This is to certify that the

thesis entitled

POSTEMERGENCE WEED CONTROL IN SOYBEAN [Glycine max (L.) Merr] WITH IMAZAMOX, IMAZETHAPYR, OXASULFURON, AND CLORANSULAM-METHYL

presented by

Kelly Allan Nelson

has been accepted towards fulfillment of the requirements for

Master's degree in Crop and Soil Sciences

Karen A. Renner
Major professor

Date April 29, 1997

POSTEMERGENCE WEED CONTROL IN SOYBEAN [*Glycine Max* (L.) Merr] WITH IMAZAMOX, IMAZETHAPYR, OXASULFURON, AND CLORANSULAM-METHYL

By

Kelly Allan Nelson

A THESIS

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

MASTER OF SCIENCE

Department of Crop & Soil Sciences

1997

ABSTRACT

POSTEMERGENCE WEED CONTROL IN SOYBEAN [*Glycine Max* (L.) Merr] WITH IMAZAMOX, IMAZETHAPYR, OXASULFURON, AND CLORANSULAM-METHYL

By

Kelly Allan Nelson

Imazamox, imazethapyr, oxasulfuron, and cloransulam-methyl controlled velvetleaf, wild mustard, and common chickweed. Imazamox and imazethapyr controlled redroot pigweed and eastern black nightshade. Imazamox controlled common lambsquarters, while cloransulam-methyl controlled common ragweed. Selected tank mixtures enhanced grass and broadleaf weed control by these herbicides, but antagonized weed control or increased soybean response in certain instances. Diphenyl ether tank mixtures with imazamox and imazethapyr increased common ragweed control, but increased giant foxtail tillering and antagonized giant foxtail control by imazethapyr more than imazamox. Grass antagonism was species and graminicide dependent for oxasulfuron. Giant foxtail control by clethodim was antagonized by imazethapyr. Methylated seed oil increased weed control with imazamox and imazethapyr compared to nonionic surfactant. Imazamox at 45 g/ha plus a methylated seed oil controlled a broad spectrum of weeds in narrow and wide row soybeans. Herbicide treatments reduced weed biomass more in narrow than wide row soybeans.

ACKNOWLEDGMENTS

An enormous thank you is extended to Dr. Karen Renner for making this degree possible, guiding my thoughts, and challenging me with new ideas and research perspectives. I would like to thank Dr. Donald Penner for his help, support, and wisdom. I am grateful for the motivation and friendship from Dr. Larry Olsen and want to thank Dr. Jim Kells for the chance to teach a wonderful class of students.

My family and friends deserve my praise for their love and support. An extraordinary thanks goes to my wife, Teak, for her confidence, encouragement, dedication, and enthusiasm. My parents deserve a particular thanks for all of the experiences they challenged me with as well as their assistance, support, and motivation. I would like to thank Ken and Barbara Nelsen for their encouragement, Gary Powell for all of his technical help, and Mike Partika for all of his assistance. A special thanks is extended to Andy Chomas, James Mickelson, Julie Lich, Jason Fausey, Karen Novosel, Brent Tharp, Corey Ransom, Christy Sprague, Matt Rinella, Paul Knoerr, Eric Spandl, John Burk, Jim Sherman, Marla VanWormer, Kyle Fiebig, and Angie Eichorn for their assistance and support through the various aspects of my graduate research career.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

CHAPTER 4
WEED CONTROL IN WIDE AND NARROW ROW SOYBEAN [*Glycine max* (L.) Merr] WITH IMAZAMOX, IMAZETHAPYR, AND OXASULFURON

LIST OF FIGURES

INTRODUCTION

Imazamox, imazethapyr, oxasulfuron, and cloransulam-methyl are selective herbicides that inhibit acetolactate synthase (ALS) in susceptible weed species. ALS is an enzyme necessary for the synthesis of leucine, isoleucine, and valine. Imazamox, oxasulfuron, and cloransulam-methyl are new herbicides for postemergence weed control in soybeans. Imazamox is an imidazolinone herbicide that was introduced by American Cyanamid in 1994. Oxasulfuron is a sulfonylurea herbicide that was discovered by Ciba-Geigy in the early 1990's. Cloransulam-methyl is a triazolopyrimidine sulfonanilide herbicide that was introduced by DowElanco in 1994.

Postemergence herbicides can provide effective weed control in soybeans. Postemergence herbicides have facilitated the increase in conservation tillage programs that reduce soil erosion and the transition from wide to narrow row soybeans that efficiently harvest sunlight for crop production. Tank mixture decisions for postemergence herbicides depend primarily upon weed pressures, weed species and size, resistance management strategies, rotational crop restrictions, interactions between herbicides, and cost effectiveness. Ideally, a herbicide tank mixture broadens or complements the weed control spectrum of one or more of the herbicides present, but may increase crop injury or antagonize weed control by one or more of the herbicides in the mixture. Antagonistic mixtures reduce weed control, reduce crop yields, and increase weed seed production. A correct adjuvant selection can increase weed control and reduce antagonistic herbicide interactions.

Imazethapyr was applied to 44% of the total soybean acres in the United States in 1995; however, rotational crop restrictions prevent its use in many geographical areas. Current rotational crop restrictions for sensitive crop species like sugarbeets are 12, 18, and 24 months for oxasulfuron, imazamox, and cloransulam-methyl, respectively. These herbicides may offer postemergence weed control options for producers with such crops in their rotation. Field and greenhouse research were initiated: to determine soybean and weed sensitivity to postemergence applications of these ALS-inhibiting herbicides applied alone and with selected tank mixtures, to determine the influence of adjuvants on soybean injury and weed control, to evaluated monocot antagonism with selected tank mixtures, and to evaluate these herbicides in narrow and wide row soybeans.

CHAPTER 1

REVIEW OF LITERATURE

INTRODUCTION

Soybeans [*Glycine max* (L.) Merr] are a major food and oil-bearing seed crop. Soybeans were first domesticated in the Orient and have been used as a food source for centuries. In 1995 and 1996, Michigan produced 59.6 and 46.7 million bushels of soybeans from 1.5 and 1.6 million planted acres, respectively (Michigan 1996; Michigan 1997). Illinois, the leading soybean producer in the United States, planted over 9.7 million acres (USDA 1996). Weed control is essential for efficient and profitable soybean production. Postemergence herbicides have facilitated conservation tillage programs as an effective method to reduce soil erosion.

Herbicides were used on 51.8 million soybean acres in 1995 which accounted for approximately 97% of the soybean acres planted in the major soybean producing states of the United States (USDA 1996). The top five soybean herbicides in the order of popularity for the eight major soybean producing states in 1995 were imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid), pendimethalin (*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine), glyphosate (*N*-(phosphonomethyl)glycine), trifluralin (2,6-dinitro-

N,N-dipropyl-4-(trifluoromethyl)benzenamine), and imazaquin (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid) (USDA 1996). Imazethapyr was applied to 37, 42, and 44 percent of the total treated acres in 1993, 1994, and 1995, respectively (USDA 1996). A total of 2.3 million pounds active ingredient of the acetolactate synthase (ALS)-inhibiting herbicides were applied in sixteen major soybean producing states in 1995 (USDA 1996). The introduction of crops resistant to non-selective herbicides and increased weed resistance will revolutionize herbicide usage patterns for soybeans as well as other crops in the next few years.

The ALS-inhibiting herbicides have provided effective weed control at low herbicide application rates. Herbicide mixtures have been used to broaden the spectrum of weeds controlled by the ALS-inhibiting herbicides. These mixtures have been both beneficial and detrimental in the case of herbicide antagonism.

The number of herbicide mixtures available to soybean producers is numerous. A mix and match approach can be quite effective depending upon weed pressures, weed species, weed sizes, and rotational crops. The introduction of new herbicides provides a producer another opportunity and decision regarding weed management. These decisions depend upon effective screening and recommendations from industry researchers, university extension, and university research. The major decisions for an integrated weed management program should include cost effectiveness, convenience, crop and herbicide rotation strategies, and environmental consciousness.

