ACETOLACTATE SYNTHASE-INHIBITING HERBICIDES: SURVEY OF WEED RESISTANCE AND ROTATIONAL CROP RESPONSE IN OKLAHOMA

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ACETOLACTATE SYNTHASE-INHIBITING HERBICIDES: SURVEY OF WEED RESISTANCE AND ROTATIONAL CROP RESPONSE IN OKLAHOMA

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INTRODUCTION

Chapters I and II of this thesis are manuscripts to be submitted for publication in Weed Technology, a Weed Science Society of America publication.

CHAPTER I

SURVEY OF WEED RESISTANCE TO ACETOLACTATE SYNTHASE-INHIBITING HERBICIDES IN OKLAHOMA

Survey of Weed Resistance to Acetolactate Synthase-Inhibiting Herbicides in Oklahoma[1]

K. TODD HEAP and THOMAS F. PEEPER[2]

Abstract: A survey was conducted across eastern Oklahoma soybean producing areas to identify sites where infestations of acetolactate synthase (ALS)-inhibitor resistant weed species biotypes, particularly common cocklebur have been suspected. Oklahoma State University Cooperative Extension personnel and industry representatives were asked to help identify fields. Posters were displayed at agribusiness locations and county extension offices across the area to explain herbicide resistant weeds and to provide a mechanism whereby farmers could seek help in controlling herbicide resistant biotypes. There were zero responses to these posters. This indicates that either the problem of herbicide resistant biotypes was not as severe as suspected, that producers had changed their weed control strategies to avoid the problem and were no longer concerned enough to respond to a survey, or that producers were unwilling to admit to the presence of herbicide resistant biotypes on their farm.

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Resistant common cocklebur was identified at two sites in Wagoner county and five sites in LeFlore county, OK.

Nomenclature: Common cocklebur, *Xanthium strumarium* L. #[3] XANST; soybean, *Glycine max* (L.) Merr.

Additional index words: Acetolactate synthase; herbicide resistant weeds, imidazolinones, sulfonylureas.

Abbreviations: ALS, acetolactate synthase; DAT, days after treatment; IMI, imidazolinone; SU, sulfonylurea.

INTRODUCTION

Sulfonylurea (SU) herbicides have been commercially available since 1982 (Holt 1992). They were soon followed by the imidazolinone (IMI) herbicides. Common characteristics include low use rates, broad spectrum of control, high efficacy, and low mammalian toxicity. SU and IMI herbicides are widely used and are applied to most major crops (Heap 1997).

Herbicide resistance has become well documented in scientific literature (Alcocer-Ruthling et al. 1992; Christopher et al. 1992; Friesen et al. 1993; Guttieri et al. 1992; Heap 1997; Holt 1992; Primiani et al. 1990; Schmitzer et al. 1993). SU and IMI herbicides, along with the triazolopyrimidine sulfonanalides and pyrimidyl-oxy-benzoates, inhibit acetolactate synthase (ALS, EC 4.1.3.18) which

[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821.

is a key enzyme in the biosynthesis of the branch-chain amino acids leucine, isoleucine, and valine (Alcocer-Ruthling et al. 1992; Christopher et al. 1992; Friesen et al. 1993; Primiani et al. 1990; Schmitzer et al. 1993). However, sensitivity of ALS to the ALS-inhibiting herbicide families of herbicides varies slightly which may be due to minute differences in the binding domains within a common binding site on the same protein (Guttieri et al. 1992).

Because of their highly specific mode of action and soil persistence, weed biotypes resistant to SU and IMI herbicides emerged in some areas within 3 to 5 yrs after use began (Holt 1992) and have been detected in the U.S.A. and 10 other countries (Heap 1997). This target site resistance has surfaced as a potential barrier to the long-term successful use of these herbicides (Schmitzer et al. 1993).

Resistance to ALS-inhibiting herbicides has been selected for in several crops including soybean, wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), and tobacco (*Nicotiana tabaccum* L.) (Schmitzer et al. 1993), which has greatly increased use of these herbicides. The increase in usage has added to selection pressure and could increase the rate of emergence of resistant weed biotypes. By 1997, there were approximately 13 ALS-inhibitor resistant weed species in the U.S. and 38 species worldwide (Heap 1997).

Kochia (*Kochia scoparia* [L.] Schrad.) and prickly lettuce (*Lactuca serriola* L.) were the first weeds reported to have biotypes resistant to SU herbicides as a result of their agronomic use (Christopher et al. 1992; Primiani et al. 1990). SU resistant kochia was reported after only 4 or 5 years of SU herbicide use (Holt

1992). Resistance has also been confirmed in annual ryegrass (*Lolium rigidum* L.) and Italian ryegrass (*Lolium multiflorum* Lam.); however, resistance in these species may be due to increased ability to metabolize the herbicide or an altered form of the target enzyme that is less sensitive (Christopher et al. 1992).

Kochia resistant to SU herbicides has been found that possessed cross-resistance to an IMI herbicide (Primiani et al.1990). ALS isolated from resistant plants showed varying levels of cross-resistance among these chemical families of ALS-inhibitors suggesting that these compounds share an overlapping but not identical binding site on ALS (Primiani et al. 1990). In contrast, Schmitzer et al. (1993) reported a lack of cross-resistance of imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} -resistant cocklebur ALS to chlorimuron {ethyl 2-[[[[(4-chloro-6-methoxypyrimidin-2-yl) amino]carbonyl]amino]sulfonyl]-benzoate}. At least six sites within the ALS gene have been identified that can confer resistance to ALS inhibitors (Friesen et al. 1993).

Factors that contribute to the selection of resistant weed biotypes include effective kill, a short soil seed bank lifetime, fitness, repeated use of the same herbicide or herbicides with the same mode of action, and minimum tillage (Primiani et al. 1990). Management practices recommended in Oklahoma to forestall the emergence of resistant biotypes include: 1. Use of crop and herbicide rotations; 2. Use of short residual herbicides, tank-mixes, prepackages, or sequential mixtures of herbicides that include different modes of action; and 3. Use of mechanical cultivation or hand hoeing in combination with

herbicides to prevent weed escapes from going to seed (Sholar and Peeper 1997).

