least the lowest rate of mesotrione in order to reduce weed competition to where only two sites were significantly different from the weed free. Yield data suggest that the reduction in weed competition may be more responsive to mesotrione rate as compared atrazine rate. Mesotrione applied alone at 158 g ha^{-1} or greater was just as effective at reducing weed competition as atrazine at 1780 g ha^{-1} in combination with the lowest rate of mesotrione.

The combination of mesotrione and atrazine that is needed for most effective, consistent weed control is species specific. All rates of each herbicide controlled triazine-susceptible common lambsquarters greater than 95 percent. Velvetleaf was easily controlled by all rates of mesotrione. Control of common ragweed was obtained by the combinations of high rates of both mesotrione and atrazine. Combinations of mesotrione and atrazine suppressed, but did not effectively control, giant ragweed, common cocklebur and ivyleaf morningglory. As a result, suppressed weeds could recover and compete with corn for moisture and nutrients, thus reducing yield. A sequential POST program may be best suited for control of these broadleaf weeds. A combination of mesotrione and atrazine PRE followed by another herbicide application POST might be the most effective strategy. The PRE treatment would provide early-season suppression while possibly providing for more herbicide options and a wider window for POST application.

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Table 1. Soil description and s-metolachlor rate applied at each location in 2002 and 2003.

Location	Soil Texture		Organic Matter (%)		Soil pH		S-metolachlor Rate (g ai ha^{-1})
	2002	2003	2002	2003	2002	2003	2002 and 2003
Illinois University of Illinois Agronomy Research Farm Urbana, IL	silt loam	silt loam	4.7	4.8	6.3	6.4	1780
Illinois University of Illinois Agronomy Research Farm Dekalb, IL	silty clay loam	silty clay loam	6.0	6.0	6.2	6.2	1780
Indiana Purdue University Agronomy Research Center West Lafayette, IN	silty clay loam	silty clay loam	3.5	2.3	6.6	6.2	1780
Kentucky University of Kentucky Spindletop Farm Lexington, KY	silt loam	silt loam	2.6	2.6	6.4	6.4	1430
Michigan Michigan State University Agronomy Research Farm East Lansing, MI	sandy clay loam	----	2.4	2.4	7.0	6.8	1430
Michigan Michigan State University Plant Biology Farm East Lansing, MI	----	loam	----	3.9	----	6.2	1430[a]
Michigan Michigan State University Clarksville Hort. Exp. Station Clarksville, MI	loam	----	2.1	----	6.4	----	1430[b]
Ohio The Ohio State University Western Branch OARDC South Charleston, Ohio	silty clay loam	silt loam	4	4	6.2	6.3	1780

[a] only in 2003
[b] only in 2002

Table 2. Rainfall distribution over 7-d intervals up to 28 d after application.

Rainfall	Clarksville	Dekalb		East Lansing-1		East Lansing-2	Lexington		South Charleston		West Lafayette		Urbana	
	2002	2002	2003	2002	2003	2003	2002	2003	2002	2003	2002	2003	2002	2003
DAA*	cm													
0-7	0.89	7.04	7.92	0.58	0.3	0.3	2.13	5.11	1.68	4.55	4.34	0.48	1.98	1.57
8-14	2.18	1.68	7.67	4.75	1.96	1.96	0	8.92	3.53	0.25	1.19	0.71	1.57	1.6
15-21	0.28	1.32	2.21	3.05	0.51	1.42	1.88	5.0	7.57	5.08	1.98	7.29	3.81	2.97
22-28	1.73	1.17	0.15	1.32	1.02	0.1	4.01	1.3	2.46	1.24	2.79	0.05	0.46	3.07
Total	5.08	11.21	17.95	9.7	3.79	3.78	8.02	20.33	15.24	11.12	10.3	8.53	7.82	9.21

* Abbreviation: DAA, days after application.

Table 3. Planting date, herbicide application, and corn hybrid at each location in 2002 and 2003.

Location	Planting Date		Preemergence Application		Corn Hybrid	
	2002	2003	2002	2003	2002	2003
Illinois University of Illinois Agronomy Research Farm Urbana, IL	5/24	4/14	5/24	4/14	Asgrow 738 RR[a]	Dekalb 6017 RR[b]
Illinois University of Illinois Agronomy Research Farm Dekalb, IL	5/5	4/29	5/7	4/29	Dekalb 53-34 RR/YG[b]	Asgrow 718 RR/YG[a]
Indiana Purdue University Agronomy Research Center West Lafayette, IN	5/30	5/27	5/30	5/27	Asgrow RX738 RR[a]	Asgrow RX738 RR[a]
Kentucky University of Kentucky Spindletop Farm Lexington, KY	4/24	4/30	5/16	4/30	Garst 8362 IT[c]	Dekalb DKC 64-11 RR[a]
Michigan Michigan State University Agronomy Research Farm East Lansing, MI	5/21	5/18	5/21	5/18	Dekalb 44-46 RR[b]	Dekalb 44-46 RR[b]
Michigan Michigan State University Plant Biology Farm East Lansing, MI	----	5/19	----	5/19	----	Pioneer 38A25[d]
Michigan Michigan State University Clarksville Hort. Exp. Station Clarksville, MI	5/22	----	5/22	----	Dekalb 44-46 RR[b]	----
Ohio The Ohio State University Western Branch OARDC South Charleston, Ohio	5/20	5/14	5/20	5/14	Pioneer 34M94[d]	Dekalb 60-09 RR[b]

[a] Asgrow, Monsanto Company, St. Louis, MO 63167

[b] Dekalb, Monsanto Company, St. Louis, MO 63167

[c] Garst Seed Company, Slater, IA 50244

[d] Pioneer Hi-Bred International, Inc., Des Moines, IA 50306

Table 4. Weeds present (**X**) by location and years.

	Clarksville	Dekalb		East Lansing-1		East Lansing-2	Lexington		South Charleston		West Lafayette		Urbana	
Weeds	2002	2002	2003	2002	2003	2003	2002	2003	2002	2003	2002	2003	2002	2003
S-CHEAL[a]	X	X								X			X	X
TR-CHEAL				X	X	X								
ABUTH	X	X	X	X		X			X	X	X	X	X	X
AMBEL				X	X				X				X	X
AMBTR		X	X				X	X	X			X		
IPOHE							X				X	X	X	
XANST							X						X	X
POLPY		X											X	X

[a]Abbreviations: S-CHEAL, triazine-susceptible common lambsquarters; TR-CHEAL, triazine-resistant common lambsquarters; ABUTH, velvetleaf; AMBEL, common ragweed; AMBTR, giant ragweed; IPOHE, ivyleaf morningglory; XANST, common cocklebur; POLPY, Pennsylvania smartweed.

Table 5. Corn yield reported as a percentage of the weed free yield.

Mesotrione (g ai ha^{-1})	Atrazine (g ai ha^{-1})	Clarksville	Dekalb		East Lansing-1		East Lansing-2	Lexington		South Charleston		West Lafayette		Urbana		Reduced Yield[a]
		2002	2002	2003	2002	2003	2003	2002	2003	2002	2003	2002	2003	2002	2003	Number
0	0	80	1	0	58	40	74	36	0	69	91	97*	34	48	32	13
0	280	86	23	0	74	41	76	36	0	81	89	99*	22	64	73	13
0	560	87	76	0	83	50	97*	39	0	89*	93*	95*	31	78	58	10
0	1120	95*[b]	80	3	87*	62	89*	53*	26	87*	98*	128*	60	84	92*	6
0	1780	93*	72	2	91*	66	57	37	40	97*	99*	127*	77	91*	93*	6
53	0	95*	79	7	86	64	103*	30	0	92*	99*	111*	68	87	78	9
53	280	101*	106*	11	91*	69	101*	41	0	82	92	105*	71	87	79	9
53	560	101*	90*	2	96*	81*	103*	69*	13	85*	99*	124*	89*	85	88*	3
53	1120	102*	105*	6	91*	92*	86*	48	46	95*	98*	114*	92*	88	95*	4
53	1780	97*	108*	0	93*	82*	103*	89*	74	90*	99*	116*	95*	99*	87*	2
105	0	97*	107*	22	84	71	102*	50*	9	93*	98*	126*	96*	86	82	5
105	280	95*	89*	11	94*	76	105*	61*	28	82	100*	117*	97*	95*	93*	4
105	560	101*	107*	7	92*	94*	101*	74*	47	94*	99*	106*	36	83	87*	4
105	1120	103*	89*	3	95*	88*	104*	69*	72	92*	102*	118*	30	100*	88*	3
105	1780	104*	100*	18	97*	89*	96*	88*	81	89*	101*	115*	109*	97*	94*	2
158	0	94*	109*	0	93*	89*	105*	99*	30	95*	95*	118*	99*	----	100*	2
158	280	99*	103*	2	96*	96*	98*	98*	34	95*	102*	111*	96*	89*	91*	2
158	560	102*	97*	12	98*	80*	95*	91*	67	99*	99*	121*	88*	92*	92*	2
158	1120	94*	98*	2	102*	88*	99*	74*	81	98*	101*	119*	102*	95*	100*	2
158	1780	104*	97*	4	99*	83*	97*	97*	101*	95*	99*	111*	103*	92*	94*	1
210	0	93*	102*	20	93*	87*	110*	58*	27	105*	95*	125*	103*	93*	93*	2
210	280	92*	105*	10	95*	83*	94*	89*	57	98*	102*	108*	98*	105*	93*	2
210	560	103*	97*	7	96*	86*	104*	67*	74	95*	99*	124*	90*	95*	98*	2
210	1120	94*	106*	14	99*	95*	102*	104*	81	91*	98*	110*	102*	106*	89*	2
210	1780	111*	106*	42	96*	99*	99*	92*	78	102*	102*	119*	----	101*	90*	2
Weed Free Yield (100 kg/ha)		96	120	63	125	99	107	27	117	121	142	88	100	106	145	

[a]Total number of instances that the treatment was signifcantly lower than the weed free check

[b]Asterisk indicate yield not significantly different than weed free check

Table 6. Weeds controlled with preemergence application of mesotrione, atrazine or the combination.