HERBICIDE MIXTURES

A herbicide mixture is a combination of two or more components which retain their own characteristics while inhibiting or ending plant growth. There are several benefits and risks associated with herbicide mixtures. The dilemma for researchers is the interaction between benefits and risks. For instance, herbicide tank mixtures have been used to broaden or enhance the weed control spectrum, avoid herbicide resistance, reduce the amount of one or both of the herbicide components, and ultimately reduce production costs. Nonetheless, there is a potential for increased crop injury, weed control antagonism by either herbicide, and increased selection for herbicide resistance when similar modes of action are utilized. Tank mixture evaluations are utilized to determine optimum weed control and solve our dilemma so producers will have a net positive benefit from these mixtures.

An ideal herbicide mixture fills the gaps of an imperfect weed control system. Postemergence tank mixtures have reduced production costs by decreasing herbicide use rates. These mixtures reduced the number of field passes and herbicide applications compared to preplant incorporated or split applications which caused less soil compaction and crop damage. An ideal herbicide mixture not only increases weed control but also reduces crop injury (Friesen 1979; Malefyt and Duke 1981).

Several herbicides have been used to enhance the control of specific weed problems. For instance, thifensulfuron (methyl 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid) has been tank mixed with several postemergence herbicides for common lambsquarters (*Chenopodium* *album* L.) control (Fielding and Stoller 1990; Green 1991; Monks et al. 1993). Common ragweed (*Ambrosia artemisiifolia* L.) has been controlled with a diphenyl ether herbicide mixture (Hoverstad 1996a, 1996b; Leif and Taylor 1993; Monks et al. 1993; Wilcut 1991). Gaeddert et al. (1996) tank mixed lactofen ((±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate) with imazethapyr to control ALS-resistant palmer amaranth (*Amaranthus palmeri* S. Wats.). However, herbicide mixtures may increase soybean injury (Bauman et al. 1996; Geier and Stahlman 1996). Simpson and Stoller (1996) observed increased soybean injury when imazethapyr was tank mixed with thifensulfuron at 4.4 g ai/ha on sulfonylurea tolerant soybeans compared to imazethapyr or thifensulfuron alone. The combination of a graminicide with a broadleaf herbicide should provide broad spectrum weed control, but numerous mixtures have resulted in weed control that was less than when the graminicide was applied alone (Cantwell et al. 1989; Ditmarsen et al. 1997; Harvey et al. 1995; Myers and Coble 1992). In addition, the diphenyl ether herbicides have antagonized giant foxtail (*Setaria faberi* Herrm.) control by imazethapyr (Bauman et al. 1996; Cantwell et al. 1989; Geier and Stahlman 1996; Hoverstad 1996a, 1996b). An antagonistic mixture is expensive. It reduces weed control, reduces crop yield, and increases weed seed production. Critical evaluations of herbicide mixtures are needed for wise weed control management decisions that avoid increased soybean injury and antagonistic herbicide mixtures.

The correct surfactant or adjuvant selection can affect soybean injury, weed control, and help overcome herbicide interactions. This important component of the herbicide mixture needs continual evaluation for the most beneficial combination. It provides another factor to the weed control design and options.

New herbicides and herbicide resistant crops have exponentially increased the number of herbicide combinations available. Extensive research has been compiled on the interaction of sethoxydim (2[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) with postemergence soybean herbicides, but the introduction of sethoxydim resistant corn has challenged researchers to keep in mind the possibilities for cross-crop herbicide combinations. This technological option provides greater herbicide and crop rotation options as well as improved management decisions.

ALS-INHIBITING HERBICIDES

Background. The ALS-inhibiting herbicides include the imidazolinone, sulfonylurea, triazolopyrimidine sulfonanilide, and pyrimidinyl thiobenzoate herbicide families. These herbicides are used for weed control in several crops and non-crop settings (Table 1). The ALS-enzyme catalyzes the condensation of two pyruvate molecules to form α-aceto-lactate and the condensation of one pyruvate and one α-ketobutyrate to form α-aceto-α-hydroxybutyrate which are necessary for leucine, isoleucine, and valine synthesis (Schloss 1990). Leucine and valine are derivatives of α-aceto-lactate, and isoleucine is a derivative of α-aceto-α-hydroxybutyrate (Schloss 1990). ALS-inhibiting herbicides block the synthesis of branched chain amino acid synthesis which disrupts and prevents cell division in the meristematic tissue of susceptible plants and results in slow plant death. Low mammalian toxicity has been related to the incapability of mammals to synthesize branched chain amino acids since they lack ALS-enzymes.

Metabolic detoxification is the primary selection difference between susceptible and non-susceptible species for ALS-inhibiting herbicides developed for crop production. The metabolic detoxification mechanism is herbicide and plant species dependent (Brown 1990; Brown et al. 1990). However, absorption, translocation, and sensitivity of the site of action can affect herbicidal activity on sensitive and marginally controlled plant species (Hinz and Owen 1996). Slight structural changes, isomeric or substitution, have drastically affected the herbicidal activity of a compound (Hill et al. 1996; Ladner 1991). This has been an important feat for researchers to identify and determine the most active and safest compounds.

Weed resistance has plagued the ALS-inhibiting herbicides. Imazethapyr resistance has been reported in smooth pigweed (*Amaranthus hybridus* L.), kochia (*Kochia scoparia* (L.) Schrad.), common waterhemp (*Amaranthus rudis* Sauer), palmer amaranth, prickly lettuce (*Lactuca serriola* L.) (Friesen et al. 1993; Gaeddert et al. 1996; Lovell et al. 1996; Mallory-Smith et al. 1990; Schmenk et al. 1996), and numerous other plant species. Some weed species have cross-resistance to several sulfonylurea herbicides (Friesen et al. 1993; Gaeddert et al. 1996; Lovell et al. 1996; Mallory-Smith et al. 1990; Schmenk et al. 1996).

Imidazolinone. The imidazolinone herbicides include imazamethabenz (($\pm$)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-4(and 5)-methylbenzoic acid (3:2)), imazamox (2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-5-

(methoxymethyl) nicotinic acid), imazapyr ((±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid), imazaquin, and imazethapyr. Ladner (1991) described the imidazolinone herbicide structure as a three part entity consisting of an acid equivalent, backbone, and imidazolinone ring. Imidazolinone ring termination or the conversion to an immobile structure, and alkyl hydroxylation followed by glucose conjugation are the primary mechanisms of metabolism (Figure 1) (Berhane et al. 1993; Shaner and Mallipudi 1991). Wild oats (*Avena fatua* L.) must de-esterfy imazamethabenz to the acid equivalent before it has herbicidal activity (Shaner and Mallipudi 1991). Typical use rates for the imidazolinones range from 35 to 530 g ai/ha depending upon the weed species, application timing, and crop or industrial use.

Slight changes in the structural configuration have affected the efficacy of the imidazolinones to sensitive plant species. The methyl and isopropyl isomers of imazapyr have nearly a two-fold difference in herbicidal activity (Ladner 1991). The imazamethabenz-methyl formulation is a mixture of the meta and para 5-methyl. The meta isomer is very active on wild oat, while the para isomer is very active on wild mustard (*Sinapis arvensis* L.) (Ladner 1991; Shaner and Mallipudi 1991).

Sulfonylurea. The sulfonylurea herbicides include bensulfuron (2-[[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]methyl]benzoic acid), chlorimuron (2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid), chlorsulfuron (2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzensulfonamide), ethametsulfuron (2-[[[[[4-ethoxy-6-

(methylamino)-1,3,5-triazin-2-yl]amino]carbonyl]amino]sulfonyl]benzoic acid), metsulfuron (2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid), nicosulfuron (2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide), oxasulfuron, (2[[[[(4,6-dimethyl-2-pyrimidinyl)-amino]-carbonyl]-amino]sulfonyl] benzoic acid, 3-oxetanyl ester (CAS)), primisulfuron (2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl]amino]sulfonyl]benzoic acid), sulfometuron (2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid), thifensulfuron, triasulfuron (2-(2-chloroethoxy)-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide), tribenuron (2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoic acid), and triflusulfuron (2-[[[[[4-(dimethylamino)-6-(2,2,2-trifluoroethoxy)-1,3,5-triazin-2-yl]amino]carbonyl]amino]sulfonyl]-3-methylbenzoic acid). The sulfonylureas are used for weed control in numerous crops and non-crop settings (Table 1). The sulfonylurea herbicide structure consists of a phenyl ring, sulfonylurea bridge, and heterocycle moiety (Figure 2) (Hay 1990). Metabolism depends on the plant species and the herbicide. The sulfonylureas have been metabolized through aryl and aliphatic hydroxylation followed by subsequent glucose conjugation, homoglutathione conjugation, de-esterification, oxidative O-demethylation, and hydrolysis or cleavage of the bridge (Brown 1990; Brown et al. 1990). In water, the sulfonylureas may undergo hydrolysis which cleaves the bridge and heterocycle which then releases carbon dioxide, or form an anionic salt in a neutral or basic solution (Hay 1990). At a higher pH, there is less hydrolysis and the sulfonylurea remains in a net anionic form (Hay 1990). This process is important in soil persistence since hydrolysis is greater in acidic soils (Hay 1990). Typical use rates for the sulfonylureas range from 4.2 to 420 g ai/ha depending upon the weed species, application timing, and crop or industrial use.