In Oklahoma, soybeans are generally grown on soils in deep river bottoms in the eastern part of the state (Sholar 1997). In these areas, soybeans are generally seeded in 50 to 76 cm wide rows. A growing trend has been to plant in rows 38 to 50 cm. The advantage of narrow row soybeans is that the crop will fully utilize the land area and close the plant canopy by the time the plants begin to flower (Sholar 1997). Earlier canopy coverage may be beneficial for weed control. The first 6 to 8 wks are the most critical time for weed control in soybean (Sholar 1997). However, narrow row soybeans may require greater postemergence herbicide usage for common cocklebur control since cultivation may not be possible and soil applied herbicides may not be effective for season long control (Sholar 1997). With the increased usage of postemergence herbicides, selection pressure on common cocklebur has increased. The increase in selection pressure and the repeated use of a herbicide has increased the emergence of resistant weed species biotypes.

The objectives of this research were to (a) identify sites where suspected herbicide resistant species biotypes are growing and (b) verify the presence of herbicide resistant biotypes at these sites.

MATERIALS AND METHODS

Survey. A survey was initiated during the summer of 1996 and continued into the fall of 1997 across eastern Oklahoma soybean producing areas to identify

sites where infestations of suspected ALS-inhibitor resistant weed species biotypes were growing. Posters were displayed from May to August 1997 in 14 county Cooperative Extension Service offices and 26 agribusiness locations across the area to draw attention to the problems with ALS-inhibitor resistant weeds.

The colorful 56 by 72 cm posters contained six sections with information about the occurrence of herbicide resistant weed species biotypes and two color photographs illustrating soybean fields infested with common cocklebur. Poster information is detailed in Appendix A. Simple forms were attached to each poster for farmers to voluntarily report suspected herbicide resistant weeds on their farm and to indicate whether they wanted Oklahoma State University personnel to survey that farm for ALS-inhibitor resistant cocklebur. Two months after posters were distributed, telephone calls were made to those locations to tabulate responses to the poster survey.

A herbicide manufacturer's representative initially identified soybean fields with infestations of common cocklebur suspected to be ALS-inhibitor resistant biotypes. He identified these biotypes in the Arkansas River bottom of LeFlore County and the Verdigris River bottom of Wagoner County of east central Oklahoma. Those fields that were identified were used in this research to verify the presence of ALS-inhibitor resistant common cocklebur.

Mature seed of suspected ALS-inhibitor resistant common cocklebur was collected from ten randomly selected plants per field. Five fields were sampled in

LeFlore County and four fields were sampled in Wagoner County, OK, in October 1996 and 1997.

Field histories for these fields obtained from the growers are summarized in Tables 1 through 3. In LeFlore county, one producer applied imazaquin each year for 9 yrs after it became commercially available, while the other producer applied imazaquin for 7 yrs. In Wagoner county, one producer farmed all of the fields from which the seeds were collected, using the same management program on all fields. Imazaquin was applied preplant incorporated (PPI) from 1989 through 1993, and as a sequential postemergence (POST) treatment in 1992 and 1993 for common cocklebur control in soybean. All herbicide treatments were applied at maximum labeled rates.

Mature seeds of common cocklebur were collected from the Agronomy Research Station at Stillwater, OK, and included as a susceptible standard. All seed samples were stored at 4 C and 50% relative humidity from time of collection until planting.

Resistance. Seeds of suspected ALS-inhibitor resistant common cocklebur collected and seeds of the susceptible standard were soaked in tap water for 6 hrs prior to planting. One hundred seeds from each field were planted 1 to 2 cm deep in 39 by 54 cm flats containing a Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll). One flat was used for seed from each field. Seedlings emerged 7 to 10 days after planting (DAP). Within each flat, two 10 cm diameter tubes were inserted through the soil to the bottom of the flat around two seedlings per tube. These seedlings were covered during herbicide application and served as

untreated control plants. Plants were grown in a lab maintained at 25 C ± 3 C. Fluorescent lighting was used to provide a 16-hr photoperiod. Plants were watered daily and 15-30-15 fertilizer was applied every 10 days.

Imazaquin was applied at 280 g ai/ha 21 DAP using a CO_2-pressurized backpack sprayer in a total volume of 190 L/ha when common cocklebur plants had three to five leaves (7 to 9 cm tall). Phytotoxicity was visually estimated 14 DAT based on a scale of 0 to 100 where 0 = no control and 100 = plant death.

RESULTS AND DISCUSSION

Survey. There were no responses to the posters displayed in eastern Oklahoma about the problems of herbicide resistant weed biotypes. This indicates that either the problem of herbicide resistant biotypes was not as severe as suspected, that producers had changed their weed control strategies to avoid the problem and were no longer concerned enough to respond to a survey, or that producers were unwilling to admit to the presence of herbicide resistant biotypes on their farm. In contrast, several responses were reported by Baughman et al. (1992), who conducted a similar survey on the distribution of red horned poppy (*Glaucium corniculatum* (L.) Rudolph) in western Oklahoma.

The farmers whose fields contained ALS-inhibitor resistant cocklebur biotypes took one of two actions to circumvent the problem. In LeFlore County, farmers seeded glyphosate {*N*-(phosphonomethyl)glycine} resistant soybean in their fields in 1997 and applied glyphosate as needed to control common cocklebur and other weed species. In Wagoner County, field 4 was rotated from soybean

to corn in 1997, and atrazine {2-chloro-4-ethylamino-6-isopropylamino-s-triazine} was applied preemergence for weed control. These changes in control strategies controlled common cocklebur and prevented seed collection from these sites in 1997.