	Herbicide		
Weed Species	atrazine	mesotrione	combination
S-CHEAL[a]	**C**	**C**	**C**
TR-CHEAL		**C**	**C**
ABUTH		**C**	**C**
AMBEL			**C**
AMBTR			**PC**
IPOHE			**PC**
XANST			**PC**
POLPY	**C**	**C**	**C**

[a]Abbreviations: S-CHEAL, triazine-susceptible common lambsquarters; TR-CHEAL, triazine-resistant common lambsquarters; ABUTH, velvetleaf; AMBEL, common ragweed; AMBTR, giant ragweed; IPOHE, ivyleaf morningglory; XANST, common cocklebur; POLPY, Pennsylvania smartweed;
C = control; PC = partial control

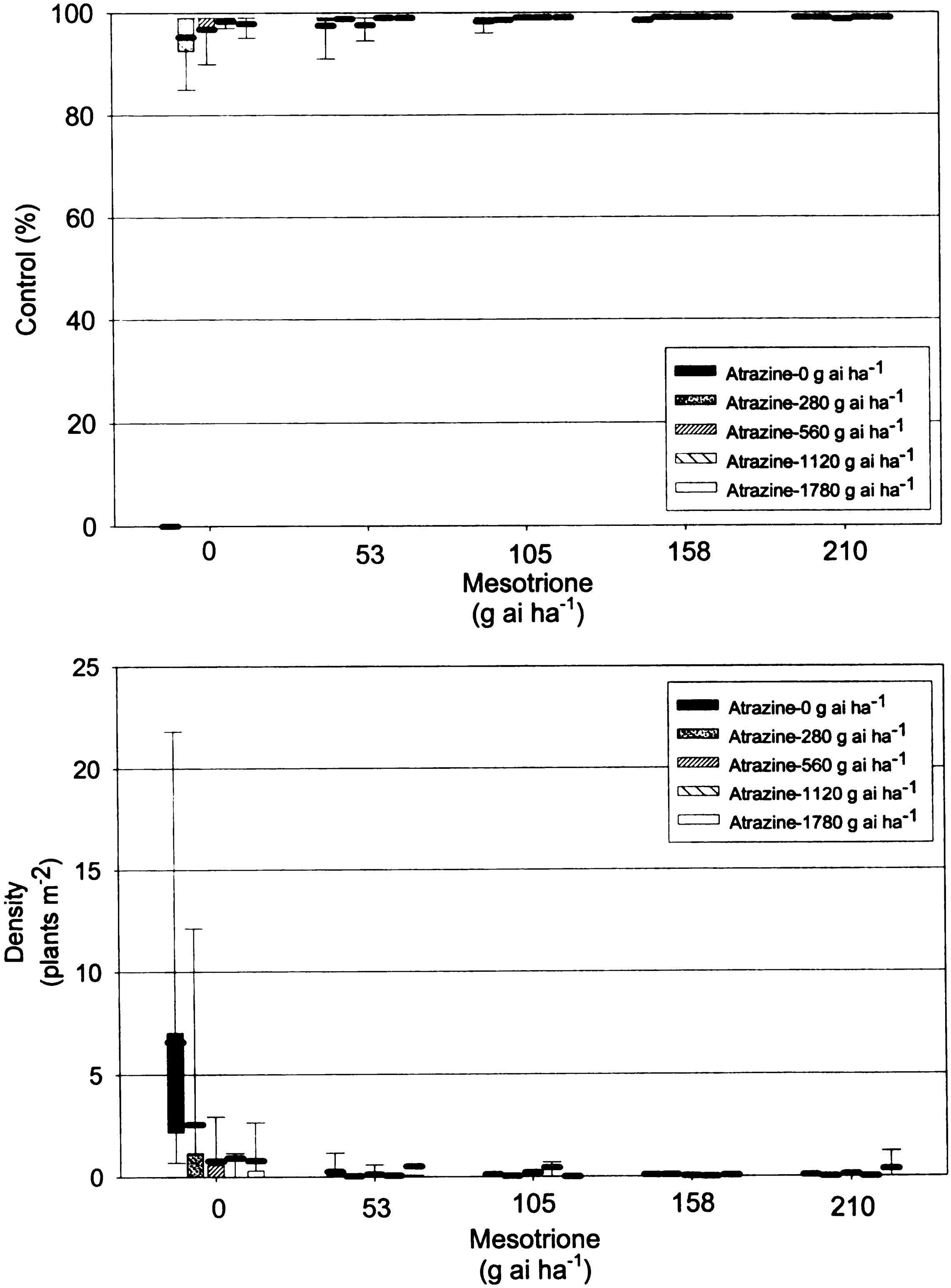


Figure 1. Boxplot figures represent control and density of triazine-susceptible common lambsquarters. Data summarized from 2002 and 2003. Data collected from studies in Illinois, Michigan, and Ohio. Means of each treatment are indicated by (▬) inside of each boxplot.

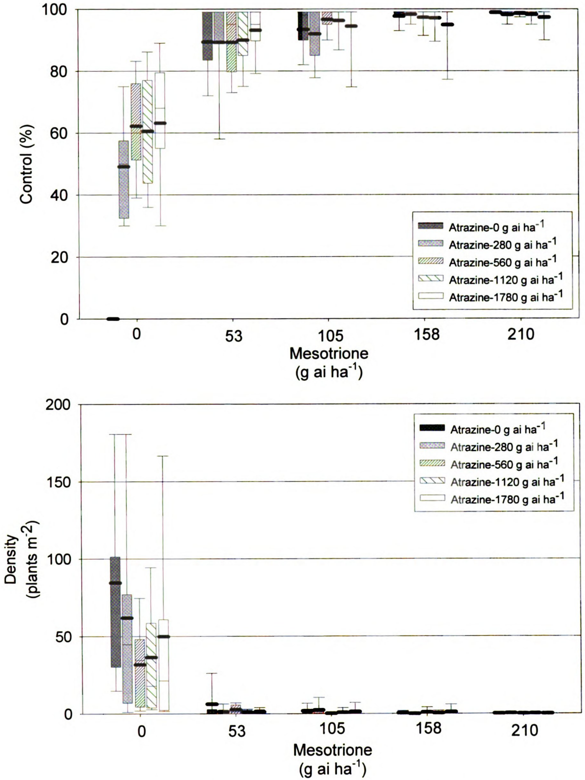


Figure 2. Boxplot figures represent control and density of triazine-resistant common lambsquarters. Data summarized from 2002 and 2003. Data collected from studies in Michigan. Means of each treatment are indicated by (▬) inside of each boxplot.

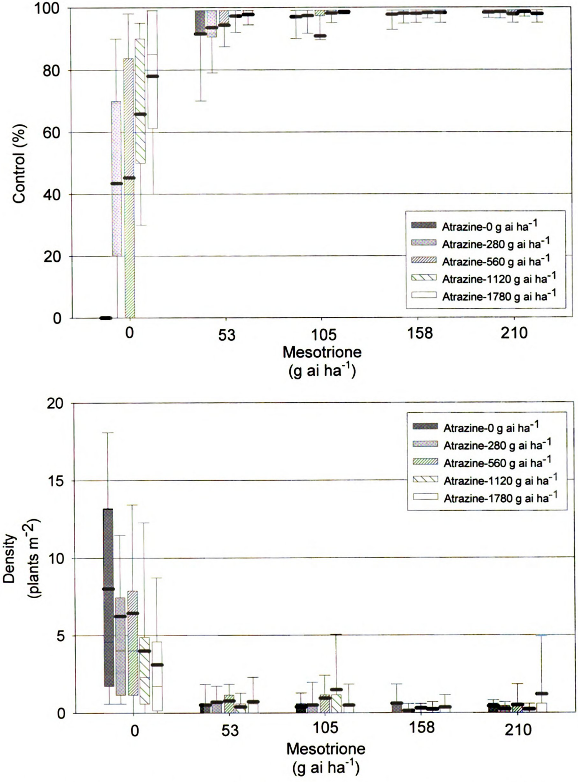
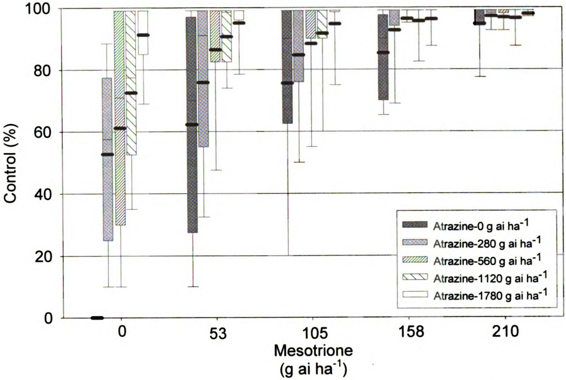


Figure 3. Boxplot figures represent control and density of velvetleaf. Data summarized from 2002 and 2003. Data collected from studies in Illinois, Indiana, Michigan, and Ohio. Means of each treatment are indicated by (▬) inside of each boxplot.



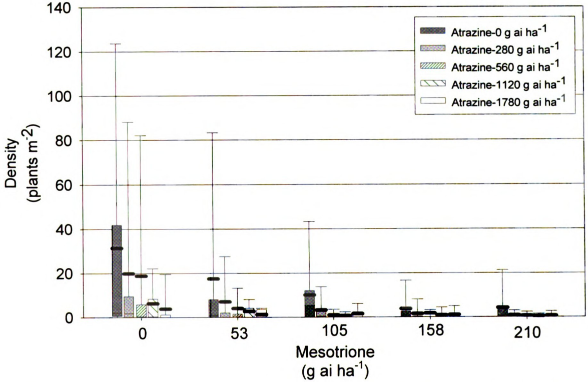
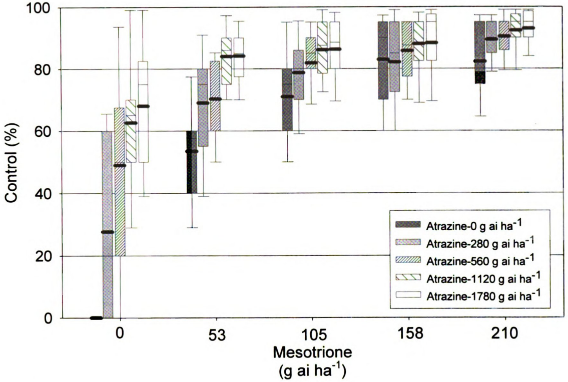


Figure 4. Boxplot figures represent control and density of common ragweed. Data summarized from 2002 and 2003. Data collected from studies in Illinois, Michigan, and Ohio. Means of each treatment are indicated by (▬) inside of each boxplot.



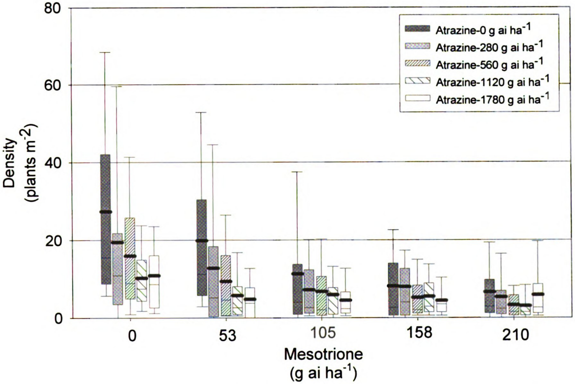


Figure 5. Boxplot figures represent control and density of giant ragweed. Data summarized from 2002 and 2003. Data collected from studies in Illinois, Indiana, Kentucky, and Ohio. Means of each treatment are indicated by (▬) inside of each boxplot.