Triazolopyrimidine sulfonanilide. The triazolopyrimidine sulfonanilides include flumetsulam (*N*-(2,6-difluorophenyl)-5-methyl[1,2,4]triazolo[1,5-*a*]pyrimidine-2-sulfonamide) and cloransulam-methyl (2-[[(5-ethoxy-7-fluoro[1,2,4]triazolo[1,5-c]pyrimidin-2yl)sulfonyl]amino]-3-cloro-benzoic acid, methyl ester). Rapid metabolism of the triazolopyrimidine sulfonanilides by grass species allows them to be less susceptible than broadleaf plants due to homoglutathione conjugation (Hodges et al. 1990; Jachetta et al. 1995). Triazolopyrimidine sulfonanilides are primarily metabolized by hydroxylation followed by subsequent glucose conjugation of the methyl substituent or the aniline ring (Figure 3) (Hodges et al. 1990). Typical use rates range from 17.5 to 78 g ai/ha depending upon the crop, weed species, and application timing.

HERBICIDES

Imazethapyr. Imazethapyr is an imidazolinone herbicide for preplant incorporated, preemergence, and postemergence grass and broadleaf weed control in soybeans. Postemergence applications have been recommended at 70 g ai/ha (Anonymous a). Extensive research has been conducted on imazethapyr with respect to rotational crop safety, weed control, herbicide mixtures, and weed resistance.

Imazethapyr is a residual herbicide and has injured sugarbeets (*Beta vulgaris* L.) up to 2 years after postemergence applications (Renner and Powell 1991). Moyer and Esau (1996) reported that there was a yield loss potential for sugarbeet and potatoes (*Solanum tuberosum* L.) planted 3 years after a postemergence application of imazethapyr to dry beans (*Phaseolus vulgaris* L.). A 40 month rotational crop restriction is currently recommended for sugarbeets after a postemergence application of imazethapyr (Crop Protection Reference 1996).

Imazethapyr controls a large spectrum of annual weeds (Anonymous a), but marginally controlled species and resistant species must be taken into account for weed control management decisions. Hager and Renner (1994) reported similar common ragweed dry weight reduction by bentazon and imazethapyr 14 days after treatment (DAT) in the field, but greater control was observed by bentazon in the greenhouse compared to imazethapyr. Common ragweed is partially susceptible to postemergence imazethapyr applications. Lateral and axillary buds initiate regrowth approximately 21 DAT (Ballard et al. 1996). Ballard et al. (1996) reported that the relative growth rate of common ragweed treated with imazethapyr decreased at a slow rate, but by 56 DAT it increased. The relative growth rate and metabolism of imazethapyr was greater in common ragweed than giant ragweed (*Ambrosia trifida* L.), but basipetal translocation was less (Ballard et al. 1995). This explains the primary difference in control of these two species by imazethapyr. Soil applied imazethapyr was more effective for common lambsquarters control than postemergence applications, as postemergence applications did not adequately control this problematic weed (Cantwell et al. 1989; Hoverstad 1996c;

Wilcut 1991). Nonetheless, smooth pigweed, palmer amaranth, prostrate pigweed (*Amaranthus blitoides* S. Wats.), and redroot pigweed (*Amaranthus retroflexus* L.) were controlled with imazethapyr (Arnold et al. 1993; Cantwell et al. 1989; Cole et al. 1989; Klingaman et al. 1992). Cole et al. (1989) reported that the half-life of imazethapyr in redroot pigweed was longer compared to soybean, peanut (*Arachis hypogaea*), sicklepod (*Cassia obtusifolia* L.), and Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], and control was related to this value. However, other *Amaranthus* species like common waterhemp can tolerate several times the recommended normal use rates of imazethapyr (Lovell et al. 1996). Velvetleaf (*Abutilon theophrasti* Medik.) was controlled by imazethapyr and 70 g/ha was needed to maintain control (Cantwell et al. 1989; Klingaman et al. 1992). In addition, imazethapyr has suppressed yellow nutsedge (*Cyperus esculentus* L.) growth in field and greenhouse studies. Yellow nutsedge suppression has been evaluated up to 142 days after treatment (DAT) by Grichar et al. (1992). Ackley et al. (1996) evaluated ALS-inhibiting herbicides in the greenhouse and had greater yellow nutsedge control with imazethapyr in the greenhouse than in the field. This study compared ALS-inhibitors, but the surfactants were different depending on the ALS-inhibiting herbicide used. Chlorimuron and halosulfuron (methyl 5-{[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonylaminosulfonyl}-3-chloro-1-methyl-1-*H*-pyrazole-4-carboxylate) controlled yellow nutsedge in the field, but there was no reported difference between control by chlorimuron and imazethapyr in the greenhouse (Ackley et al. 1996). However, Derr and Wilcut (1993) reported that chlorimuron reduced yellow nutsedge fresh weight more than imazethapyr. Richburg et al. (1993) determined that foliar and soil or soil treatments alone were more effective in controlling nutsedge than foliar applications only.

Imazamox. Imazamox (AC 299,263) is an imidazolinone herbicide for postemergence grass and broadleaf weed control in soybeans (Anonymous 1995b). The structure of imazamox was revealed in 1994 and the recommended postemergence rate was established at 35 and 45 g ai/ha (Quakenbush et al. 1994). There has been a tendency for greater control of common ragweed and common lambsquarters at the 45 than 35 g/ha rate in wide row soybeans (Ballard and Hellmer 1995).

Rapid metabolism of imazamox by soybeans is the basis for selectivity (Anonymous 1995b). At 140 g ha, soybean heights were reduced and lower yields observed compared to the 35 g/ha rate (Lueschen et al. 1995). Microbes are primarily responsible for the degradation of this herbicide in the soil (Quakenbush et al. 1994). Current rotational crop restrictions recommend 4 months for small grains; 10 months for corn (*Zea maize* L.), tobacco (*Nicotiana tabacum*), sunflower (*Helianthus annuus* L.), sorghum (*Sorghum bicolor*), rice (*Oryza sativa* L.), and potato; and 18 months for sensitive crops like sugarbeet and canola (*Brassica napus* L.) prior to planting (Anonymous 1995b; Hayden et al. 1995).

Soybean injury and weed control differences with imazamox have been attributed to the adjuvant used in the herbicide mixture. A methylated seed oil (MSO) increased weed control by imazamox on several species compared to a nonionic surfactant (NIS) (Nalewaja 1994). McMullan (1994a) reported greater wild oat and volunteer barley (*Hordeum vulgare* L.) control when a MSO was added compared to other adjuvants and the use of 28% urea ammonium nitrate (UAN) was beneficial. Gednalski et al. (1995) had more soybean injury with a MSO compared to NIS, but weed control averaged over weed species was greater with a MSO. Kleven and Zollinger (1995) reported greater dry edible bean injury with imazamox plus a MSO compared to NIS.