Resistance. Common cocklebur germination ranged from 10 to 37% for seed collected in LeFlore County and 5 to 28% for seed collected in Wagoner County (Table 4). Common cocklebur seedlings from seed collected in 1996 from fields 1, 2, 3, 4, and 5 in LeFlore county were controlled by imazaquin 14, 0, 23, 13, and 7%, respectively (Table 4). Common cocklebur was not present in these fields in 1997. Seedlings from seed collected in 1996 from field 3 in Wagoner county were controlled 67% by imazaquin (Table 4). Imazaquin controlled all seedlings from fields 1, 2, and 4. Seedlings from seed collected in 1997 from field 3 were controlled 60%, while seedlings from field 1 and 2 were controlled 100% by imazaquin. Common cocklebur was not present in field 4 in 1997.

These results verify that resistance to ALS-inhibiting herbicides exists in Oklahoma. However, soybean growers have been able to change weed control strategies or switch to alternative crops to avoid problems associated with the presence of herbicide resistant biotypes.

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Table 1: Field histories for fields 1, 2, and 3 in LeFlore County, OK.[a]

Year	Crop	PPI treatment	First POST treatment	Second POST treatment
1987	Soybean	Imazaquin	--	--
1988	Soybean	Imazaquin	--	--
1989	Soybean	Imazaquin	--	--
1990	Soybean	Imazaquin	--	--
1991	Soybean	Imazaquin	Imazaquin	--
1992	Soybean	Imazaquin	Imazaquin	Bentazon
1993	Soybean	Imazaquin + pendimethalin	Imazaquin	--
1994	Soybean	Imazaquin + pendimethalin	Bentazon + acifluorfen	--
1995	Soybean	Imazaquin + pendimethalin	Bentazon + acifluorfen	--
1996	Soybean	Pendimethalin	Bentazon + acifluorfen	--
1997	Roundup Ready™ soybean	Pendimethalin	Glyphosate	Glyphosate

[a]Fields 1, 2, and 3 are legally described as the S ½, NE ¼, Section 1, T 9N, R 26E; N ½, NE ¼, Section 1, T 9N, R 26E; and S ½, SE ¼, Section 36, T 10N, R 26E, respectively.

Table 2: Field histories for fields 4 and 5 in LeFlore County, OK.[a]

Year	Crop	PPI treatment	First POST treatment	Second POST treatment
1989	Soybean	Imazaquin	--	--
1990	Soybean	Imazaquin	--	--
1991	Soybean	Imazaquin	Imazaquin	--
1992	Soybean	Imazaquin	Imazaquin	--
1993	Soybean	Imazaquin + pendimethalin	Imazaquin	Bentazon
1994	Soybean	Imazaquin + pendimethalin	Imazaquin + acifluorfen	Bentazon
1995	Soybean	Imazaquin + pendimethalin	Imazaquin + acifluorfen	--
1996	Soybean	Imazaquin + pendimethalin	Bentazon + acifluorfen	--
1997	Roundup Ready™ soybean	Pendimethalin	Glyphosate	--

[a]Fields 4 and 5 are legally described as the SE ¼, Section 31, T 10N, R 27E and SW ¼, Section 29, T 10N, R 27E.

Table 3: Field histories for fields 1, 2, 3, and 4 in Wagoner County, OK.[a]

Field	Year	Crop	PPI treatment	First POST treatment	Second POST treatment
1-4	1989	Soybean	Imazaquin	--	--
1-4	1990	Soybean	Imazaquin	--	--
1-4	1991	Soybean	Imazaquin	--	--
1-4	1992	Soybean	Imazaquin	Imazaquin	--
1-4	1993	Soybean	Imazaquin	Imazaquin	--
1-4	1994	Soybean	Trifluralin	Lactofen	--
1-4	1995	Soybean	Trifluralin	Lactofen	--
1-4	1996	Soybean	Trifluralin	Lactofen	--
1	1997	Soybean	Trifluralin	Imazaquin + acifluorfen	Fomesafen
2,3	1997	Soybean	Trifluralin	Imazaquin + acifluorfen	Lactofen
4	1997	Corn	Atrazine	--	--

[a]Fields 1, 2, 3, and 4 are legally described as the NE ¼, Section 14, T 18N, R 16E; SW ¼, Section 12, T 18N, R 16E; NE ¼, Section 12, T 18N, R 16E; and W ½, Section 7, T 18N, R 17E, respectively.

Table 4: Response of cocklebur seedlings to imazaquin applied over-the-top at 280 g ai/ha.

Collection site	Emergence	Resistant
	%	
LeFlore 1-96[a]	10	86
LeFlore 2-96	37	100
LeFlore 3-96	17	77
LeFlore 4-96	12	88
LeFlore 5-96	19	93
Wagoner 1-96	16	0
Wagoner 1-97	6	0
Wagoner 2-96	24	0
Wagoner 2-97	8	0
Wagoner 3-96	28	33
Wagoner 3-97	14	40
Wagoner 4-96	5	0
Standard[b]	32	0

[a]Indicates year common cocklebur seed were collected.

[b]Susceptible standard collected from the Agronomy Research Station, Stillwater, OK.

CHAPTER II

ROTATIONAL CROP RESPONSE TO SULFONYLUREA HERBICIDES APPLIED TO WINTER WHEAT (*Triticum aestivum*)

Rotational Crop Response to Sulfonylurea Herbicides Applied to Winter Wheat (*Triticum aestivum*)[1]

K. TODD HEAP, THOMAS F. PEEPER, and JASON P. KELLEY[2]

Abstract: Field research was conducted from 1994 to 1997 at the Agronomy Research Station near Perkins, OK, to examine injury to double crops from residual sulfonylurea herbicides applied to hard red winter wheat. Treatments included CGA-152005, chlorsulfuron + metsulfuron (5:1 w/w premix), MON 37532, and triasulfuron applied at labeled use rates in late-February or early-March. MON 37532 was not applied in 1995. No treatment reduced yield of corn, IR corn, STS soybean, or garbanzo bean. Grain sorghum yield was reduced by triasulfuron in 1995 and by MON 37532 in 1996 and 1997. Soybean yield was reduced by CGA-152005, chlorsulfuron + metsulfuron, and triasulfuron in 1995. Mungbean yield was reduced by chlorsulfuron + metsulfuron in 1996. Cotton yield was reduced by chlorsulfuron + metsulfuron in 1995. Early season crop injury often did not result in yield loss.