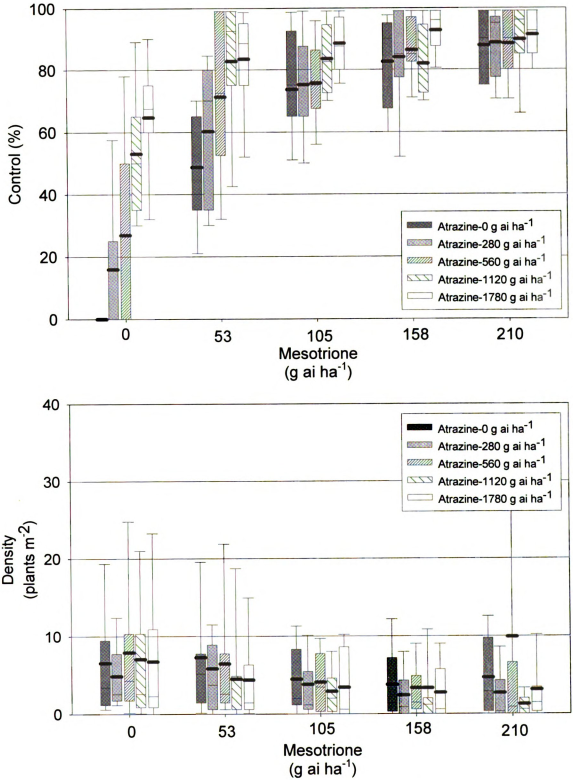
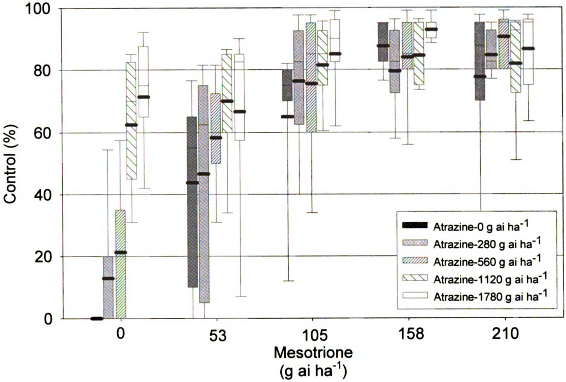


Figure 6. Boxplot figures represent control and density of ivyleaf morningglory. Data summarized from 2002 and 2003. Data collected from studies in Illinois, Indiana, and Kentucky. Means of each treatment are indicated by (▬) inside of each boxplot.



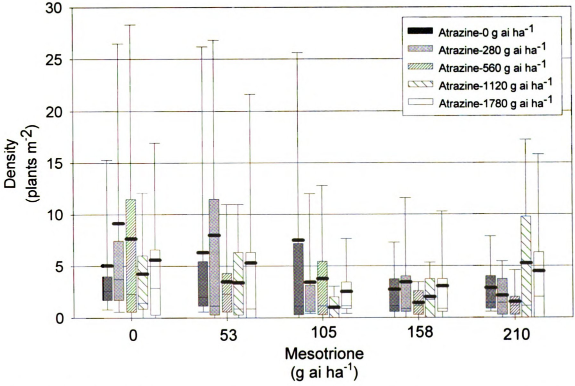
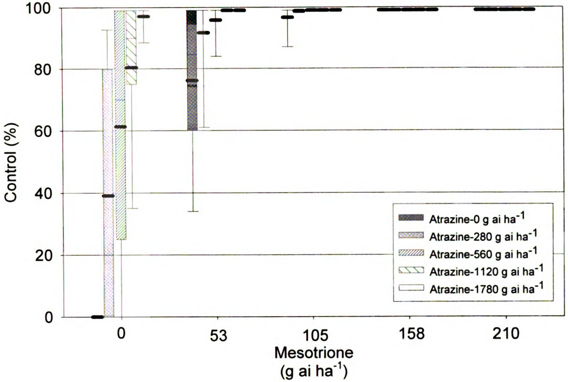


Figure 7. Boxplot figures represent control and density of common cocklebur. Data summarized from 2002 and 2003. Data collected from studies in Illinois and Kentucky. Means of each treatment are indicated by (▬) inside of each boxplot.



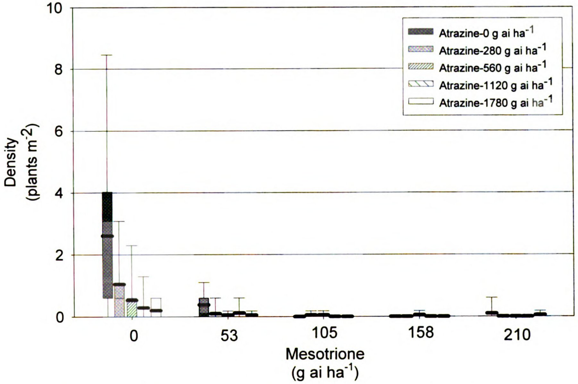


Figure 8. Boxplot figures represent control and density of Pennsylvania smartweed. Data summarized from 2002 and 2003. Data collected from studies in Illinois. Means of each treatment are indicated by (▬) inside of each boxplot.

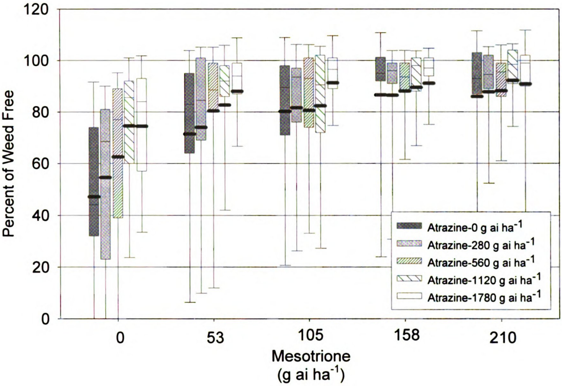


Figure 9. Boxplot figures represent corn yield as a percentage of the weed free. Data summarized from 2002 and 2003. Data collected from studies in Illinois, Indiana, Kentucky, Michigan, and Ohio. Means of each treatment are indicated by (▬) inside of each boxplot.

CHAPTER 2

WEED RESPONSE TO MESOTRIONE AND ATRAZINE APPLIED PREEMERGENCE UNDER GREENHOUSE CONDITIONS

Abstract: Greenhouse studies were conducted to evaluate the control of velvetleaf, common cocklebur, and ivyleaf morningglory from mesotrione and atrazine applied preemergence and to determine the interaction of mesotrione and atrazine for velvetleaf and ivyleaf morningglory control. Sensitivity to mesotrione was as follows: velvetleaf > common cocklebur > ivyleaf morningglory. Sensitivity to atrazine was as follows: ivyleaf morningglory > common cocklebur > velvetleaf. Combinations of mesotrione and atrazine resulted in at least an additive interaction. Synergistic interactions between mesotrione and atrazine occurred frequently with velvetleaf and once with ivyleaf morningglory.

Nomenclature: atrazine, 6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine; mesotrione, 2-(4-mesyl-2-nitrobenzoyl)-3-hydroxycyclohex-2-enone; velvetleaf, *Abutilon theophrasti* Medicus #[1] ABUTH; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. # IPOHE; common cocklebur, *Xanthium strumarium* L. # XANST; corn, *Zea mays* L.

Additional index words: synergism, additive, herbicide interaction

Abbreviations: PRE, preemergence; POST, postemergence; HPPD, 4-hydroxyphenylpyruvate dioxygenase; DAT, days after treatment; GR_{50}, rate causing 50% growth reduction.

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

INTRODUCTION

Mesotrione (2-(4-mesyl-2-nitrobenzoyl)-3-hydroxycyclohex-2-enone) is a new selective herbicide used for preemergence (PRE) and postemergence (POST) control of annual broadleaf weeds in field corn (*Zea mays* L.) (Black et al. 1999). A member of the triketone family, mesotrione inhibits the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD). HPPD is involved in plastiquinone biosynthesis, which indirectly blocks carotenoid synthesis, resulting in bleaching of new growth followed by plant death (Lee 1997; Vencill 2002; Black et al. 1999). Corn exhibits excellent tolerance to mesotrione as a result of rapid metabolism into inactive metabolites (Vencill 2002).

Previous research showed that mesotrione applied PRE was effective for control of velvetleaf (*Abutilon theophrasti* Medicus) (Anonymous 2003; Sprague et al. 2004). Other studies reported variable control of common cocklebur (*Xanthium strumarium* L.) and *Ipomoea* spp. (Armel et al. 2003; Johnson et al. 1999; Young et al. 1999). The use of a tank-mix partner, such as atrazine (6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine), could enhance weed control and broaden the spectrum of weed species controlled.

Atrazine has been in use since 1958 and was applied to 75 percent of the corn hectares in 2001 (Anonymous 2001). Because of its low cost and wide spectrum of control, atrazine is a popular PRE herbicide. Although atrazine is effective at controlling several broadleaf weed species, it is inconsistent for control of velvetleaf, common cocklebur, and *Ipomoea* spp. (Sprague et al. 2004;

Wax and Maxwell 1998). Since most growers have a wide spectrum of broadleaf weed species in their fields, a combination of mesotrione and atrazine might be desirable to broaden the spectrum of weeds controlled by having both herbicides in tank-mix combination.

A tank-mix combination of two herbicides often provides more consistent and a broader spectrum of control, prevents weed resistance to certain herbicides, and reduces costs while applying less total active ingredient (Harker and O'Sullivan 1991, Sprague et al. 2004, Zhang et al. 1995). The basic assumption of a herbicide mixture is that each acts independently when applied in combination (Zhang et al. 1995). However, it has been observed that control from a combination may be greater than, less than, or equal to the summed effect of the herbicides applied alone. Thus, an interaction may occur between the herbicides causing a synergistic, antagonistic, or additive effect (Colby 1967, Green 1989, Hatzios and Penner 1985).

The increased activity of the combination of mesotrione and atrazine POST provides evidence for a synergistic interaction. Abendroth et al. (2004) reported synergistic interaction between mesotrione and photosynthetic inhibitors POST for the control of velvetleaf, sunflower (*Helianthus annuus* L.), and Palmer amaranth (*Amaranthus palmeri* S.Wats). Armel et al. (2003) showed that the addition of atrazine at 560 g ai ha^{-1} to mesotrione PRE increased control of common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters (*Chenopodium album* L.) and *Ipomoea* spp.

While previous research has been conducted on the interaction between mesotrione and atrazine applied POST, few studies have examined this interaction PRE. The objectives of this research were (1) to characterize the response of velvetleaf, ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.), and common cocklebur to mesotrione and atrazine applied PRE and (2) to characterize the interaction between mesotrione and atrazine for control of velvetleaf and ivyleaf morningglory.

MATERIALS AND METHODS

General Experimental Procedures.