Busse and Hartberg (1994) reported that imazamox controlled panicum spp., foxtail spp., wild mustard, Pennsylvania smartweed (*Polygonum pensylvanicum* L.), eastern black nightshade (*Solanum ptycanthum* Dun.), common sunflower (*Helianthus annuus* L.), redroot pigweed, velvetleaf, and common lambsquarters over several locations. In addition, early postemergence applications of imazamox on common ragweed, johnsongrass [*Sorghum halepense* (L.) Pers.], giant ragweed, wild buckwheat (*Polygonum convolvulus* L.), jimsonweed (*Datura stramonium* L.), common purslane (*Portulaca oleracea* L.), barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], wild oat, and quackgrass (*Agropyron repens* (L.) Beauv.) provided 85-100% control of these species (Anonymous 1995b). Other studies have shown that imazamox plus a MSO controlled wild mustard (Nalewaja 1994), common cocklebur (*Xanthium strumarium* L.) (Hoverstad 1996a; Kapusta et al. 1995; Lueschen and Getting 1996; Owen et al. 1996b), redroot pigweed (Harvey et al. 1994; Hoverstad 1996c; Kapusta et al. 1995; Nalewaja 1994), rox orange (Peterson and Regehr 1995), velvetleaf (Kapusta et al. 1994, 1995; Owen et al. 1995b; Peterson and Regehr 1996; Wax et al. 1995), giant foxtail (Harvey et al. 1994; Hoverstad 1996a, 1996c; Kapusta et al. 1994, 1995; Owen et al. 1996b; Wax et al. 1995), common ragweed (Kapusta et al. 1994), giant ragweed (Hayden et al. 1995), common lambsquarters (Harvey et al. 1994; Hoverstad and Gunsolus 1996; Lueschen and

Getting 1996; Wax et al. 1995), smooth pigweed (Hayden et al. 1995; Wax et al. 1995), palmer amaranth (Peterson and Regehr 1995, 1996), ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.) (Kapusta et al. 1994), and wild-proso millet (*Panicum miliaceum* L.) (Mickleson et al. 1996b) at a standard postemergence application timing. However, inadequate control of common waterhemp (Krausz and Kapusta 1996; Owen et al. 1996b; Peterson and Regehr 1996), common lambsquarters (Hoverstad 1996c; Nelson and Renner 1995a; Owen et al. 1995b, 1996b), common ragweed (Dobbles and Loux 1996; Hoverstad 1996a, 1996c; Hoverstad and Gunsolus 1996; Nelson and Renner 1995a), woolly cupgrass (*Eriochloa villosa* (Thunb.) Kunth) (Owen et al. 1996a), wild-proso millet (Mickelson et al. 1996b), yellow nutsedge (Kapusta et al. 1995), ivyleaf morningglory (Kapusta et al. 1995; Peterson and Regehr 1996), giant foxtail (Dobbles and Loux 1996; Kapusta et al. 1994; Peterson and Regehr 1996), large crabgrass (*Digitaria sanguinalis* (L.) Scop.) (Peterson and Regehr 1995, 1996), and quackgrass (Frasier et al. 1995) has been reported. These studies did not specify whether this was due to regrowth or new weed emergence.

Tank mixtures with imazamox have been evaluated to broaden the weed control spectrum and maintain consistent control of marginally or inadequately controlled species. Several tank mixtures have broadened the weed control spectrum of imazamox, but some have antagonized the control of other weed species. For example, the diphenyl ether herbicides have been tank mixed with imazamox to increase common ragweed (Dobbles and Loux 1996; Hoverstad 1996a; Nelson and Renner 1995b) and common waterhemp control (Peterson and Regehr 1996). Dobbles and Loux (1996) had greater common ragweed control when imazamox was tank mixed with lactofen than acifluorfen (5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid). Lactofen or acifluorfen reduced giant foxtail control with imazamox compared to imazamox alone (Dobbles and Loux 1996; Hoverstad 1996a; Lueschen and Getting 1996; Nelson and Renner 1995a, 1995b; Owen et al. 1995b; Peterson and Regehr 1996; Wax et al. 1995). Acifluorfen antagonism of giant foxtail control by imazamox was greater as the acifluorfen rate increased (Hoverstad 1996a), but Peterson and Regehr (1995, 1996) observed no difference in antagonism as the rate of acifluorfen increased. Peterson and Regehr (1995, 1996) also reported that mixtures of imazamox with lactofen or acifluorfen antagonized large crabgrass control, while acifluorfen reduced ivyleaf morningglory control compared to imazamox alone. However, fall panicum (*Panicum dichotomiflorum* Michx.) control by imazamox was not affected by bentazon, fomesafen (5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide), or lactofen tank mixtures, and there was no difference in johnsongrass or giant foxtail control between imazamox alone and imazamox tank mixed with clethodim ((E,E)-2-[1-[[3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) (Hayden et al. 1995; Mickelson et al. 1996a).

Imazamox and Imazethapyr Comparison. Imazamox and imazethapyr are imidazolinone herbicides that differ structurally by a single oxygen molecule. This slight difference has affected the total amount of active ingredient applied, soil persistence, rotational crop restrictions, and weed control alone or tank mixed.

Herbicide carryover into sensitive crops has prevented the use of several herbicides in certain soybean cropping systems. The recommended use rate for imazamox is one half that for imazethapyr. Imazamox has had less reported carryover than imazethapyr due to a slight chemical structural difference and reduced active ingredient applied per hectare. Dexter et al. (1994) reported that sugarbeets were injured by imazethapyr, but not imazamox 1 year after a soybean application at two locations with a soil pH of 8.0 to 8.1. Imazamox applied at four times the recommended field rate injured sugarbeets (Lueschen et al. 1997). Carryover was greater when the soil had a low pH (1997). Imazamox had better sugarbeet safety than imazethapyr (Lueschen et al. 1995).

With a more active herbicide, there is usually greater crop injury associated; however, injury by imazamox at 35 g/ha and imazethapyr at 70 g/ha was similar (Geier and Stahlman 1996; Lueschen et al. 1995; Owen et al. 1996a). Researchers have shown that weed control with imazamox has been greater than imazethapyr on common ragweed (Hoverstad 1996c; Hoverstad and Gunsolus 1996; Kapusta et al. 1994; Nelson and Renner 1995a), common lambsquarters (Hoverstad 1996c; Nalewaja 1994; Nelson and Renner 1995a, 1995b; Owen et al. 1995b), giant foxtail (Hoverstad 1995, 1996b; Kapusta et al. 1994; Nelson and Renner 1995a, 1995b; Owen et al. 1995b; Wax et al. 1995), and yellow nutsedge (Kapusta et al. 1995) at 45 g/ha. Other studies have shown there was no difference in common lambsquarters, velvetleaf, ivyleaf morningglory, giant ragweed, Pennsylvania smartweed, giant foxtail, stinkgrass (*Eragrostis cilianensis* (All.) E.Mosher), or green foxtail control between imazamox and imazethapyr (Bauman et al.

1996; Geier and Stahlman 1996; Getting and Gunsolus 1996; Hoverstad 1995; Hoverstad and Gunsolus 1996).

Oxasulfuron. Oxasulfuron (CGA-277476) is a postemergence herbicide for selective grass and primarily broadleaf weed control in soybeans. It was discovered in the early 1990's by Ciba Crop Protection now Novartis (Anonymous 1995a; Brooks et al. 1995). Limited soil residual and no rotational crop restrictions have been reported (Anonymous 1995a).