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Nomenclature: CGA-152005, 1-(4-methoxy-6-methyl-triazin-2-yl)-3-[2-(3,3,3-trifluoro-propyl)-phenylsulfonyl]-urea; chlorsulfuron, 2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide; metsulfuron-methyl, 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino] sulfonyl]benzoate; MON 37532, 1-(2-ethylsulfonylimidazo[1,2-a]pyridin-3-ylsulfonyl)-3-(4,6-dimethoxypyrimidin-2-yl)urea; triasulfuron, 2-(2-chloroethoxy)-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide; wheat, 'Ike,' '2163,' '2180.'; corn, *Zea mays* L. 'Pioneer 3162IR', '3223'; soybean, *Glycine max* L. Merr. 'Asgrow A3304STS,' 'Essex'; green mungbean, *Vigna radiata* L. 'Berken'; garbanzo bean, *Cicer arietinum* L. 'Kala Chana'; grain sorghum, *Sorghum bicolor* L. 'Pioneer 8467'; cotton, *Gossypium hirsutum* L. 'Paymaster HS26.'

Additional index words: CGA-152005, chlorsulfuron, metsulfuron, MON 37532, triasulfuron.

Abbreviations: ALS, acetolactate synthase; DAP, days after planting; FFA, freedom to farm act; IR, imidazolinone resistant; MAP, months after planting; STS, sulfonylurea tolerant soybean.

INTRODUCTION

The Freedom to Farm Act (FFA) allows flexibility in farm production decisions. The decision to plant or leave land idle depends mainly on anticipated market returns (Dicks et al. 1995). Thus, FFA increases the opportunities for Southern Great Plains farmers to double crop after wheat.

However, decisions to double crop after wheat are frequently made on short notice and depend on weather conditions, particularly moisture, and anticipated crop prices. These decisions are often made after residual sulfonylurea herbicides have been applied to wheat.

The sulfonylurea herbicides, chlorsulfuron, metsulfuron, and triasulfuron control many broadleaf weeds in cereal crops at application rates from 5 to 30 g ai/ha (Brewster and Appleby 1983; Friesen and Wall 1991; Ivany 1987). However, these herbicides may persist in soils and damage sensitive rotational crops (Brewster and Appleby 1983; Friesen and Wall 1991; Ivany 1987; Moyer 1995; Moyer et al. 1990; Peterson and Arnold 1985; Ritter et al. 1988).

CGA-152005 is labeled for broadleaf weed control in winter cereals and grain sorghum when applied at 10 to 30 g ai/ha (Obermeier and Kapusta 1996). MON 37532, an experimental sulfonylurea herbicide, is being evaluated for control of grass weeds in winter wheat at applications rates from 20 to 35 g ai/ha (Geier and Stahlman 1996).

Soil residues of chlorsulfuron at 26 g/ha injured snap beans (*Phaseolus vulgaris* L.) and sweet corn seeded 5 months after treatment, and alfalfa (*Medicago sativa* L.), Italian ryegrass (*Lolium multiflorum* Lam.), sugarbeets (*Beta vulgaris* L.) and rape (*Brassica napus* L.) seeded 8 months after treatment (Brewster and Appleby, 1983). Chlorsulfuron at 26 g/ha reduced foliage weight of sugarbeets seeded 26 months after application. Brewster and Appleby (1983) also reported phytotoxic levels of the herbicide 10 to 20 cm deep 168 days after application on a silt loam soil with pH 5.8.

In contrast, corn and sunflower (*Helianthus annuus* L.) were not injured when planted as rotational crops 8 months after preemergence applications and 4 months after postemergence applications of 5 to 40 g/ha of chlorsulfuron to a silty clay soil with pH 7.4 (Eleftherohorinos and Kotoula-Syka, 1989).

Factors known to increase the probability of phytotoxic residues of chlorsulfuron, metsulfuron, and triasulfuron persisting in soil are high pH, low soil temperature, low soil moisture, intermittent water logging, reduced permeability, and low organic matter (Blair and Martin 1988; Frederickson and Shea 1986; Mersie and Foy 1985; Smith and Hsiao 1985; Thirunarayanan et al. 1985; Wiese et al. 1988).

Resistance to ALS-inhibiting herbicides has been selected for in soybean and corn (Schmitzer et al. 1993). However, these genetically engineered crops may vary in their tolerance to ALS-inhibiting herbicides. Simpson and Stoller (1996) reported that there are two or three isozymes of ALS present in STS soybean with only one isozyme having increased sulfonylurea tolerance. Cross tolerance of STS soybean to sulfonylurea herbicides applied to winter wheat has not been reported. Wright and Penner (1998) reported that the ALS from imidazolinone resistant corn hybrids was cross-resistant to all four ALS-inhibiting herbicide families. However, the imidazolinone tolerant hybrids did not exhibit cross-resistance to the sulfonylurea herbicides.

Current labels for CGA-152005[3], chlorsulfuron + metsulfuron[4], and triasulfuron[5], applied to wheat prevent rotation to STS soybeans for 11 months and soybeans for 14 months after application. Corn and grain sorghum can be seeded 1 month after application of CGA-152005 to wheat; however, chlorsulfuron + metsulfuron and triasulfuron have 14 month restrictions for replanting corn or grain sorghum. MON 37532 is presumed to have residual activity, but rotation restrictions have not yet been defined.

The objective of this research was to determine the potential for rotational crop injury following spring applications of CGA-152005, chlorsulfuron + metsulfuron, MON 37532, and triasulfuron.

MATERIALS AND METHODS

Field experiments were initiated in the fall of 1994, 1995, and 1996 at the Agronomy Research Station, Perkins, OK, to examine injury to double crops from residual sulfonylurea herbicides applied to hard red winter wheat. The experimental design each year was a randomized complete block with four

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[3]Novartis. 1998. Peak Product Label. Novartis Crop Protection. Greensboro, NC 27409.