Ten velvetleaf seeds, ten ivyleaf morningglory seeds, and four common cocklebur pods were planted in plastic pots (10-cm by 10-cm) filled with a Spinks loamy sand soil (sand, mixed, mesic Psammentic Hapludalfs) with 2.4 percent organic matter and a pH of 6.8. Velvetleaf and ivyleaf morningglory seeds were planted 0.75 cm deep while common cocklebur pods were planted to a depth of 1.5 cm. Immediately after planting, the soil surface was treated with either mesotrione or atrazine. Herbicide treatments were applied with a single tip track-sprayer with a Teejet[1] 8003E flat-fan nozzle calibrated to deliver 187 L ha^{-1} at 207 kPa. Herbicide treatments were incorporated with surface irrigation (0.64 cm) each of the first five days and then pots were watered equally as needed. At 14 days after planting, 50 ml of a fertilizer solution containing 70 mg L^{-1} of 20% nitrogen, 20% P_2O_5, and 20% K_2O was applied to each pot. Weeds were grown in the greenhouse and sunlight was supplemented with sodium vapor lighting to provide a total midday light intensity of 1000 µmol/m/s photosynthetic photon flux at plant height in a 16 h day. Greenhouse temperature was maintained at 25 ± 2° C. Once plants emerged, germination percentage was determined and pots were then thinned to two plants per pot. Weed control was determined 28 DAT

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

by visually evaluating plants for bleaching, necrosis, and stunting. Weed injury was rated from 0 (no effect) to 100 (plant death). All aboveground plant tissue was then harvested, dried, and weighed to determine reduction of plant biomass. Data were then converted to percent control for data presentation. All studies were designed as randomized complete blocks with four replications and were repeated. All data were subjected to ANOVA and since no interactions between repeated experiments were observed, data were combined and reported as the means of the repeated experiments.

Control of Mesotrione and Atrazine Applied Alone.

An experiment was designed to evaluate the control of velvetleaf, ivyleaf morningglory, and common cocklebur to mesotrione and atrazine applied preemergence. Using results from a preliminary experiment (data not shown), varying rates of mesotrione and atrazine were selected and applied to the three weed species to determine sensitivity to each herbicide. Following the same general experimental procedures as stated above, velvetleaf, common cocklebur and ivyleaf morningglory were planted and treated with different rates of mesotrione and atrazine alone (Table 1). At 28 DAT, weeds were visually evaluated and plant biomass was determined and then was converted to percent control. Using dry weights the GR_{50} was calculated using Logistic Dose Response (LDR) equation $Y=A+B/ [1+(X/C)^D]$, where Y is the herbicide activity as a percent control, X is rate of application, A is the upper limit, B is the lower limit, C is the dose that causes GR_{50}, and D is the slope of the curve around the GR_{50}.

TableCurve 2D[2] software was used to calculate regression curves and equations. Deviations from regressions were assessed by r^2 values. From the GR_{50} value, GR_{25} and GR_{75} were estimated for interaction experiments by multiplying the GR_{50} by 0.5 and 1.5, respectively.

Interaction of Mesotrione and Atrazine Applied in Combination.

An experiment was designed to determine the type of interaction between mesotrione and atrazine once weed sensitivity was established. Following the same general experimental procedures as stated above, velvetleaf, and ivyleaf morningglory seeds were planted and treated with all possible rate combinations of mesotrione and atrazine from growth reduction values (25%, 50%, and 75%) from the weed response experiment (Table 2). At 28 DAT, weeds were visually evaluated and plant biomass was determined and then was converted to percent control. Since mesotrione and atrazine have different sites of action, the multiplicative method, E=X+Y-XY/100, developed by Colby (1967) was used to calculate "expected" plant responses to herbicide combinations. In this equation, X is the percent inhibition of growth by herbicide A, Y is the percent inhibition of growth by herbicide B, and E is the expected percent inhibition by herbicides A + B.

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

Means were separated by Fisher's Protected Least Significant Difference (LSD) method. The LSD ($P = 0.1$) for the observed responses was used to determine significant differences between observed and expected responses (Hamill and Penner 1973). When the observed response of the herbicide combination was greater than, equal to, or less than the calculated expected, the interaction was deemed synergistic, additive, or antagonistic, respectively.

RESULTS AND DISCUSSION

Control of Mesotrione and Atrazine Applied Alone.

Sensitivity to mesotrione was as follows: velvetleaf > common cocklebur > ivyleaf morningglory (Figure 1). Growth response curves indicate that only 5.25 g ha^{-1} of mesotrione was required to reduce velvetleaf growth by 50 percent (Table 2). However, common cocklebur required about twice as much mesotrione compared to velvetleaf to reduce plant growth by 50 percent. Ivyleaf morningglory was the least sensitive weed to mesotrione, requiring 17.5 g ha^{-1} to inhibit growth by 50 percent, more than three times as much active ingredient as compared to velvetleaf. Field studies showed similar trends in mesotrione efficacy. Research by Sprague et al. (1999) and Wax and Maxwell (1998) showed the efficacy of mesotrione on velvetleaf was greater than common cocklebur. In addition, Dewell et al. (2003) reported mesotrione was more effective on velvetleaf compared to ivyleaf morningglory.

Sensitivity of the three weed species to atrazine was opposite of that of mesotrione (Figure 1). Sensitivity to atrazine was as follows: ivyleaf morningglory > common cocklebur > velvetleaf. Unlike mesotrione, the GR_{50} rates did not vary greatly. The GR_{50} rates for ivyleaf morningglory, common cocklebur and velvetleaf were 336, 420, and 448 g ha^{-1}, respectively (Table 2). These results agree with Wax and Maxwell (1998), Waltz et al. (1999), and Hasty et al. (2003) who reported poor control of velvetleaf with atrazine. In addition, previous research reported poor control of common cocklebur with atrazine (Wax and Maxwell 1998).

Interaction of Mesotrione and Atrazine Applied in Combination.

Velvetleaf.

All rate combinations of mesotrione and atrazine resulted in at least an additive interaction for velvetleaf control (Figure 2). The combination that contained atrazine at the GR_{25} rate resulted in a synergistic interaction when mesotrione was applied at the GR_{50} rate. When the GR_{50} rate of atrazine was applied in combination with any rate of mesotrione, a synergistic interaction occurred. When the GR_{75} rate of mesotrione was applied in combination with the GR_{75} atrazine rate a synergistic interaction also occurred. Out of the nine combinations applied to velvetleaf, five resulted in a synergistic interactions.

Ivyleaf morningglory.

No antagonism was observed between mesotrione and atrazine when applied to ivyleaf morningglory (Figure 3). A synergistic interaction was observed only when atrazine at the GR_{50} rate was applied in combination with mesotrione at the GR_{25} rate. All other combinations resulted in an additive response.

Possible Basis of Interaction.

The site of action of mesotrione is to inhibit HPPD, an enzyme involved in plastiquinone biosynthesis, which indirectly blocks carotenoid synthesis (Lee

1997; Vencill 2002; Black et al. 1999). Although the inhibition of plastiquinone production is an indirect effect of mesotrione activity, it may actually increase the activity of atrazine. The site of action for atrazine is to bind to the D_1 protein of photosystem II (PS II), which inhibits photosynthetic electron transport, resulting in free radicals which leads to lipid peroxidation, loss of membrane integrity, and then plant death (Anderson 1996; Vencill 2002). Both atrazine and plastoquinone compete for the same D_1 protein binding site in PS II (Malkin and Niyogi 2000; Vencill 2002). Inhibition of plastoquinone biosynthesis by mesotrione, resulting in an increase in binding of atrazine to the D1 protein, may contribute to the synergistic interaction between mesotrione and atrazine.

Further explanation of this interaction can be attributed to the relationship between HPPD inhibitors, PS II, and the antioxidant α-tocopherol. In addition to biosynthesis of plastiquinone, the enzyme HPPD is a co-factor involved in the production of α-tocopherol (Hess 1993; Mitchell et al. 2001; Pallet et al. 1998). The role of α-tocopherol in the plant is as a scavenger of damaging singlet oxygen and hydroxyl ions along with continual maintenance of the D1 protein in PS II (Bray et al. 2000; Hess 1993; Trebst et al. 2002). The production of α-tocopherol is also affected by PS II. In the presence of high light, enzymes are activated by PS II for the production of α-tocopherol (Trebst et al. 2002). When mesotrione and atrazine are applied in combination, the mesotrione may prevent the production of α-tocopherol while the atrazine inhibits electron transport, resulting in free singlet oxygen and hydroxyl ions (Anderson 1996; Mitchell et al. 2001; Pallet et al. 1998; Vencill 2002). As a result, the inhibition α-tocopherol by mesotrione may increase the activity of the free singlet oxygen and hydroxyl ions produced by the inhibition of electron transport.

Tank mixtures of mesotrione and atrazine are at least additive, and in several cases synergistic, for the control of velvetleaf and ivyleaf morningglory. Combinations of the two herbicides complement each other very well since they have different sites of action and vary in effectiveness on the species. For example, mesotrione was more effective on velvetleaf, but less effective on ivyleaf morningglory; however, the opposite response was observed with atrazine. A tank mixture of mesotrione and atrazine provides several benefits to the grower. The combination uses less active ingredient of each herbicide, while broadening the spectrum control. In addition, the use of more than one site of action reduces the potential for weed resistance (Shaner et al. 1997).

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Table 1. Mesotrione and atrazine rates used to evaluate weed sensitivity.

ABUTH[a]		IPOHE		XANST	
Mesotrione	Atrazine	Mesotrione	Atrazine	Mesotrione	Atrazine
g ai ha^{-1}					
0	0	0	0	0	0
4.4	140	6.6	140	4.4	70
8.8	280	13	280	8.8	140
17.5	560	26	560	17.5	280
35	1120	53	1120	35	420
70	2240	105	2240	70	560
-	-	-	-	-	1120

[a]Abbreviations: ABUTH, velvetleaf; IPHOE, ivyleaf morningglory; XANST, common cocklebur

Table 2. Mesotrione and atrazine rates associated with each growth reduction value.