Oxasulfuron at 79 g ai/ha rate has controlled velvetleaf (Anderson et al. 1996a; Anonymous 1995a; Brooks et al. 1995; Gonzini et al. 1995b; Hoverstad 1996b; Hoverstad and Gunsolus 1995; Kidder and Porpiglia 1996; Owen et al. 1995a; Peterson and Regehr 1995; Sander et al. 1995; Wax et al. 1996), common cocklebur (Anonymous 1995a; Brooks et al. 1995; Lueschen and Getting 1995; Owen et al. 1995a; Ritter and Menbere 1997; Sander et al. 1995), Pennsylvania smartweed (Anonymous 1995a; Getting and Gunsolus 1996; Gonzini et al. 1995a; Lueschen and Getting 1995; Owen et al. 1995a; Sander et al. 1995), common sunflower (Anderson et al. 1996a; Anonymous 1995a; Brooks et al. 1995; Sander et al. 1995), common ragweed (Anonymous 1995a; Brooks et al. 1995; Hoverstad 1996b; Kidder and Porpiglia 1996; Ritter and Menbere 1997; Sander et al. 1995; Wax et al. 1996), giant ragweed (Ritter and Menbere 1997), morningglory spp. (Anonymous 1995a; Brooks et al. 1995; Kidder and Porpiglia 1996; Smith et al. 1997; Wax et al. 1996), hemp sesbania (*Sesbania exaltata* (Raf.) Rydb. ex A.W.Hill) (Anonymous 1995a; Brooks et al. 1995; Smith et al. 1997), shattercane (*Sorghum bicolor* (L.) Moench) (Kidder and Porpiglia 1996), rox orange (Peterson and Regehr 1995), sicklepod (*Cassia obtusifolia* L.) (Smith et al. 1997), burcucumber (*Sicyos angulatus* L.) (Ritter and Menbere 1997) common lambsquarters (Getting and Gonsolus 1996; Gonzini et al. 1995a; Hoverstad 1996b; Hoverstad and Gunsolus 1995, 1996; Kidder and Porpiglia 1996; Wax et al. 1996), pigweed spp. (Brooks et al. 1995; Wax et al. 1996), and barnyardgrass (Kidder and Porpiglia 1996). Kidder and Johnson (1997) reported barnyardgrass, broadleaf signalgrass, johnsongrass, shattercane, foxtails, and volunteer corn was either supressed or controlled by oxasulfuron alone. Bruns and Nalewaja (1995) reported soybean injury and common lambsquarters control was less with a nonionic surfactant compared to a methylated vegetable oil or petroleum oil adjuvant. Other researchers have reported that eastern black nightshade (Anonymous 1995a; Owen et al. 1996d), giant foxtail (Gonzini et al. 1995a, 1995b, 1996), common waterhemp (Krausz and Kapusta 1996; Owen et al. 1996d), common ragweed (Fausey and Renner 1996; Hoverstad 1995; Hoverstad and Gunsolus 1995, 1996), common lambsquarters (Fausey and Renner 1996; Gonzini et al. 1995b, 1996; Lueschen and Getting 1995; Owen et al. 1995a, 1996d; Ritter and Menbere 1997), redroot pigweed (Fausey and Renner 1996; Lueschen and Getting 1995), palmer amaranth (Peterson and Regehr 1995), pigweed spp. (Owen et al. 1995a), velvetleaf (Gonzini et al. 1995a, 1996), and large crabgrass (Gonzini et al. 1995b; Owen et al. 1996d; Peterson and Regehr 1995) were not controlled by oxasulfuron alone.

Tank mixtures have been used for the control of eastern black nightshade and enhanced control of common lambsquarters or pigweed spp. with oxasulfuron (Anonymous 1995a; Gonzini et al. 1995b, 1996; Hoverstad 1996b; Kidder and Porpiglia

1996; Owen et al. 1996d; Sander et al. 1995). Oxasulfuron tank mixed with lactofen provided better common ragweed control than the tank mixture with acifluorfen (Hoverstad 1996b). CGA-248757 (methyl [[2-chloro-4-fluoro-5-[(tetrahydro-3-oxo-1*H*,3*H*-[1,3,4]thiadiazolo[3,4-a]pyridazin-1-ylidene)amino]phenyl]thio]acetate) has enhanced common ragweed, pigweed spp., and common lambsquarters control with oxasulfuron (Fausey and Renner 1996; Hoverstad 1995; Kidder and Porpiglia 1996; Lueschen and Getting 1995; Owen et al. 1995a), but reduced common cocklebur and common ragweed control in other studies (Hoverstad 1996b; Hoverstad and Gunsolus 1995; Lueschen and Getting 1995). Redroot pigweed and giant foxtail control was increased, but velvetleaf control was not increased when ALS-inhibiting herbicides like oxasulfuron were tank mixed with glyphosate on Roundup Ready® soybeans (Gonzini et al. 1996; Lich et al. 1997). Oxasulfuron has reduced grass control of some postemergence graminicides (Kidder and Johnson 1997; Ritter and Menbere 1997); therefore, graminicide applications should be made 1 day before or 7 days after an oxasulfuron application (Anonymous 1995a; Kidder and Johnson 1997). Increased graminicide rates have helped overcome grass antagonism by oxasulfuron (Kidder and Johnson 1997). Kidder and Johnson (1997) reported that grass antagonism was weed, herbicide, and solution mixture pH related. Preemergence grass herbicides followed by oxasulfuron have provided broad spectrum weed control (Bauer et al. 1995, 1996; Hoverstad 1996b; Kidder and Johnson 1997; Wax et al. 1996).

Cloransulam-methyl. Cloransulam-methyl is a triazolopyrimidine sulfonanilide applied at 26 to 44 g ai/ha early preplant, preplant incorporated, or preemergence timings, and at

17.5 g/ha postemergence for broadleaf weed control in soybeans. Its structure was revealed in 1994 (Jachetta et al. 1994). A ten month rotational crop restriction was recommended for cereal crops, rice, peanuts, and cotton (*Glossypium hirsutum* L.); however, sugarbeets and sunflowers require twenty-four months (Anonymous b; Jachetta et al. 1995). Soybeans metabolize cloransulam-methyl through homoglutathione conjugation of the 7-fluorine of the molecule (Jachetta et al. 1995).

Postemergence applications of cloransulam-methyl controlled common cocklebur (Anonymous b; Hunter et al. 1994; Jachetta et al. 1995; Menbere and Ritter 1997; Owen et al. 1995c; Schultz et al. 1996; Thompson et al. 1995), velvetleaf (Anderson et al. 1996b; Anonymous b; Hoverstad 1996b; Hoverstad and Gunsolus 1996; Hunter et al. 1994; Jachetta et al. 1995; Owen et al. 1995c, 1996c; Schultz et al. 1996), common ragweed (Anonymous b; Hoverstad 1996b; Hoverstad and Gunsolus 1996; Hunter et al. 1994; Jachetta et al. 1995; Menbere and Ritter 1997; Schultz et al. 1996; Thompson et al. 1995), giant ragweed. (Anonymous b; Hunter et al. 1994; Jachetta et al. 1995; Menbere and Ritter 1997; Schultz et al. 1996; Thompson et al. 1995), common sunflower (Anderson et al. 1996b; Anonymous b; Hunter et al. 1994; Jachetta et al. 1995; Schultz et al. 1996; Thompson et al. 1995), jimsonweed (Anonymous b; Jachetta et al. 1995; Schultz et al. 1996), morningglory spp. (Anonymous b; Hunter et al. 1994; Jachetta et al. 1995; Oliver and Gander 1997; Owen et al. 1996c; Thompson et al. 1995), burcucumber (Menbere and Ritter 1997), and spurred anoda (*Anoda cristata* (L.) Schlecht.) (Menbere and Ritter 1997). Common lambsquarters (Anonymous b; Menbere and Ritter 1997; Owen et al. 1995c), pigweed spp. (Anonymous b; Smith et al. 1997; Sweat et al. 1995;

Thompson et al. 1995), eastern black nightshade (Anonymous b; Jachetta et al. 1995), purple moonflower (*Ipomoea alba* L.) (Oliver and Gander 1997), hemp sesbania (Smith et al. 1997), sicklepod (Smith et al. 1997), and grass spp. (Jachetta et al. 1995) were not controlled with cloransulam-methyl applied postemergence.

Acifluorfen or thifensulfuron have been tank mixed to increase pigweed spp. and common lambsquarters control (Anderson et al. 1996b; Hoverstad et al. 1996; Owen et al. 1995c, 1996c; Thompson et al. 1995). These tank mixtures caused greater soybean injury than cloransulam-methyl alone (Anderson et al. 1996b; Owen et al. 1995c; Thompson et al. 1995). Ditmarsen et al. (1997) reported grass antagonism by cloransulam-methyl was weed species related when tank mixed with the aryloxyphenoxypropionates, but no antagonism was indicated when tank mixed with the cyclohexanediones. Preemergence acetaanilide followed by cloransulam-methyl postemergence weed management programs have been evaluated for broad spectrum weed control (Anderson et al. 1996b; Hoverstad 1996b; Schultz et al. 1996).