[4]DuPont. 1997. Finesse Product Label. E. I. du Pont de Nemours and Company. Wilmington, DE 19898.

[5]Novartis. 1998. Amber Product Label. Novartis Crop Protection. Greensboro, NC 27409.

replicates. The soil was a Teller sandy loam (fine-loamy, mixed, thermic Udic Argiustoll) with pH 5.7, 0.7% organic matter, CEC 9.0 in 1994 and 1995, and pH 6.5, 1.0% organic matter, CEC 8.8 in 1996. Plot size was 6- by 35-m. Hard red winter wheat 'Ike' (1994), '2163' (1995), and '2180' (1996) was seeded in early October into conventionally tilled seedbeds at 67 kg/ha in 20 cm spaced rows using a single disk opener end-wheel drill. Fertilizer was applied preplant and topdressed in the spring according to soil test recommendations for a 4000 kg/ha wheat grain yield goal.

Treatments included an untreated check, CGA-152005 at 20 and 30 g ai/ha, chlorsulfuron + metsulfuron (5:1 w/w premix) at 21 g ai/ha, MON 37532 at 35 g ai/ha, and triasulfuron at 29 g ai/ha applied March 6, 1995, March 14, 1996, and February 24, 1997, except that MON 37532 was not applied in 1995. Herbicides were applied using a CO_2-pressurized backpack sprayer equipped with 11004VS flat-fan nozzles in a total volume of 187 L/ha with water carrier and 0.5% v/v nonionic surfactant. Wheat plant height at the time of application was 10 to 15 cm in 1995, 12 to 15 cm in 1996, and 15 to 20 cm in 1997.

At wheat maturity, grain was harvested from a 1.5- by 7.6-m area from each plot using a small plot combine. Grain yield was determined after each sample was re-cleaned using a small commercial seed cleaner and moisture was adjusted to 13.5%. Immediately after the plot samples were harvested, a commercial type combine was used to harvest the remaining wheat in each plot. After all wheat had been harvested, the wheat straw was mowed using a rotary mower.

One day after wheat was harvested, the experimental area was moldboard plowed approximately 20-cm deep and then tilled using an s-tine harrow with double rolling baskets. Immediately following seedbed preparation, each double crop was seeded in four 91-cm wide rows in 1995 and 1996 and in 76-cm wide rows in 1997. Crops were seeded on June 14, 1995; June 11, 1996; and June 24, 1997.

Corn was seeded at 183,000 seeds/ha in 1995 and 215,000 seeds/ha in 1996 and 1997; IR corn was seeded at 205,000 seeds/ha in 1995 and 215,000 seeds/ha in 1996 and 1997; CGA-133205 {O-(1,3-dioxolan-2-yl-methyl)-2,2,2-trifluoro-4'-chloroaceto-phenone-oxime} treated grain sorghum was seeded at 215,000 seeds/ha in 1995, 251,000 seeds/ha in 1996, and 258,000 seeds/ha in 1997; soybean was seeded at 233,000 seeds/ha in 1995, 251,000 seeds/ha in 1996, and 319,000 seeds/ha in 1997; STS soybean was seeded at 251,000 seeds/ha in 1996 and 319,000 seeds/ha in 1997; mungbean was seeded at 280,000 seeds/ha in 1995, 287,000 seeds/ha in 1996, and 319,000 seeds/ha in 1997; garbanzo bean was seeded at 395,000 seeds/ha in 1996 and 215,000 seeds/ha in 1997; and cotton was seeded at 233,000 seeds/ha in 1995 and 287,000 seeds/ha in 1996. STS soybeans and garbanzo beans were not planted in 1995, and cotton was not planted in 1997.

Metolachlor {2-chloro-*N*-(2-ethyl-6-methyl-phenyl)-*N*-(2-methoxy-1-methylethyl)acetamide} at 2.2 kg ai/ha was applied preemergence to all crops each year. The number of plants in 3.0 m of each row of each plot was counted 37 to 45 days after planting (DAP). Crop height was determined 37 DAP in

1995, 64 DAP in 1996, and 58 DAP in 1997 by measuring the height of five plants in each plot. Heights were averaged and reported as the mean plant height (cm). Crop injury was evaluated visually 64 DAP in 1995, 72 DAP in 1996, and 58 DAP in 1997 using a scale of 0 to 100, where 0 = no effect and 100 = complete crop destruction.

In 1995, permethrin {(3-phenoxyphenyl)methyl (±)-cis,trans-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate} at 224 g ai/ha was broadcast once for insect control. Lambda-cyhalothrin {[1α(*S**), 3α(*Z*)]-(±)-cyano-(3-phenoxy-phenyl)methyl-3(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate} at 45 g ai/ha was broadcast once in 1996 and twice in 1997 for insect control.

At physiological maturity, approximately 4 to 5 months after planting (MAP), 5.5 m of the center two rows for mungbean, grain sorghum, soybean, and STS soybean was harvested from each plot using a small plot combine. Harvested samples were then cleaned using a small commercial seed cleaner to remove foreign material. Due to later than typical planting, yields of corn and IR corn were determined by removing and weighing the above ground dry biomass 5 MAP from 5.5 m of all four rows from each plot. Garbanzo bean yield was determined by removing and weighing the above ground green biomass 5 MAP from 5.5 m of the center two rows. Cotton yields were determined by hand harvesting seed cotton from 5.5 m of the center two rows in each plot.

Analysis of variance was conducted on all data. Means reported were separated by Fisher's protected LSD Test (P = 0.05). Crop injury data were

subjected to arcsine transformations before analyses. Original data are reported with means separation from the transformed data. Although some data would pool across year, such pooling masked the range of rotational crop injury observed. Thus, data were reported by year.

RESULTS AND DISCUSSION

Weather patterns during the three years of the study varied. Annual rainfall was 125%, 80%, and 96% of normal (90 cm/yr) in 1995, 1996, and 1997, respectively. The first rain after treatment application occurred within 12 hours in 1995 (1.4 cm), 4 days in 1996 (0.7 cm), and 2 days in 1997 (0.9 cm). Rainfall from time of application until double crop seeding was 67, 13, and 31 cm in 1995, 1996, and 1997, respectively. June through September rainfall was 173%, 139%, and 115% of normal (36 cm) in 1995, 1996, and 1997, respectively.