Growth Reduction	ABUTH[a]		IPOHE		XANST	
	Mesotrione	Atrazine	Mesotrione	Atrazine	Mesotrione	Atrazine
-----(%)-----	---------------------------------g ai ha^{-1}---------------------------------					
25	2.63	224	8.75	168	5.5	210
50	5.25	448	17.5	336	11	420
75	7.88	672	26.25	504	16.5	630

[a]Abbreviations: ABUTH, velvetleaf; IPHOE, ivyleaf morningglory; XANST, common cocklebur

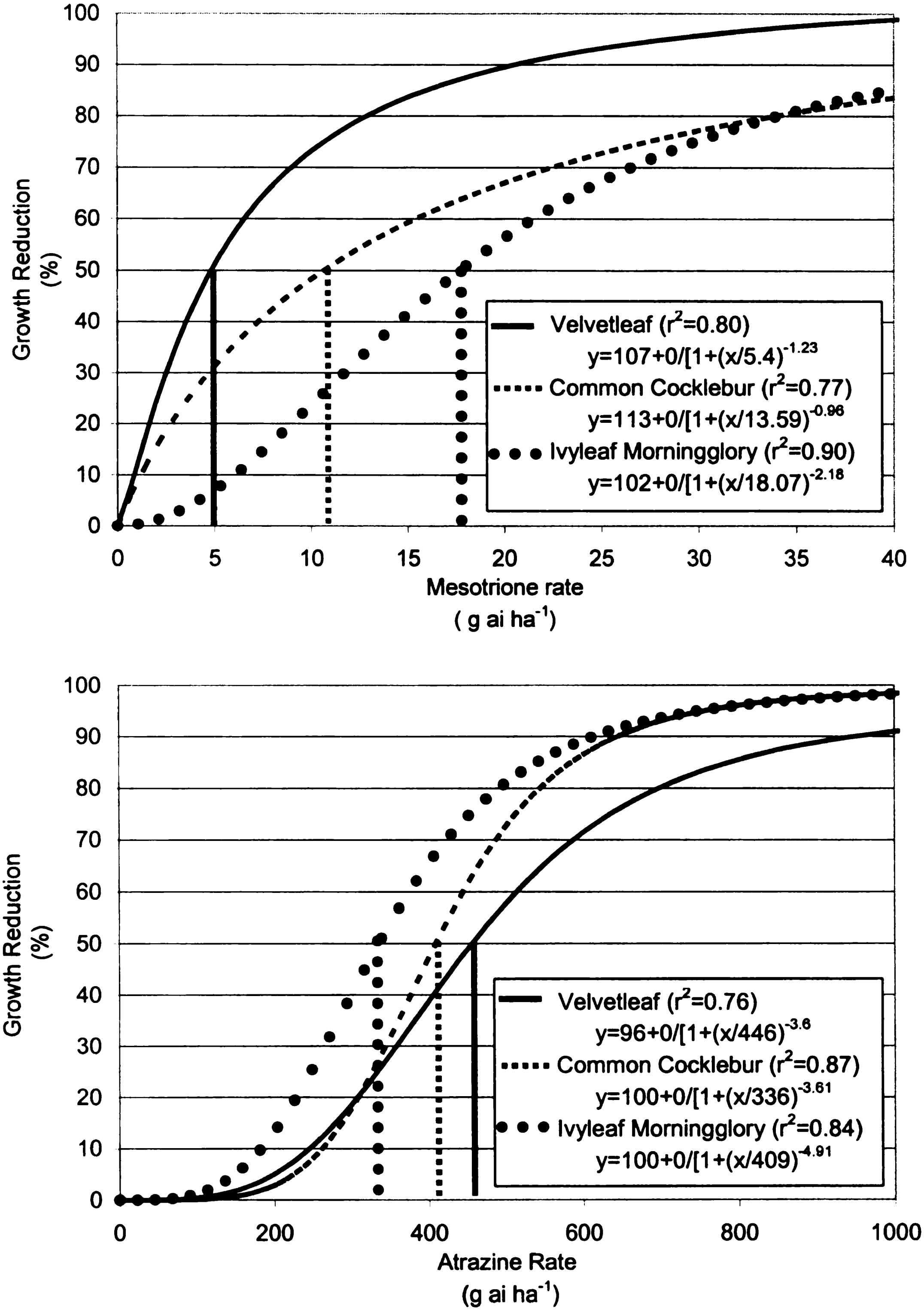

Figure 1. Growth response of velvetleaf, ivyleaf morningglory, and common cocklebur to mesotrione and atrazine (Vertical lines indicate GR_{50} rates).

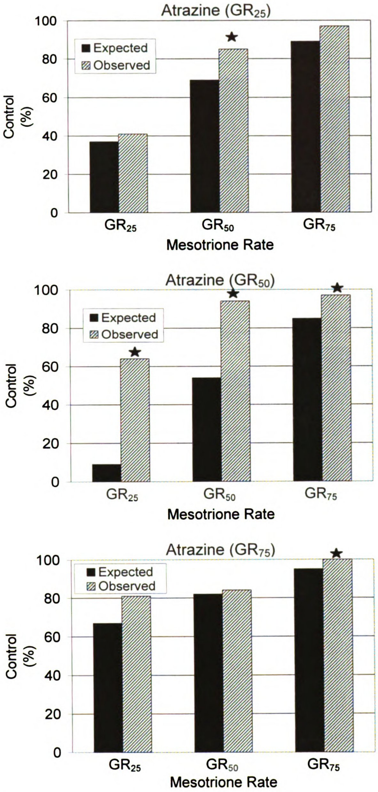

Figure 2. Expected and observed control of velvetleaf from mesotrione and atrazine combinations. Asterisks (★) indicate when observed responses are significantly greater than expected (P=0.1).

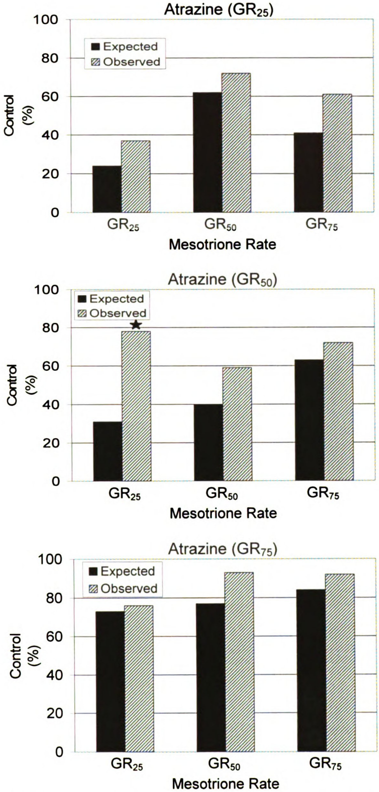

Figure 3. Expected and observed control of ivyleaf morningglory from mesotrione and atrazine combinations. Asterisks (★) indicate when observed responses are significantly greater than expected (P=0.1).

APPENDIX A

Table A1. Weed control, weed densities, and corn yield with mesotrione and atrazine. Clarksville, MI. 2002.

		Weed Control 30 DAT[a]		Weed Density 30 DAT		
Mesotrione	Atrazine	S-CHEAL	ABUTH	S-CHEAL	ABUTH	Corn Yield
----------g ai ha^{-1}------------		------------%-----------		--------plants m^{-2}---------		---% of WF---
0	0	0	0	6	26	80
0	280	99	24	0	20	86
0	560	99	43	0	17	87
0	1120	99	39	0	12	95
0	1780	99	65	0	5	93
53	0	96	91	1	0	95
53	280	98	93	0	0	101
53	560	99	89	0	1	101
53	1120	99	96	0	0	102
53	1780	99	98	0	1	97
105	0	98	99	0	0	97
105	280	99	99	0	0	95
105	560	99	99	0	1	101
105	1120	99	98	0	0	103
105	1780	99	99	0	0	104
158	0	99	99	0	5	94
158	280	99	99	0	0	99
158	560	99	99	0	0	102
158	1120	99	99	0	0	94
158	1780	99	99	0	0	104
210	0	99	99	0	0	93
210	280	99	99	0	0	92
210	560	98	99	0	0	103
210	1120	99	99	0	0	94
210	1780	99	99	0	0	111
$LSD_{0.05}$		2	11	1	17	13

[a] Abbreviations; DAT, days after treatment; S-CHEAL, triazine-susceptible common lambsquarters; ABUTH, velvetleaf; WF, weed free.

Table A2. Weed control, weed densities, and corn yield with mesotrione and atrazine. Dekalb, IL. 2002.

		Weed Control 30 DAT[a]				Weed Density 30 DAT				
Mesotrione	Atrazine	S-CHEAL	ABUTH	AMBTR	POLPY	S-CHEAL	ABUTH	AMBTR	POLPY	Corn Yield
---g ai ha^{-1}---		---%---				---plants m^{-2}---				---% of WF---
0	0	0	0	0	0	2	1	28	1	1
0	280	91	38	18	80	1	5	28	5	23
0	560	99	53	64	97	0	9	3	9	76
0	1120	99	84	68	97	0	2	3	2	80
0	1780	99	66	66	93	1	4	5	4	72
53	0	99	78	45	99	0	1	7	1	79
53	280	99	76	79	99	1	1	1	1	106
53	560	99	91	76	99	0	3	6	3	90
53	1120	99	98	87	99	0	1	2	1	105
53	1780	99	99	88	99	0	1	1	1	108
105	0	99	89	71	99	0	1	3	1	107
105	280	99	98	79	99	0	3	7	3	89
105	560	99	93	89	99	0	1	2	1	107
105	1120	99	96	85	99	0	1	1	1	89
105	1780	99	98	90	99	0	1	1	1	100
158	0	99	96	86	99	0	2	13	2	109
158	280	99	94	81	99	0	1	2	1	103
158	560	98	96	79	99	0	1	13	1	97
158	1120	99	94	78	99	0	2	10	2	98
158	1780	99	95	74	99	0	1	2	1	97
210	0	99	98	87	99	0	1	2	1	102
210	280	99	97	87	99	0	1	1	1	105
210	560	99	96	89	99	0	1	1	1	97
210	1120	99	97	95	99	0	1	1	1	106
210	1780	99	98	94	99	0	1	1	1	106
$LSD_{0.05}$		2	9	12	6	1	3	19	3	19

[a] Abbreviations; DAT, days after treatment; S-CHEAL, triazine-susceptible common lambsquarters; ABUTH, velvetleaf; AMBTR, giant ragweed; POLPY, Pennsylvania smartweed; WF, weed free.

Table A3. Weed control, weed densities, and corn yield with mesotrione and atrazine. Dekalb, IL. 2003.

		Weed Control 30 DAT[a]		Weed Density 30 DAT		
Mesotrione	Atrazine	ABUTH	AMBTR	ABUTH	AMBTR	Corn Yield
------------g ai ha^{-1}------------		--------------%-------------		--------plants m^{-2}---------		---% of WF---
0	0	0	0	13	43	0
0	280	0	0	8	14	0
0	560	0	0	9	17	0
0	1120	33	33	4	18	3
0	1780	93	40	3	20	2
53	0	99	53	1	20	7
53	280	99	49	1	36	11
53	560	99	54	0	17	2
53	1120	99	79	0	17	6
53	1780	99	75	0	1	0
105	0	99	63	0	26	22
105	280	99	71	0	15	11
105	560	99	84	0	17	7
105	1120	99	76	1	11	3
105	1780	99	70	1	13	18
158	0	99	63	0	11	0
158	280	99	66	1	26	2
158	560	99	83	0	9	12
158	1120	99	90	0	1	2
158	1780	99	81	1	10	4
210	0	99	71	1	11	20
210	280	99	93	0	6	10
210	560	99	83	0	6	7
210	1120	99	90	0	9	14
210	1780	99	89	1	6	42
$LSD_{0.05}$		2	15	2	25	26

[a] Abbreviations; DAT, days after treatment; ABUTH, velvetleaf; AMBTR, giant ragweed; WF, weed free.

Table A4. Weed control, weed densities, and corn yield with mesotrione and atrazine. East Lansing, MI. 2002.