ACCase-Inhibitors. ACCase (acetyl-CoA carboxylase) is responsible for catalyzing acetyl-CoA into malonyl-CoA which is the first step in fatty acid synthesis. Fatty acids are essential for the formation of phospholipids which are the building blocks for plant cell membranes. Cyclohexanedione (clethodim and sethoxydim) and aryloxyphenoxypropionate (fenoxaprop (($\pm$)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid) and quizalofop (($\pm$)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid)) herbicides are ACCase inhibitors in monocot species (Rendina and Felts 1988; Sasaki et al. 1995). Sasaki et al. (1995) reported that there were a prokaryotic and eukaryotic forms of ACCase. The prokaryotic form of ACCase in pea (*Pisum sativum* L.) plants was insensitive to the graminicides, but the eukaryotic form was sensitive due to the lack of the accD gene in the plastid genome (1995). Dicots like soybeans have the eukaryotic form in the cytosol and the prokaryotic form in the plastids; however, monocots like giant foxtail have the eukaryotic form of ACCase in the plastids and cytosol. In addition, Barnwell and Cobb (1994) have reported that the cyclohexanedione absorption was less and slower than the aryloxyphenoxypropionate graminicides in grass species, but translocation was similar. Enhanced absorption was related to the ester formulation of the aryloxyphenoxypropionates (1994). Once in the plant, it is quickly converted to the acid form. The R(±)-entaniomer of the aryloxyphenoxypropionates is responsible for grass phytotoxicity (1994).

Derr et al. (1985) has noted that differences between giant foxtail, large crabgrass, and goosegrass (*Eleusine indica* (L.) Gaertn.) control with fluazifop-P (*R*)-2-[4-[[5-trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) could not be explained by uptake, retention, or absorption differences alone. Differences in graminicide tolerance by tall (*Festuca arundinacea* Schreb.) and red (*Festuca rubra* L.) fescue to sethoxydim and haloxyfop ((±)-2-[4-[[3-chloro-5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) were due to ACCase differences between the species which allowed for differential metabolism of these graminicides (Stolenberg et al. 1989).

The graminicides have been used to effectively control monocot weeds in soybeans (Jordan et al. 1993; Krausz et al. 1993; Myers and Coble 1992). Krausz et al. (1993) evaluated quizalofop, fenoxaprop, fluazifop-P, sethoxydim, clethodim, and haloxyfop for control of giant foxtail at four heights from 7 to 60 centimeters. There was no difference in control between graminicides treated on foxtail that was sixty centimeters tall, but under drought stress clethodim and haloxyfop had the most consistent control (Krausz et al. 1993). Large crabgrass control by quizalofop and clethodim was similar at field rates, but under stressed conditions or a half-rate clethodim had greater control (Myers and Coble 1992). However, Jordan et al. (1993) had greater large crabgrass control with quizalofop in the field at two locations than clethodim. A half rate of quizalofop had greater control than clethodim (1993). Increasing the graminicide rate increased the control of large crabgrass for all of the graminicides (1993). Seedling johnsongrass was controlled by fluazifop-P, quizalofop, sethoxydim, and clethodim at the field and 1.5 times the field rate (1993). Minton et al. (1989b) had superior red rice (*Oryza sativa* L.) control by quizalofop in the field compared to fluazifop-P, sethoxydim, or haloxyfop.

Diphenyl ethers. The diphenyl ether herbicides (acifluorfen, fomesafen, and lactofen) inhibit the porphyrinogen oxidase (Protox) enzyme. This causes an increase in protoporphyrin IX which is a product of protox (Duke et al. 1991; Lee and Duke 1994; Nandihalli et al. 1992; Sherman et al. 1991). Protoporphyrin IX accumulates in the cellular membranes and subsequently peroxidizes the cellular membrane upon exposure to light by generating singlet oxygen (Duke et al. 1991; Lee and Duke 1994; Nandihalli et al. 1992; Sherman et al. 1991).

Soybean injury by the diphenyl ether herbicides causes bronzing of the leaves, necrosis, and leaf crinkling (Harris et al. 1991; Lee and Oliver 1982; Wichert and Talbert 1993). Harris et al. (1991) compared soybean injury between fomesafen, acifluorfen, and lactofen, and soybean injury was greater with lactofen or acifluorfen than fomesafen. Lactofen at 220 or 440 g ai/ha caused 20-37% visual injury 8 DAT (days after treatment) and reduced soybean dry weights 16 and 26 DAT compared to the untreated soybeans, but soybean yield was not affected (Wichert and Talbert 1993). Common ragweed was controlled by acifluorfen (Monks et al. 1993; Ritter and Coble 1981b). Ritter and Coble (1981b) reported that common ragweed was more susceptible to acifluorfen than soybeans due to slower metabolism.

Environmental conditions can affect weed control with the diphenyl ether herbicides (Lee and Oliver 1982). Acifluorfen provided better control of common ragweed and common cocklebur at 85% relative humidity compared to 50% relative humidity (Ritter and Coble 1981a). Wichert et al. (1992) reported that the control of prickly sida (*Sida spinosa* L.), common cocklebur, and pitted (*Ipomoea lacunosa* L.) or entireleaf morningglory (*Ipomoea hederacea* var. integriuscula Gray) by all of the diphenyl ethers was enhanced at a high relative humidity. Lactofen was the least sensitive of the diphenyl ethers to reduced control at 50% relative humidity (1992).

HERBICIDE ANTAGONISM

Background. Herbicide interactions define a situation, process, and result. Synergism, additivity effect, and antagonism have been used to describe weed control interactions by herbicide mixtures (Hatzios and Penner 1985; Putnam and Penner 1974). A correct evaluation of an interaction depends on an accurate comparison between the observed control and the expected control. The Weed Science Society of America has defined synergism as "an interaction of two or more factors such that the effect when combined is greater than the predicted effect based on the response to each factor applied separately" (Ahrens 1994). An additive effect described interactions that did not affect the biological activity of the most active herbicide (Colby 1967). Possibly a more appropriate term for an additive effect is an independent one since some combinations, herbicide-fungicide or grass-broadleaf herbicide, would not imply an interaction (Putnam and Penner 1974). However, generalized grass or broadleaf herbicide classifications would not do justice to an independent effect label since several broadleaf herbicides have biological activity on grasses. Antagonism is an "interaction of two or more chemicals such that the effect when combined is less than the predicted effect based on the activity of each chemical applied separately" (Ahrens 1994). Several reviews on herbicide interactions have been published (Barnwell and Cobb 1994; Green 1989; Hatzios and Penner 1985; Putnam and Penner 1974).

Antagonism may take place at numerous locations between the herbicide mixture in the tank and the site of action in the plant. Hatzios and Penner (1985) classified herbicide antagonism into four mechanisms: 1) chemical, a transformation of a herbicide structure into a less active or ineffective form; 2) biochemical, a biological reduction in herbicide absorption into or translocation within the plant; 3) competitive, an interaction that depends on the relative concentration of two or more herbicides for the target enzyme or site of action; and 4) physiological, one herbicide's activity negates the separate and opposite properties of the other herbicide.

Several researchers have proposed methods for analyzing herbicide interactions (Colby 1967; Morse 1978; Nash 1981; Nash and Harris 1973). Putnam and Penner (1974) and more recently Hatzios and Penner (1985) reviewed the methodology for analyzing herbicide interactions. Colby (1967) developed a simplistic equation to calculate the expected control of a herbicide mixture based on the control of the herbicides in the mixture applied alone: $E = XY/100$. An expected control value (E) was calculated by taking the product of the percent of control by herbicide X and Y divided by 100 (1967). According to this equation, when the expected percent of control was greater than the observed percent of control then synergism resulted; however, the opposite was necessary for antagonism. Fisher's protected LSD value has been used as a conservative method to compare the significance between the expected value and observed value. When there was no significant difference between these values, the interaction was classified as additive or there was no net effect on the herbicide with the most biological activity. The percent dry weight reduction has been used by numerous researchers to quantitatively evaluate the relative weed control by herbicides. A percent dry weight reduction must be converted to a percent of control. One hundred minus the percent dry weight reduction gives the percent of control for herbicides X and Y. These numbers are inserted into Colby's equation and the expected value calculated. The expected value is subtracted from 100 to get the expected percent dry weight reduction. The herbicide combination is antagonistic when the observed percent dry weight reduction is less than the expected percent dry weight reduction.