Drought prevailed from fall 1995 through spring 1996, and freeze damage occurred on the wheat in April 1995 and 1997. These events reduced wheat yields in 1995 (mean = 350 kg/ha, P = 0.98), 1996 (mean = 1090 kg/ha, P = 0.95), and 1997 (mean = 800 kg/ha, P = 0.10). Treatment effects on wheat yield were not expected because the herbicides applied are either registered for use on wheat or registration is pending and broadleaf weed densities in the wheat were below levels that affect yield (Scott and Peeper 1994).

No treatment affected stand establishment of corn in 1995 (mean=11.4 plants/m^2, P = 0.89), 1996 (mean=5.9 plants/m^2, P = 0.51), or 1997 (mean=8.9

plants/m^2, P = 0.28). No treatment affected stand establishment of IR corn in 1995 (mean=13.2 plants/m^2, P = 0.41), 1996 (mean=6.7 plants/m^2, P = 0.75), or 1997 (mean=4.6 plants/m^2, P = 0.12).

Chlorsulfuron + metsulfuron reduced corn height by more than 50% of the untreated, and stunted corn more than any other treatment in 1995 (Table 2). Corn height was not reduced in 1996 (mean=175 cm, P = 0.50) or 1997 (mean=134 cm, P = 0.30). IR corn height was not reduced by any treatment in any year.

All herbicide treatments visibly injured corn in 1995 (Table 2), but corn was injured more by chlorsulfuron + metsulfuron than any other treatment. MON 37532 and chlorsulfuron + metsulfuron injured corn more than triasulfuron in 1996. In 1997, there were no differences among herbicide treatments on corn injury. IR corn was not injured by any treatment in 1995. MON 37532 injured IR corn more than CGA-152005 at 20 g/ha and triasulfuron in 1996. MON 37532 and CGA-152005 at 30 g/ha injured IR corn more than any other treatment in 1997.

Despite visible crop injury, no herbicide reduced biomass of either crop. However in 1995, IR corn yield was greater for all treatments except chlorsulfuron + metsulfuron than the untreated plots (Table 2). Lack of timely moisture during each growing season, rather than herbicide residue, was likely the primary factor that limited yield. In dry periods, plants in the untreated plots were more drought stressed because they had been growing more vigorously before than the plants in the treated plots, and thus, ran out of moisture. Corn

biomass in the untreated plots was 10200 kg/ha in 1995, 11000 kg/ha in 1996, and 13600 kg/ha in 1997. IR corn biomass in the untreated plots was 9600 kg/ha in 1995, 9800 kg/ha in 1996, and 11000 kg/ha in 1997.

There were no differences in grain sorghum stand establishment among treatments in 1995 (mean=6.8 plants/m^2, P = 0.44) or 1997 (mean=5.0 plants/m^2, P = 0.39). In 1996, MON 37532 reduced grain sorghum stand more than chlorsulfuron + metsulfuron and triasulfuron (Table 3). Chlorsulfuron + metsulfuron reduced plant height more than any other treatment in 1995. MON 37532 reduced plant height more than any other treatment in 1996 and 1997.

In 1995, chlorsulfuron + metsulfuron and triasulfuron injured grain sorghum more than CGA-152005 at 30 g/ha (Table 3). All treatments injured grain sorghum in 1996. MON 37532 caused more severe injury on grain sorghum in the form of stunting and necrosis than any other treatment in 1996 and 1997. Chlorsulfuron + metsulfuron and triasulfuron reduced grain sorghum yield more than CGA-152005 at 20 g/ha in 1995. MON 37532 reduced yield more than any other treatment in 1996 and 1997.

No treatment reduced soybean stand in 1995 (mean=11.8 plants/m^2, P = 0.17), 1996 (mean=7.1 plants/m^2, P = 0.61), or 1997 (mean=8.3 plants/m^2, P = 0.28). Soybeans were severely stunted by all treatments in 1995 (Table 4). No treatment reduced plant height in 1996 (mean=52.1 cm, P = 0.06). MON 37532 and triasulfuron reduced soybean height more than CGA-152005 at 20 g/ha in 1997.

All treatments severely injured soybeans in 1995 (Table 4), but chlorsulfuron + metsulfuron injured soybean more than CGA-152005 at 20 g/ha. All treatments injured soybean in 1996, but there were no differences among herbicide treatments. In 1997, MON 37532 and triasulfuron injured soybean more than CGA-152005 at 20 g/ha. Soybean injury was much more severe in 1995 than in any other year. Thus, yield was reduced by all treatments in 1995, but not in 1996 or 1997. Rainfall was greater during the spring of 1995 than in 1996 or 1997 (Table 1). This may have caused more of the herbicide to be moved down through the soil profile. When the experimental area was plowed, it is likely that the herbicide residues were buried into the rooting zone.

No treatment reduced STS soybean stand in 1996 (mean=9.7 plants/m^2, P = 0.97) or 1997 (mean=10.5 plants/m^2, P = 0.25). No treatment reduced plant height in 1996 (mean=38.5 cm, P = 0.55) or 1997 (mean=48.0 cm, P = 0.56). MON 37532, CGA-152005 at 30 g/ha, and triasulfuron injured STS soybean more than chlorsulfuron + metsulfuron in 1996 (Table 4). No treatment injured mungbean in 1997. No treatment reduced STS soybean yield in 1996 (mean=571 kg/ha, P = 0.76) or 1997 (mean=914 kg/ha, P = 0.14).