		Weed Control 30 DAT[a]			Weed Density 30 DAT			
Mesotrione	Atrazine	TR-CHEAL	ABUTH	AMBEL	TR-CHEAL	ABUTH	AMBEL	Corn Yield
-----------g ai ha^{-1}-----------		-----------------%-----------------			------------plants m^{-2}------------			---% of WF---
0	0	0	0	0	53	8	38	58
0	280	49	54	70	7	7	8	74
0	560	65	46	85	36	11	5	83
0	1120	67	70	82	5	14	1	87
0	1780	80	86	98	1	10	1	91
53	0	99	93	73	1	1	3	87
53	280	98	93	96	0	7	2	91
53	560	99	93	98	1	6	1	96
53	1120	99	95	95	0	1	1	91
53	1780	99	92	98	0	5	2	93
105	0	98	96	83	1	1	1	84
105	280	99	90	96	0	2	2	94
105	560	96	94	96	0	2	0	92
105	1120	99	97	99	0	1	0	95
105	1780	99	96	99	0	2	4	97
158	0	99	97	90	0	2	1	93
158	280	99	97	99	0	1	0	96
158	560	99	95	99	0	3	1	98
158	1120	99	97	97	0	1	0	100
158	1780	99	96	99	0	2	0	99
210	0	99	95	95	0	1	1	93
210	280	99	97	98	0	1	1	95
210	560	99	96	92	0	2	1	96
210	1120	99	98	99	0	0	0	99
210	1780	99	97	99	0	0	1	96
$LSD_{0.05}$		11	10	11	27	5	23	13

[a] Abbreviations; DAT, days after treatment; TR-CHEAL, triazine-resistant common lambsquarters; ABUTH, velvetleaf; AMBEL, common ragweed; WF, weed free.

Table A5. Weed control, weed densities, and corn yield with mesotrione and atrazine. East Lansing-1, MI. 2003.

		Weed Control 30 DAT[a]		Weed Density 30 DAT		
Mesotrione	Atrazine	TR-CHEAL	AMBEL	TR-CHEAL	AMBEL	Corn Yield
---------g ai ha^{-1}---------		------------%-----------		--------plants m^{-2}---------		-----% of WF-----
0	0	0	0	84	112	40
0	280	46	28	77	65	41
0	560	54	35	41	82	50
0	1120	51	55	38	17	62
0	1780	55	70	89	21	66
53	0	89	38	3	83	64
53	280	76	54	0	43	69
53	560	80	68	6	13	81
53	1120	81	78	2	15	92
53	1780	87	81	4	4	82
105	0	86	61	2	40	71
105	280	87	62	6	14	76
105	560	96	84	0	3	94
105	1120	92	84	4	2	88
105	1780	87	78	4	5	89
158	0	97	67	0	21	89
158	280	94	77	0	8	96
158	560	94	86	5	3	80
158	1120	94	85	1	3	88
158	1780	88	89	4	5	83
210	0	99	81	0	22	87
210	280	97	91	0	5	83
210	560	98	95	1	2	86
210	1120	97	91	0	1	95
210	1780	95	93	0	1	99
$LSD_{0.05}$		14	17	33	40	22

[a] Abbreviations; DAT, days after treatment; TR-CHEAL, triazine-resistant common lambsquarters; AMBEL, common ragweed; WF, weed free.

Table A6. Weed control, weed densities, and corn yield with mesotrione and atrazine. East Lansing-2, MI. 2003.

		Weed Control 30 DAT[a]		Weed Density 30 DAT		
Mesotrione	Atrazine	TR-CHEAL	ABUTH	TR-CHEAL	ABUTH	Corn Yield
----------g ai ha^{-1}-------------		------------%-----------		--------plants m^{-2}---------		---% of WF---
0	0	0	0	196	9	74
0	280	53	91	64	10	76
0	560	70	90	26	4	97
0	1120	65	95	59	2	89
0	1780	52	99	118	1	57
53	0	77	98	1	0	103
53	280	95	99	0	1	101
53	560	88	99	0	0	103
53	1120	90	99	1	1	86
53	1780	89	99	0	1	103
105	0	96	98	0	1	102
105	280	89	99	1	1	105
105	560	99	99	0	1	101
105	1120	99	97	0	1	104
105	1780	99	99	0	1	96
158	0	98	99	0	0	105
158	280	98	99	0	1	98
158	560	99	98	0	1	95
158	1120	99	99	0	0	99
158	1780	99	99	0	1	97
210	0	99	98	0	0	110
210	280	99	99	0	1	94
210	560	99	99	0	0	104
210	1120	99	99	1	0	102
210	1780	99	99	0	1	99
$LSD_{0.05}$		22	3	137	5	25

[a] Abbreviations; DAT, days after treatment; TR-CHEAL, triazine-resistant common lambsquarters; ABUTH, velvetleaf; WF, weed free.

Table A7. Weed control, weed densities, and corn yield with mesotrione and atrazine. Lexington, KY. 2002.

		Weed Control 30 DAT[a]			Weed Density 30 DAT			
Mesotrione	Atrazine	AMBTR	IPOHE	XANST	AMBTR	IPOHE	XANST	Corn Yield
-----------g ai ha^{-1}---------		---------------%--------------			------------plants m^{-2}-----------			---% of WF---
0	0	0	0	0	8	16	3	36
0	280	34	35	59	9	12	7	36
0	560	49	45	59	11	19	5	39
0	1120	64	79	93	10	26	7	53
0	1780	84	79	90	2	21	5	37
53	0	61	16	34	5	24	6	30
53	280	76	59	76	4	21	6	41
53	560	70	49	79	3	20	4	69
53	1120	84	70	88	6	16	3	48
53	1780	80	73	90	10	13	0	89
105	0	60	18	49	6	11	1	50
105	280	79	50	70	8	9	1	61
105	560	89	75	89	3	9	6	74
105	1120	91	81	91	3	9	0	69
105	1780	94	76	90	1	11	2	88
158	0	93	40	64	5	11	3	99
158	280	88	63	83	3	8	1	98
158	560	91	75	89	3	9	2	91
158	1120	91	70	91	2	11	3	74
158	1780	95	79	95	3	6	2	97
210	0	90	66	84	8	9	1	58
210	280	90	61	83	8	9	2	89
210	560	90	81	91	6	7	3	67
210	1120	95	85	95	3	2	1	100
210	1780	94	84	94	11	8	4	92
$LSD_{0.05}$		18	20	18	9	13	7	51

[a] Abbreviations; DAT, days after treatment; AMBTR, giant ragweed; IPOHE, ivyleaf morningglory; XANST, common cocklebur; WF, weed free.

Table A8. Weed control, weed density, and corn yield with mesotrione and atrazine. Lexington, KY. 2003.

		Weed Control 30 DAT[a]	Weed Density 30 DAT	
Mesotrione	Atrazine	AMBTR	AMBTR	Corn Yield
---------g ai ha^{-1}----------		------------%-----------	--------plants m^{-2}------	---% of WF---
0	0	0	76	0
0	280	28	56	0
0	560	40	28	0
0	1120	70	19	26
0	1780	79	15	40
53	0	25	52	0
53	280	50	38	0
53	560	69	15	13
53	1120	78	11	46
53	1780	88	7	74
105	0	59	33	9
105	280	73	14	28
105	560	81	14	47
105	1120	90	9	72
105	1780	92	6	81
158	0	73	25	30
158	280	74	15	34
158	560	84	11	67
158	1120	93	7	81
158	1780	95	3	101
210	0	71	18	27
210	280	81	16	57
210	560	91	6	74
210	1120	92	6	81
210	1780	93	4	78
$LSD_{0.05}$		16	22	17

[a] Abbreviations; DAT, days after treatment; AMBTR, giant ragweed; WF, weed free.

Table A9. Weed control, weed densities, and corn yield with mesotrione and atrazine. South Charleston, OH. 2002.

		Weed Control 30 DAT[a]				Weed Density 30 DAT				
Mesotrione	Atrazine	ABUTH	AMBEL	AMBTR	HIBTR	ABUTH	AMBEL	AMBTR	HIBTR	Corn Yield
---------g ai ha^{-1}----------		---------------------%---------------------				-----------------plants m^{-2}----------------				---% of WF---
0	0	0	0	0	0	4	2	.	2	69
0	280	75	91	73	82	1	0	0	1	81
0	560	85	99	85	97	1	0	.	1	89
0	1120	77	99	94	98	0	0	.	0	87
0	1780	84	99	94	99	1	0	.	0	97
53	0	94	89	80	80	0	0	.	1	92
53	280	97	98	90	98	0	0	0	1	81
53	560	99	99	77	98	0	1	1	0	85
53	1120	89	90	95	94	1	0	1	0	95
53	1780	98	99	91	99	0	0	0	1	90
105	0	99	83	86	92	1	0	1	1	92
105	280	99	99	85	99	0	1	1	1	82
105	560	99	99	85	97	1	1	0	0	94
105	1120	99	99	89	99	0	0	1	0	92
105	1780	99	99	90	99	3	1	1	0	89
158	0	99	99	92	97	1	0	1	1	95
158	280	97	95	89	92	0	0	1	1	95
158	560	99	99	84	97	0	0	2	0	99
158	1120	99	99	82	99	0	0	9	0	98
158	1780	99	99	93	99	2	1	3	0	95
210	0	98	98	83	88	1	0	0	1	105
210	280	99	99	93	99	1	0	0	0	98
210	560	99	99	96	99	1	0	1	0	95
210	1120	99	99	90	99	1	0	1	0	91
210	1780	96	99	94	99	1	3	6	0	102
$LSD_{0.05}$		12	10	17	11	2	2	2	1	20

[a] Abbreviations; DAT, days after treatment; ABUTH, velvetleaf; AMBEL, common ragweed; AMBTR, giant ragweed; HIBTR, Venice mallow; WF, weed free.

Table A10. Weed control, weed densities, and corn yield with mesotrione and atrazine. South Charleston, OH. 2003.

		Weed Control 30 DAT[a]		Weed Density 30 DAT		
Mesotrione	Atrazine	S-CHEAL	ABUTH	S-CHEAL	ABUTH	Corn Yield
---------g ai ha^{-1}	-----------	------------%	-----------	--------plants m^{-2}	---------	---% of WF---
0	0	0	0	5	1	91
0	280	92	91	13	2	89
0	560	90	92	2	1	93
0	1120	96	94	3	1	98
0	1780	93	96	1	1	99
53	0	99	98	1	0	99
53	280	99	99	0	2	92
53	560	99	99	0	0	99
53	1120	99	99	0	1	98
53	1780	99	99	0	0	99
105	0	99	99	0	1	98
105	280	99	99	0	0	100
105	560	99	99	0	0	99
105	1120	99	98	0	1	102
105	1780	99	99	0	1	101
158	0	97	97	0	0	95
158	280	99	99	1	0	102
158	560	98	98	0	0	99
158	1120	99	99	0	1	101
158	1780	99	99	1	0	99
210	0	99	99	0	0	95
210	280	99	99	0	0	102
210	560	99	98	1	0	99
210	1120	99	99	0	0	98
210	1780	99	98	1	1	102
$LSD_{0.05}$		4	3	6	2	7

[a] Abbreviations; DAT, days after treatment; S-CHEAL, triazine-susceptible common lambsquarters; ABUTH, velvetleaf; WF, weed free.