Herbicide mixtures need to be evaluated for interactions to ensure crop safety and weed control. Early detection of synergism, additive effects, or antagonism is the key for quality herbicide recommendations as well as efficient and effective weed management. Antagonism has been regarded as a negative aspect of herbicide mixtures. However, such mixtures can be utilized to evaluate and understand herbicide modes of action, promote crop safety, and predict future problems. For instance, bentazon (3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide) reduced ^{14}C-imazethapyr absorption and translocation by pinto beans, and safened them from imazethapyr injury (Bauer et al. 1995a). Herbicide rates, formulation, mode of action, adjuvant selection, target species, time of application, plant growth stage, and environmental conditions can help overcome or avoid antagonistic interactions.

Diphenyl ether Antagonism. The diphenyl ether herbicides have antagonized grass and/or broadleaf weed control by several postemergence herbicides. As a result, soybean yields have been reduced in some situations (Whitwell et al. 1985). The mechanism of antagonism for this interaction has not been completely defined. This discussion evaluates diphenyl ether antagonism of grass control by the graminicides (Godley and Kitchen 1986; Holshouser and Coble 1990; Minton et al. 1989a; Whitwell et al. 1985; Wilhm et al. 1986) and some broadleaf weed control (Shaw and Wesley 1993; Sorensen et al. 1987; Wesley and Shaw 1992; Westberg and Coble 1992). Recent studies have reported grass antagonism with the ALS-inhibiting herbicides (Bauman et al. 1996; Geier and Stahlman 1996; Hoverstad 1996a, 1996b).

Acifluorfen has antagonized johnsongrass, fall panicum, large crabgrass, red rice, and goosegrass control with sethoxydim (Holshouser and Coble 1990; Minton et al. 1989b; Vidrine 1989; Whitwell et al. 1985), large crabgrass and barnyardgrass control with fluazifop (Godley and Kitchen 1986; Minton et al. 1989a), barnyardgrass control with haloxyfop and fenoxaprop (Minton et al. 1989a), and quackgrass control with haloxyfop (Whitwell et al. 1985). Acifluorfen reduced haloxyfop absorption by quackgrass (1985) and sethoxydim absorption by one-third in large crabgrass (Holshouser and Coble 1990). Minton et al. (1989a) reported that the control of barnyardgrass by quizalofop and sethoxydim was antagonized by lactofen. Similarly, fomesafen antagonized barnyardgrass control by quizalofop and fluazifop (Minton et al. 1989a) as well as goosegrass control by sethoxydim (Holshouser and Coble 1990). Sethoxydim absorption was reduced by acifluorfen more than fomesafen (Holshouser and Coble 1990). Fomesafen and lactofen had less graminicide antagonism than acifluorfen (Holshouser and Coble 1990; Minton et al. 1989a). Johnsongrass control with sethoxydim was reduced by acifluorfen and lactofen, but not fomesafen (Vidrine 1989). However, Vidrine (1989) reported that lactofen caused greater antagonism of johnsongrass control by fluazifop-P and quizalofop than acifluorfen or fomesafen. On the contrary, johnsongrass control by haloxyfop was not antagonized by lactofen, fomesafen, or acifluorfen (Vidrine 1989).

Grass antagonism by the diphenyl ethers is weed and herbicide dependent. Chen and Penner (1985) observed synergism between acifluorfen and sethoxydim for barnyardgrass control, but acifluorfen had no effect on barnyardgrass control by diclofop (($\pm$)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid). Minton et al. (1989b) observed enhanced control of red rice by acifluorfen tank mixed with fluazifop-P, haloxyfop, or sethoxydim while fomesafen did not influence red rice control in the field. Greenhouse studies indicated lactofen antagonized red rice control by fluazifop-P and fomesafen antagonized red rice control by sethoxydim, but no interactions were observed with acifluorfen (Minton et al. 1989b). Godley and Kitchen (1986) had no reduction in itchgrass (*Rottboellia exaltata* L.f.) control when acifluorfen was tank mixed with fluazifop-P, but observed antagonism of large crabgrass control. The difference between the antagonistic response was because itchgrass was more susceptible to fluazifop-P than large crabgrass (Godley and Kitchen 1986). Under adequate moisture and ideal environmental conditions, there has been no diphenyl ether antagonism observed (Godley and Kitchen 1986; Holshouser and Coble 1990; Vidrine 1989). As discussed earlier, the diphenyl ethers have antagonized grass control by the ALS-inhibiting herbicides in several instances (Bauman et al. 1996; Cantwell et al. 1989; Geier and Stahlman 1996; Hoverstad 1996a, 1996b). Grass suppression by acifluorfen has been reported from 0 to 74% depending on the grass species and the environmental conditions at the time of application (Chen and Penner 1985; Godley and Kitchen 1986; Holshouser and Coble 1990; Minton et al. 1989a). Lactofen and fomesafen have some activity on grass species, but to a much lesser extent (Holshouser and Coble 1990; Minton et al. 1989a).

Wesley and Shaw (1992) found that fomesafen and acifluorfen antagonized common cocklebur control by chlorimuron, but no interaction was observed with lactofen. Antagonism was more evident on larger common cocklebur (1992). Common cocklebur, pitted morningglory, and prickly sida absorbed more ^{14}C-chlorimuron in the presence of acifluorfen or lactofen than when applied alone (Shaw and Wesley 1993). However, in whole plant treatments conducted by Westberg and Coble (1992), chlorimuron absorption by common cocklebur was reduced when tank mixed with acifluorfen. This resulted in reduced translocation of chlorimuron to the meristematic tissue (Westberg and Coble 1992). There was no difference in the absorption or translocation of chlorimuron in sicklepod, a species more tolerant to acifluorfen (Westberg and Coble 1992). Metabolism experiments could not explain the antagonism observed (Westberg and Coble 1992).

Cantwell et al. (1989) reported that bentazon tank mixed with imazethapyr antagonized giant foxtail and smooth pigweed control. The absorption and translocation of ^{14}C-imazethapyr by redroot pigweed was reduced by bentazon in greenhouse studies by Bauer et al. (1995b). Numerous studies have evaluated antagonism between bentazon and sethoxydim on several grass species (Gerwick 1988; Holshouser and Coble 1990; Lassiter and Coble 1987; Minton et al. 1989; Rhodes and Coble 1984a, 1984b; Wanamarta et al. 1989; Whitwell et al. 1985; Wilhm et al. 1986). Wanamarta et al. (1989) determined that sodium and other cations antagonized sethoxydim uptake by quackgrass similar to a bentazon tank mixture with sethoxydim. Sodium ions in the bentazon formulation complexed with sethoxydim to form Na-sethoxydim (Wanamarta et al. 1989). In the presence of organic acids, sethoxydim antagonism was reduced (Wanamarta et al. 1989). In addition, the ammonium ion in ammonium phosphate, ammonium nitrate, or ammonium sulfate successfully competed with the sodium ion; therefore, alleviating the antagonism of Na-bentazon on sethoxydim absorption (Jordan and York 1989; Jordan et al. 1989; Wanamarta et al. 1993). Similar ionic complexes with glyphosate have resulted in reduced weed control in hard water situations (Nalewaja and Matysiak 1993; Thelen et al. 1995).

The formulation of fomesafen and acifluorfen includes a combination of the acid and sodium salt similar to the bentazon formulation (Ahrens 1994). The interaction between the ALS-inhibiting herbicides and diphenyl ethers with respect to giant foxtail antagonism could be due to the formation of cationic complexes. However, Godley and Kitchen (1986) as well as Westberg and Coble (1992) have proposed that the diphenyl ethers cause wide spread membrane disruption of the epidermal cells which interferes with normal absorption and translocation of the systemic herbicide resulting in antagonism. This appears to be the most logical explanation for the diphenyl ether antagonism.