Mungbean stand establishment was not affected by any treatment in 1995 (mean=12.6 plants/m^2, P = 0.76), 1996 (mean=11.0 plants/m^2, P = 0.88), or 1997 (mean=20.2 plants/m^2, P = 0.71). Chlorsulfuron + metsulfuron and triasulfuron reduced plant height more than any other treatment in 1995 (Table 5). No treatment reduced plant height in 1996 (mean=55.5 cm, P = 0.45) or 1997 (mean=36.3 cm, P = 0.44). Chlorsulfuron + metsulfuron and triasulfuron injured

mungbean more than CGA-152005 at 20 g/ha in 1995. All treatments injured mungbean in 1996, but chlorsulfuron + metsulfuron injured mungbean more than CGA-152005 at 20 g/ha. No treatment injured mungbean in 1997. Yield was higher in chlorsulfuron + metsulfuron and CGA-152005 plots than triasulfuron and the untreated check in 1995. Chlorsulfuron + metsulfuron reduced yield more than CGA-152005 and MON 37532 in 1996. No treatment reduced mungbean yield in 1997 (mean=1858 kg/ha, P = 0.52).

No treatment affected stand establishment in 1996 (mean=4.6 plants/m^2, P = 0.49) or 1997 (mean=2.1 plants/m^2, P = 0.64). No treatment reduced plant height in 1996 (mean=14.1 cm, P = 0.11) or 1997 (mean=9.7 cm, P = 0.32). CGA-152005 at 20 g/ha, chlorsulfuron + metsulfuron, and triasulfuron injured plant height more than CGA-152005 at 30 g/ha in 1996 (Table 5). No treatment reduced garbanzo bean biomass in 1996 or 1997.

No treatment reduced cotton stand establishment in 1995 (mean=12.0 plants/m^2, P = 0.08) or 1996 (mean=8.1 plants/m^2, P = 0.29). Chlorsulfuron + metsulfuron reduced plant height more than CGA-152005 both rates in 1995 and 1996 (Table 6). Chlorsulfuron + metsulfuron and triasulfuron injured cotton more than CGA-152005 in 1995. All treatments injured cotton in 1996, but there were no differences among herbicide treatments. Chlorsulfuron + metsulfuron reduced cotton yield more than triasulfuron in 1995, but no treatment reduced yield in 1996.

Observed crop injury seen generally agrees with information that each product label details for crop rotation. In many cases, visible crop injury did not

reduce yield. Thus, some viable cropping options are available. Corn, IR corn, and STS soybean are crops that were grown with minimal crop injury or yield loss with any of these herbicides. Other crops may also be grown depending on the herbicide used, the pH of the soil, and the amount of rainfall.

In 1997, supplemental labels for chlorsulfuron + metsulfuron were approved (DuPont 1997) which permit rotation to STS soybean and IR corn 4 months after application, where a catastrophic wheat crop loss has occurred due to a natural disaster. However, growers must be willing to accept some level of temporary discoloration, crop injury, or yield loss.

Variation in double crop response from year to year may be attributed to the differences in rainfall and wheat canopy at time of herbicide application. The most severe visible injury observed was in 1995. The interception of the herbicides by the wheat canopy may have been less that year because wheat plants were shorter and plants were less tillered than in the succeeding years.

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Table 1. Summary of growing season rainfall for 1995 through 1997 at Perkins, OK and 25 year average.

Month	1995	1996	1997	25 Year average
		cm		
March	9	3	1	7
April	12	1	13	8
May	17	3	6	15
June	29	6	10	12
July	9	14	13	7
August	10	11	8	7
September	12	17	8	10
Annual	112	72	87	90

Table 2. Effect of herbicide treatment on corn.

		Corn				IR corn		
		Height	Injury					
		1995	1995	1996	1997	1996	1997	Biomass
Treatment	Rate	37 DAP[a]	64 DAP	72 DAP	58 DAP	72 DAP	58 DAP	1995
	g ai/ha	cm	%[b]					% of check
CGA-152005	20	52 b	23 b	25 ab	15 a	16 b	0 b	134 a
CGA-152005	30	53 ab	25 b	25 ab	23 a	29 ab	10 a	128 a
Chlor + met[c]	21	22 c	68 a	38 a	30 a	21 ab	0 b	118 ab
Mon 37532	35	--	--	39 a	33 a	39 a	10 a	--
Triasulfuron	29	47 b	28 b	14 b	23 a	18 b	0 b	121 a
Untreated		58 a	0 c	0 c	0 b	0 c	0 b	100 b
LSD (0.05)		6						20

[a]DAP = days after planting

[b]Means followed by the same letter are not significantly different according to LSD 0.05 from arcsine transformed data.

[c]Chlor + met = chlorsulfuron + metsulfuron

Table 3. Effect of herbicide treatment on grain sorghum.

		Grain sorghum								
		Stand	Height			Injury			Yield	
		1996	1995	1996	1997	1995	1996	1997		
Treatment	Rate	45 DAP[a]	37 DAP	64 DAP	58 DAP	64 DAP	72 DAP	58 DAP	1995	1996	1997
	g ai/ha	plants/m^2	cm			%[b]			kg/ha		
CGA-152005	20	4.9 bc	59 a	86 a	69 a	20 bc	25 bc	0 b	6610	2340	6030
CGA-152005	30	5.3 bc	58 a	97 a	73 a	18 c	31 bc	0 b	5980	2350	6930
Chlor + met[c]	21	5.7 ab	42 b	100 a	67 a	48 a	23 bc	0 b	5680	2350	7000
MON 37532	35	3.6 c	–	59 b	25 b	--	65 a	79 a	--	1780	150
Triasulfuron	29	6.6 ab	54 a	97 a	66 a	40 ab	18 c	5 b	5390	2610	5400
Untreated		7.3 a	63 a	97 a	72 a	0 c	0 d	0 b	6140	2460	6880
LSD (0.05)		1.9	11	17	18				680	450	1940

[a]DAP = days after planting

[b]Means followed by the same letter are not significantly different according to LSD 0.05 from arcsine transformed data.

[c]Chlor + met = chlorsulfuron + metsulfuron

Table 4. Effect of herbicide treatment on soybean and STS soybean.