Table A11. Weed control, weed densities, and corn yield with mesotrione and atrazine. West Lafayette, IN. 2002.

		Weed Control 30 DAT[a]		Weed Density 30 DAT		
Mesotrione	Atrazine	ABUTH	IPOHE	ABUTH	IPOHE	Corn Yield
----------g ai ha^{-1}	-------------	------------%	-----------	--------plants m^{-2}	---------	---% of WF---
0	0	0	0	15	8	97
0	280	66	20	3	5	99
0	560	45	15	3	5	95
0	1120	65	40	2	4	128
0	1780	70	45	0	1	127
53	0	69	38	0	8	111
53	280	92	63	1	7	105
53	560	93	81	0	4	124
53	1120	99	97	0	2	114
53	1780	99	97	0	1	116
105	0	92	91	0	5	126
105	280	94	84	0	5	117
105	560	97	99	0	3	106
105	1120	98	.	0	1	118
105	1780	99	92	1	1	115
158	0	94	95	0	6	118
158	280	99	99	0	1	111
158	560	98	96	0	3	121
158	1120	98	97	1	1	119
158	1780	99	96	0	1	111
210	0	98	99	0	3	125
210	280	98	94	1	1	108
210	560	95	98	0	1	124
210	1120	98	98	1	1	110
210	1780	99	99	0	1	119
$LSD_{0.05}$		22	20	5	3	88

[a] Abbreviations; DAT, days after treatment; ABUTH, velvetleaf; IPOHE, ivyleaf morningglory; WF, weed free.

Table A12. Weed control, weed densities, and corn yield with mesotrione and atrazine. West Lafayette, IN. 2003.

		Weed Control 30 DAT[a]			Weed Density 30 DAT			
Mesotrione	Atrazine	AMBTR	ABUTH	IPOHE	AMBTR	ABUTH	IPOHE	Corn Yield
----------g ai ha^{-1}-----------		---------------%---------------			---------plants m^{-2}----------			---% of WF---
0	0	0	0	0	2	4	2	34
0	280	60	15	20	1	2	3	22
0	560	80	7	15	1	1	2	31
0	1120	48	43	40	1	1	3	60
0	1780	45	38	45	0	1	3	77
53	0	58	99	38	2	0	3	68
53	280	70	98	63	0	0	1	71
53	560	76	99	81	1	1	2	89
53	1120	82	99	97	1	0	1	92
53	1780	84	96	97	2	0	1	95
105	0	88	98	91	1	0	1	96
105	280	86	99	84	1	0	1	97
105	560	.	.	.	.	.	.	.
105	1120	.	.	.	.	.	.	.
105	1780	83	99	92	0	0	1	109
158	0	93	99	95	0	0	1	99
158	280	95	99	99	0	0	0	96
158	560	95	99	96	0	0	1	88
158	1120	94	99	97	0	0	1	102
158	1780	92	99	96	0	0	0	103
210	0	91	99	99	0	1	1	103
210	280	92	99	94	0	0	0	98
210	560	94	99	98	0	0	0	90
210	1120	93	99	98	0	0	1	102
210	1780	93	.	99	0	0	1	35
$LSD_{0.05}$		18	16	20	2	1	2	16

[a] Abbreviations; DAT, days after treatment; AMBTR, giant ragweed; ABUTH, velvetleaf; IPOHE, ivyleaf morningglory; WF, weed free.

Table A13. Weed control, weed densities, and corn yield with mesotrione and atrazine. Urbana, IL. 2002.

Mesotrione	Atrazine	Weed Control 30 DAT[a]							
		S-CHEAL	AMBEL	ABUTH	IPOHE	XANST	POLPY	DATST	SIDSP
----------g ai ha^{-1}-----------		-----%-----							
0	0	0	0	0	0	0	0	0	0
0	280	95	63	30	0	99	5	92	75
0	560	97	94	45	55	99	58	99	78
0	1120	99	90	63	75	99	73	99	85
0	1780	99	99	77	80	99	99	99	98
53	0	97	97	92	70	95	65	99	97
53	280	92	96	86	90	97	92	96	95
53	560	99	99	99	99	99	97	99	99
53	1120	99	97	99	84	99	97	99	99
53	1780	99	99	99	92	99	99	99	99
105	0	99	99	99	88	99	99	99	99
105	280	99	99	99	92	99	99	99	99
105	560	99	99	99	83	99	99	99	99
105	1120	99	99	99	97	99	99	99	99
105	1780	99	99	99	92	99	99	99	99
158	0	.	.	.	.	.	.	.	.
158	280	99	99	99	81	99	99	99	99
158	560	99	99	99	92	99	99	99	99
158	1120	99	99	99	86	99	99	99	99
158	1780	99	99	99	94	99	99	99	99
210	0	99	99	99	91	99	99	99	99
210	280	99	99	99	97	99	99	99	99
210	560	99	99	99	97	99	99	99	99
210	1120	99	99	99	98	99	99	99	99
210	1780	99	99	99	94	99	99	99	99
$LSD_{0.05}$		4	5	11	15	2	9	3	5

[a] Abbreviations; DAT, days after treatment; S-CHEAL, triazine-susceptible common lambsquarters; AMBEL, common ragweed; ABUTH, velvetleaf; IPOHE, ivyleaf morningglory; XANST,common cocklebur; POLPY, Pennsylvania smartweed; DATST, jimsonweed; SIDSP, prickely sida.

Table A13. (cont'd).

Mesotrione	Atrazine	Weed Density 30 DAT[a] S-CHEAL	AMBEL	ABUTH	IPOHE	XANST	POLPY	DATST	SIDSP	Corn Yield
------------g ai ha^{-1}	----------	---plants m^{-2}							--	---% of WF---
0	0	4	1	1	7	1	3	1	2	48
0	280	1	1	1	3	1	0	2	1	64
0	560	0	1	1	3	1	1	0	1	78
0	1120	0	0	1	1	1	0	1	1	84
0	1780	0	0	1	1	0	1	1	1	91
53	0	1	1	0	3	1	1	1	1	87
53	280	0	1	0	1	1	0	1	1	87
53	560	1	1	0	2	1	0	0	1	85
53	1120	0	0	0	1	1	1	0	1	88
53	1780	0	1	0	2	1	0	0	0	99
105	0	1	0	1	1	1	0	0	0	86
105	280	0	1	0	1	1	0	1	1	95
105	560	0	0	0	2	0	0	0	0	83
105	1120	0	0	0	0	0	0	0	1	100
105	1780	0	0	0	5	1	0	0	0	97
158	0	.	.	.	.	.	.	.	.	----
158	280	0	0	0	1	1	0	0	0	89
158	560	0	0	0	1	1	0	1	0	92
158	1120	0	0	0	1	0	0	1	1	95
158	1780	0	0	0	2	1	0	0	0	92
210	0	1	0	0	7	1	1	1	0	93
210	280	0	0	0	1	1	0	0	1	105
210	560	0	0	0	0	1	0	0	0	95
210	1120	0	0	0	0	1	0	1	1	106
210	1780	0	0	0	2	0	0	1	0	101
$LSD_{0.05}$		1	1	1	6	1	1	1	1	12

[a] Abbreviations; DAT, days after treatment; S-CHEAL, triazine-susceptible common lambsquarters; AMBEL, common ragweed; ABUTH, velvetleaf; IPOHE, ivyleaf morningglory; XANST,common cocklebur; POLPY, Pennsylvania smartweed; DATST, jimsonweed; SIDSP, prickely sida; WF, weed free.

Table A14. Weed control, weed densities, and corn yield with mesotrione and atrazine. Urbana, IL. 2003.

		Weed Control 30 DAT[a]					Weed Density 30 DAT					
Mesotrione	Atrazine	S-CHEAL	AMBEL	ABUTH	XANST	POLPY	S-CHEAL	AMBEL	ABUTH	XANST	POLPY	Corn Yield
----------g ai ha^{-1}----------		--------%				--------	----------plants m^{-2}				----------	---% of WF---
0	0	0	0	0	0	0	3	2	4	16	1	32
0	280	99	15	8	5	33	0	1	2	4	1	73
0	560	99	10	5	5	30	0	1	1	14	1	58
0	1120	99	38	71	54	72	0	1	1	1	0	92
0	1780	99	94	91	54	99	0	0	1	1	1	93
53	0	97	13	99	15	65	0	2	0	14	1	78
53	280	99	38	99	3	84	0	0	0	6	1	79
53	560	99	70	79	53	92	0	1	1	12	1	88
53	1120	99	89	99	63	99	1	1	0	5	0	95
53	1780	99	99	99	34	99	0	2	0	13	0	87
105	0	97	36	92	45	94	0	1	0	33	1	82
105	280	97	69	97	61	84	0	1	0	2	0	93
105	560	99	65	99	50	99	0	0	0	9	0	87
105	1120	99	77	99	71	99	0	0	0	2	0	88
105	1780	99	99	99	73	99	0	0	0	2	0	94
158	0	99	86	99	83	.	0	0	0	1	0	100
158	280	99	99	99	63	99	0	0	0	12	0	91
158	560	99	99	99	63	99	0	0	0	2	0	92
158	1120	99	99	99	86	99	0	0	0	1	0	100
158	1780	99	95	99	89	99	0	0	0	12	0	94
210	0	99	99	99	57	99	0	0	1	2	1	93
210	280	99	99	99	80	99	0	0	0	3	0	93
210	560	99	99	99	93	99	0	0	0	1	0	98
210	1120	99	94	99	59	99	0	0	0	10	0	89
210	1780	99	99	99	69	99	0	0	0	10	0	90
$LSD_{0.05}$		2	15	16	36	28	1	2	1	21	1	14

[a] Abbreviations; DAT, days after treatment; S-CHEAL, triazine-susceptible common lambsquarters; AMBEL, common ragweed; ABUTH, velvetleaf; XANST, common cocklebur; POLPY, Pennsylvania smartweed; WF, weed

Table A15. Triazine-susceptible common lambsquarters control with mesotrione and atrazine in Illinois, Michigan and Ohio in 2002 and 2003.