		Soybean							STS soybean
		Height			Injury				Injury
		1995	1996	1997	1995	1996	1997	Yield	1996
Treatment	Rate	37 DAP[a]	64 DAP	58 DAP	64 DAP	72 DAP	58 DAP	1995	72 DAP
	g ai/ha	cm			%[b]			kg/ha	%
CGA-152005	20	8 b	58 a	41 ab	63 b	20 a	15 b	150 b	10 b
CGA-152005	30	7 b	54 ab	37 abc	73 ab	20 a	25 ab	100 b	20 a
Chlor + met[c]	21	8 b	45 b	35 bc	75 a	26 a	25 ab	390 b	3 c
MON 37532	35	--	50 ab	30 c	--	24 a	40 a	--	19 a
Triasulfuron	29	8 b	49 ab	30 c	68 ab	30 a	40 a	380 b	18 ab
Untreated		27 a	58 a	44 a	0 c	0 b	0 c	1410 a	0 c
LSD (0.05)		3	9	8				308	

[a]DAP = days after planting

[b]Means followed by the same letter are not significantly different according to LSD 0.05 from arcsine transformed data.

[c]Chlor + met = chlorsulfuron + metsulfuron

Table 5. Effect of herbicide treatment on mungbean and garbanzo bean.

		Mungbean					Garbanzo bean
		Height	Injury				Injury
		1995	1995	1996	Yield		1996
Treatment	Rate	37 DAP[a]	64 DAP	72 DAP	1995	1996	72 DAP
	g ai/ha	cm	——— %[b] ———		——— kg/ha ———		%
CGA-152005	20	22 ab	13 bc	13 b	480 a	860 ab	38 a
CGA-152005	30	20 b	30 ab	19 ab	490 a	850 ab	13 bc
Chlor + met[c]	21	13 c	48 a	26 a	470 a	530 c	53 a
MON 37532	35	--	--	19 ab	–	1010 a	33 ab
Triasulfuron	29	16 c	53 a	24 ab	310 b	620 bc	59 a
Untreated		25 a	0 c	0 c	330 b	880 ab	0 c
LSD (0.05)		4			140	280	

[a]DAP = days after planting

[b]Means followed by the same letter are not significantly different according to LSD 0.05 from arcsine transformed data.

[c]Chlor + met = chlorsulfuron + metsulfuron

Table 6. Effect of herbicide treatment on cotton.

		Cotton				
		Height		Injury		
		1995	1996	1995	1996	Yield
Treatment	Rate	37 DAP[a]	64 DAP	64 DAP	72 DAP	1995
	g ai/ha	cm		%[b]		% of check
CGA-152005	20	20 ab	74 a	13 c	11 a	85 abc
CGA-152005	30	18 bc	73 a	28 b	13 a	64 bc
Chlor + met[c]	21	13 c	60 b	55 a	21 a	53 c
Triasulfuron	29	17 bc	66 ab	45 ab	19 a	96 ab
Untreated		25a	77 a	0 c	0 b	100 a
LSD (0.05)		6	12			34

[a]DAP = days after planting

[b]Means followed by the same letter are not significantly different according to LSD 0.05 from arcsine transformed data.

[c]Chlor + met = chlorsulfuron + metsulfuron

APPENDIX

APPENDIX A

HERBICIDE RESISTANT WEED SURVEY POSTER CONTENTS

Panel 1:

What is the Purpose For This Survey

Oklahoma State University is trying to identify farms in Oklahoma where herbicide resistant weeds are threatening crop production. We need your help to find out how widespread these weeds are. We want to help you avoid economic loss due to herbicide resistant weeds. We are particularly looking for herbicide resistant biotypes of cocklebur, ryegrass, and pigweeds (or carelessweeds).

Panels 2 and 3:

Color Photographs

Scepter resistant common cocklebur in soybean along the Arkansas River.

Scepter resistant pigweed in soybean along the Verdigris River.

Panel 4:

What Are Herbicide Resistant Weeds

Herbicide resistant weeds are biotypes of ordinary weeds. These biotypes are not killed by herbicides that have effectively controlled that weed species in past years. After several years of using some herbicides with the same mode of action, these biotypes increase and become the dominant weed in a field because of their resistance to those herbicides. Until they fail to die from the

herbicide treatment, you cannot tell by looking at them that they are herbicide resistant weeds.

Panel 5:

What Can Be the Result of Herbicide Resistance

The result of failing to control these weeds is a loss of crop quality, yield loss, difficulty in harvesting your crop or in severe cases an entire crop failure.

Panel 6:

Where Did These Resistant Weeds Come From?

Most fields have millions of weed seeds in every acre, of which only a small proportion germinate each year. There is natural variation within each weed species, and sometimes, there is a very small natural population of herbicide resistant weeds. When herbicides are used to control the susceptible weeds, the naturally resistant weeds are not controlled and are often allowed to go to seed. After a few years of using the same herbicide, this resistant population spreads across the field and to other fields by machinery, in planting seed, or by floating in water.

Panel 7:

How Can You Prevent or Control Herbicide Resistance

OSU Agronomists and Cooperative Extension Personnel will be able to help, if we can identify fields suspected of being infested with resistant weeds. When

the infested fields are identified, we can provide you information on how to handle the problem of herbicide resistance. We can also provide information on ways to prevent herbicide resistant weeds from becoming a severe problem on your land.

Panel 8:

Do You Have This Problem? If So, Can You Help Us?

If you think that you might have herbicide resistant weeds, we would like to talk to you about them. You can call one of us (Todd Heap, Jason Kelley, or Tom Peeper) at (405) 744-9626, (405) 624-7063, or (405) 744-9589. Or you can put your name and phone number on one of the little forms below and it will be sent to us, and then we will call you if you don't mind. You will not be obligated to share any information other than what you want. Your cooperation is indeed appreciated. Our mailing address is: Dr. Tom Peeper, OSU Department of Plant and Soil Sciences, 368 Agriculture Hall, Stillwater, OK 74078.

VITA

Kenneth Todd Heap

Candidate for the Degree of

Master of Science

Thesis: ACETOLACTATE SYNTHASE-INHIBITING HERBICIDES: SURVEY OF WEED RESISTANCE AND ROTATIONAL CROP RESPONSE IN OKLAHOMA

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