		Triazine-Susceptible Common Lambsquarters Control				
		2002			2003	
Mesotrione	Atrazine	Clarksville	Dekalb	Urbana	S. Charleston	Urbana
-----------g ai ha^{-1} ---------		----------------	----------------	%	----------------	----------------
0	0	0	0	0	0	0
0	280	99	91	95	92	99
0	560	99	99	97	90	99
0	1120	99	99	99	96	99
0	1780	99	99	99	93	99
53	0	96	99	97	99	97
53	280	98	99	92	99	99
53	560	99	99	99	99	99
53	1120	99	99	99	99	99
53	1780	99	99	99	99	99
105	0	98	99	99	99	97
105	280	99	99	99	99	97
105	560	99	99	99	99	99
105	1120	99	99	99	99	99
105	1780	99	99	99	99	99
158	0	99	99	99	97	99
158	280	99	99	99	99	99
158	560	99	98	99	98	99
158	1120	99	99	99	99	99
158	1780	99	99	99	99	99
210	0	99	99	99	99	99
210	280	99	99	99	99	99
210	560	98	99	99	99	99
210	1120	99	99	99	99	99
210	1780	99	99	99	99	99
$LSD_{0.05}$		2	2	4	4	2

Table A16. Triazine-resistant common lambsquarters control with mesotrione and atrazine in Michigan in 2002 and 2003.

		Triazine-Resistant Common Lambsquarters Control		
		2002	2003	
Mesotrione	Atrazine	E. Lansing	E. Lansing-1	E. Lansing-2
g ai ha^{-1}		%		
0	0	0	0	0
0	280	49	46	53
0	560	65	54	70
0	1120	67	51	65
0	1780	80	55	52
53	0	99	89	77
53	280	98	76	95
53	560	99	80	88
53	1120	99	81	90
53	1780	99	87	89
105	0	98	86	96
105	280	99	87	89
105	560	96	96	99
105	1120	99	92	99
105	1780	99	87	99
158	0	99	97	98
158	280	99	94	98
158	560	99	94	99
158	1120	99	94	99
158	1780	99	88	99
210	0	99	99	99
210	280	99	97	99
210	560	99	98	99
210	1120	99	97	99
210	1780	99	95	99
$LSD_{0.05}$		11	14	22

Table A17. Velvetleaf control with mesotrione and atrazine in Illinois, Indiana, Michigan and Ohio in 2002.

		Velvetleaf Control					
		2002					
Mesotrione	Atrazine	Clarksville	Dekalb	E. Lansing	S. Charleston	Urbana	W. Lafayette
------------g ai ha^{-1} ---------		---------- % ----------					
0	0	0	0	0	0	0	0
0	280	24	38	54	75	30	66
0	560	43	53	46	85	45	45
0	1120	39	84	70	77	63	65
0	1780	65	66	86	84	77	70
53	0	91	78	93	94	92	69
53	280	93	76	93	97	86	92
53	560	89	91	93	99	99	93
53	1120	96	98	95	89	99	99
53	1780	98	99	92	98	99	99
105	0	99	89	96	99	99	92
105	280	99	98	90	99	99	94
105	560	99	93	94	99	99	97
105	1120	98	96	97	99	99	98
105	1780	99	98	96	99	99	99
158	0	99	96	97	99	.	94
158	280	99	94	97	97	99	99
158	560	99	96	95	99	99	98
158	1120	99	94	97	99	99	98
158	1780	99	95	96	99	99	99
210	0	99	98	95	98	99	98
210	280	99	97	97	99	99	98
210	560	99	96	96	99	99	95
210	1120	99	97	98	99	99	98
210	1780	99	98	97	96	99	99
$LSD_{0.05}$		11	9	10	12	11	22

Table A18. Velvetleaf control with mesotrione and atrazine in Illinois, Indiana, Michigan and Ohio in 2003.

		Velvetleaf Control				
		2003				
Mesotrione	Atrazine	Dekalb	E. Lansing-2	S. Charleston	Urbana	W. Lafayette
---- g ai ha^{-1} ----		---- % ----				
0	0	0	0	0	0	0
0	280	0	91	91	8	15
0	560	0	90	92	5	7
0	1120	33	95	94	71	43
0	1780	93	99	96	91	38
53	0	99	98	98	99	99
53	280	99	99	99	99	98
53	560	99	99	99	79	99
53	1120	99	99	99	99	99
53	1780	99	99	99	99	96
105	0	99	98	99	92	98
105	280	99	99	99	97	99
105	560	99	99	99	99	.
105	1120	99	97	98	99	.
105	1780	99	99	99	99	99
158	0	99	99	97	99	99
158	280	99	99	99	99	99
158	560	99	98	98	99	99
158	1120	99	99	99	99	99
158	1780	99	99	99	99	99
210	0	99	98	99	99	99
210	280	99	99	99	99	99
210	560	99	99	98	99	99
210	1120	99	99	99	99	99
210	1780	99	99	98	99	.
$LSD_{0.05}$		2	3	3	16	16

Table A19. Common ragweed control with mesotrione and atrazine in Illinois, Michigan and Ohio in 2002 and 2003.

		Common Ragweed Control				
		2002			2003	
Mesotrione	Atrazine	E. Lansing	S. Charleston	Urbana	E. Lansing-1	Urbana
g ai ha^{-1}		%				
0	0	0	0	0	0	0
0	280	70	91	63	28	15
0	560	85	99	94	35	10
0	1120	82	99	90	55	38
0	1780	98	99	99	70	94
53	0	73	89	97	38	13
53	280	96	98	96	54	38
53	560	98	99	99	68	70
53	1120	95	90	97	78	89
53	1780	98	99	99	81	99
105	0	83	83	99	61	36
105	280	96	99	99	62	69
105	560	96	99	99	84	65
105	1120	99	99	99	84	77
105	1780	99	99	99	78	99
158	0	90	99	99	67	86
158	280	99	95	99	77	99
158	560	99	99	99	86	99
158	1120	97	99	99	85	99
158	1780	99	99	99	89	95
210	0	95	98	99	81	99
210	280	98	99	99	91	99
210	560	92	99	99	95	99
210	1120	99	99	99	91	94
210	1780	99	99	99	93	99
$LSD_{0.05}$		11	10	5	17	15

Table A20. Giant ragweed control with mesotrione and atrazine in Illinois, Kentucky and Ohio in 2002 and 2003.

		Giant Ragweed Control				
		2002			2003	
Mesotrione	Atrazine	Dekalb	Lexington	S. Charleston	Dekalb	Lexington
---------- g ai ha^{-1} ---------		%				
0	0	0	0	0	0	0
0	280	18	34	73	0	28
0	560	64	49	85	0	40
0	1120	68	64	94	33	70
0	1780	66	84	94	40	79
53	0	45	61	80	53	25
53	280	79	76	90	49	50
53	560	76	70	77	54	69
53	1120	87	84	95	79	78
53	1780	88	80	91	75	88
105	0	71	60	86	63	59
105	280	79	79	85	71	73
105	560	89	89	85	84	81
105	1120	85	91	89	76	90
105	1780	90	94	90	70	92
158	0	86	93	92	63	73
158	280	81	88	89	66	74
158	560	79	91	84	83	84
158	1120	78	91	82	90	93
158	1780	74	95	93	81	95
210	0	87	90	83	71	71
210	280	87	90	93	93	81
210	560	89	90	96	83	91
210	1120	95	95	90	90	92
210	1780	94	94	94	89	93
$LSD_{0.05}$		12	18	17	15	16

Table A21. Ivyleaf morningglory control with mesotrione and atrazine in Illinois, Indiana, and Kentucky in 2002 and 2003.

		Ivyleaf Morningglory Control			
		2002			2003
Mesotrione	Atrazine	Lexington	W. Lafayette	Urbana	W. Lafayette
---- g ai ha^{-1} ----		---- % ----			
0	0	0	0	0	0
0	280	35	28	0	20
0	560	45	20	55	15
0	1120	79	58	75	40
0	1780	79	68	80	45
53	0	16	53	70	38
53	280	59	36	9	63
53	560	49	55	99	81
53	1120	70	87	84	97
53	1780	73	84	92	97
105	0	18	70	88	91
105	280	50	76	92	84
105	560	75	64	83	99
105	1120	81	79	97	.
105	1780	76	89	92	92
158	0	40	74	.	95
158	280	63	86	81	99
158	560	75	76	92	96
158	1120	70	75	86	97
158	1780	79	96	94	96
210	0	66	83	91	99
210	280	61	91	97	94
210	560	81	83	97	98
210	1120	85	91	98	98
210	1780	84	90	94	99
$LSD_{0.05}$		20	23	15	20

Table A22. Common cocklebur control with mesotrione and atrazine in Illinois and Kentucky in 2002 and 2003.

		Common Cocklebur Control		
		2002		2003
Mesotrione	Atrazine	Lexington	Urbana	Urbana
g ai ha^{-1}		%		
0	0	0	0	0
0	280	59	99	5
0	560	59	99	5
0	1120	93	99	54
0	1780	90	99	54
53	0	34	95	15
53	280	76	97	3
53	560	79	99	53
53	1120	88	99	63
53	1780	90	99	34
105	0	49	99	45
105	280	70	99	61
105	560	89	99	50
105	1120	91	99	71
105	1780	90	99	73
158	0	64	99	83
158	280	83	99	63
158	560	89	99	63
158	1120	91	99	86
158	1780	95	99	89
210	0	84	99	57
210	280	83	99	80
210	560	91	99	93
210	1120	95	99	59
210	1780	94	99	69
$LSD_{0.05}$		18	2	36

Table A23. Pennsylvania smartweed control with mesotrione and atrazine in Illinois in 2002 and 2003.

		Pennsylvania Smartweed Control		
		2002		2003
Mesotrione	Atrazine	Dekalb	Urbana	Urbana
g ai ha^{-1}		%		
0	0	0	0	0
0	280	80	5	33
0	560	97	58	30
0	1120	97	73	72
0	1780	93	99	99
53	0	99	65	65
53	280	99	92	84
53	560	99	97	92
53	1120	99	97	99
53	1780	99	99	99
105	0	99	99	94
105	280	99	99	84
105	560	99	99	99
105	1120	99	99	99
105	1780	99	99	99
158	0	99	.	.
158	280	99	99	99
158	560	99	99	99
158	1120	99	99	99
158	1780	99	99	99
210	0	99	99	99
210	280	99	99	99
210	560	99	99	99
210	1120	99	99	99
210	1780	99	99	99
$LSD_{0.05}$		6	9	28

Table A24. Venice mallow and prickly sida control with mesotrione and atrazine in Illinois and Ohio in 2002.

		Venice Mallow Control		Prickly Sida Control
		2002		2002
Mesotrione	Atrazine	S. Charleston	Dekalb	Urbana
-----------g ai ha^{-1} ---------		%		
0	0	0	0	0
0	280	82	82	75
0	560	97	97	78
0	1120	98	98	85
0	1780	99	99	98
53	0	80	80	97
53	280	98	98	95
53	560	98	94	99
53	1120	94	99	99
53	1780	99	99	99
105	0	92	92	99
105	280	99	99	99
105	560	97	97	99
105	1120	99	99	99
105	1780	99	99	99
158	0	97	97	.
158	280	92	92	99
158	560	97	97	99
158	1120	99	99	99
158	1780	99	99	99
210	0	88	88	99
210	280	99	99	99
210	560	99	99	99
210	1120	99	99	99
210	1780	99	99	99
$LSD_{0.05}$		11	11	5