ALS-Inhibitors and Graminicide Antagonism. Tank mixtures between the ALS-inhibiting herbicides and graminicides would allow consistent broad spectrum postemergence weed control; however, grass antagonism has been reported in corn (Harvey et al. 1995), cotton (Ferreira et al. 1995; Ferreira and Coble 1994), soybeans (Cantwell et al. 1989; Holshouser and Coble 1990; Myers and Coble 1992), and small grains (Baerg et al. 1996; Devine and Rashid 1993). Herbicides in the triazolopyrimidine sulfonanilide (Ditmarsen et al. 1997), imidazolinone (Bjelk and Monaco 1992; Croon and Merkle 1988; Vidrine 1989), sulfonylurea (Hall et al. 1982; O'Sullivan and Kirkland 1984), and pyrimidinyl thiobenzoate (Ferreira et al. 1995; Ferreira and Coble 1994) families have antagonized the control of several grass species by the graminicides. The mechanism of antagonism between these herbicides has not been completely understood or explained. Some researchers have observed reduced graminicide absorption (Chow 1988; Devine and Rashid 1993) and translocation (Baerg et al. 1996; Chow 1988; Croon and Merkle 1988; Ferreira et al. 1995) when an ALS-inhibiting herbicide was tank mixed with the graminicides. Gerwick et al. (1988) postulated that antagonism was based on a physiological interaction between the ALS-inhibitors and the graminicides. Further work on the interaction between the substrates of ACCase-inhibitors and ALS-inhibitors could bring greater understanding of plant biochemistry and help alleviate grass antagonism between these herbicide mixtures.

Ditmarsen et al. (1997) evaluated antagonism between cloransulam-methyl and several graminicides. Antagonism observed with the aryloxyphenoxypropionates was species dependent, but no antagonism was observed with the cyclohexanediones (Ditmarsen et al. 1997).

Imazethapyr antagonized giant foxtail (Cantwell et al. 1989) and woolly cupgrass (Owen et al. 1996a) control by sethoxydim. Imazethapyr also antagonized broadleaf signalgrass (*Brachiaria platyphylla* (Griseb.) Nash) control by fluazifop and sethoxydim as well as large crabgrass and fall panicum control by fluazifop, clethodim, quizalofop, and sethoxydim (Myers and Coble 1992). Myers and Coble (1992) reported severe antagonism under dry conditions and a sequential graminicide application overcame antagonism by imazethapyr. Grass control has been reported with imazethapyr (Cantwell et al. 1989; Myers and Coble 1992), but limited grass activity was reported by Holshouser and Coble (1990) and Minton et al. (1989).

The control of fall panicum, large crabgrass, and goosegrass by sethoxydim (Holshouser and Coble 1990), johnsongrass control by fluazifop and haloxyfop (Croon and Merkle 1988; Vidrine 1989), and red rice control by quizalofop, fluazifop, haloxyfop, fenoxaprop, clethodim, and sethoxydim (Minton et al. 1989) was antagonized when tank mixed with imazaquin. Antagonism of johnsongrass was dependent on seedling or rhizome growth habit (Vidrine 1989). Croon et al. (1989) observed no chemical interaction between haloxyfop and imazaquin. The absorption of haloxyfop or sethoxydim by sorghum or large crabgrass was not affected by imazaquin (Croon et al. 1989; Holshouser and Coble 1990); however, imazaquin reduced haloxyfop translocation in sorghum (Croon et al. 1989). Imazaquin antagonism of red rice control by the graminicides was greater than chlorimuron (Minton et al. 1989). Neither imazaquin, nor chlorimuron affected sethoxydim absorption by large crabgrass (Holshouser and Coble 1990). Inadequate rainfall before application, weed size, and graminicide rate affected grass antagonism by imazaquin or chlorimuron and grass control by the graminicides (Croon and Merkle 1988; Vidrine 1989).

Chlorimuron antagonized fall panicum and large crabgrass control by sethoxydim (Holshouser and Coble 1990); goosegrass control in the field, but not in the greenhouse by sethoxydim (1990); johnsongrass control by fluazifop (Croon and Merkle 1988;

Vidrine 1989), haloxyfop (1989), and fenoxaprop (Croon and Merkle 1988; Vidrine 1989); and broadleaf signalgrass control by quizalofop (Bjelk and Monaco 1992). Chlorimuron had no reported grass activity (Holshouser and Coble 1990; Vidrine 1989); however, Bjelk and Monaco (1992) reported broadleaf signalgrass was suppressed for 3 days after treatment and then quickly resumed growth. Croon et al. (1989) found that the absorption of ^{14}C-haloxyfop by sorghum was not affected by chlorimuron, but translocation was reduced. At the biochemical sites of action, Bjelk and Monaco (1992) determined that elevated pyruvate levels caused by the inhibition of the ALS-enzyme were not related to the antagonism of quizalofop on broadleaf signalgrass.

Kidder and Johnson (1997) reported that oxasulfuron antagonized grass control by certain graminicides. This antagonism was grass species and graminicide related (Kidder and Johnson 1997). Ritter and Menbere (1997) reported that oxasulfuron tank mixed with clethodim antagonized giant foxtail control.

Wild oat control by diclofop and flamprop (*N*-benzoyl-*N*-(3-chloro-4-fluorophenyl)-*DL*-alanine) was antagonized by chlorsulfuron (Chow 1988; O'Sullivan and Kirkland 1984). However, Hall et al. (1982) had conflicting results in the growth room and observed no antagonism between diclofop and chlorsulfuron. Devine and Rashid (1993) reported slight antagonism of wild oat control by tralkoxydim from chlorsulfuron. Chow (1988) related increased diclofop antagonism to an increase in the rate of chlorsulfuron. Chlorsulfuron also reduced the absorption and translocation of ^{14}C-diclofop in a localized treatment study (Chow 1988).

Tribenuron antagonized diclofop control of wild oat (Baerg et al. 1996; Eberlein et al. 1988). Eberlein et al. (1988) had no physical or chemical, inert ingredient, ACCase-inhibitor, or spray retention interactions between tribenuron and diclofop. The absorption and metabolism of ^{14}C-diclofop by wild oat was not affected by tribenuron; however, reduced translocation was observed (Baerg et al. 1996). A slight separation of time between tribenuron and diclofop applications greatly reduced antagonism (Baerg et al. 1996).

Several other sulfonylureas have reduced grass control when tank mixed with a graminicide. Sethoxydim-resistant corn has brought new opportunities for postemergence grass control in corn. Harvey et al. (1995) found that nicosulfuron had no additive effect on giant foxtail control by sethoxydim, but primisulfuron antagonized giant foxtail control by sethoxydim. Langton and Harvey (1997) reported that the ALS-inhibiting herbicides reduced sethoxydim absorption and translocation. Young et al. (Young et al. 1996) reported antagonism by ALS-inhibiting herbicides tank mixed with sethoxydim was related to reduced absorption of ^{14}C-sethoxydim in certain instances. Primisulfuron antagonized giant foxtail control by sethoxydim more than large crabgrass or shattercane (Young et al. 1996). Wild oat control by tralkoxydim in the growth chamber was antagonized by metsulfuron-methyl (Devine and Rashid 1993). Metsulfuron-methyl reduced ^{14}C-tralkoxydim absorption, but had no effect on translocation or ACCase activity (Devine and Rashid 1993). Since metsulfuron-methyl injured wild oat, Devine and Rashid (1993) associated this injury with antagonism since they observed no injury to wild oat by chlorsulfuron and slight antagonism when chlorsulfuron was tank mixed with tralkoxydim.

DPX-PE350 or pyrithiobac, sodium 2-chloro-6-(4,5-dimethoxypyrimidin-2-yl-thio)benzoate), is an ALS-inhibitor and a member of the pyrimidinyl thiobenzoate family. DPX-PE350 antagonized large crabgrass control by fluazifop, sethoxydim, quizalofop, and clethodim (Ferreira et al. 1995; Ferreira and Coble 1994; Jordan et al. 1993); broadleaf signalgrass control by quizalofop and fluazifop, but not sethoxydim or clethodim (Jordan et al. 1993); and johnsongrass control by sethoxydim and fluazifop, but not quizalofop (Ferreira and Coble 1994). Jordan et al. (1993) reported antagonism of sethoxydim by DPX-PE350, but not with fluazifop, clethodim, or quizalofop. DPX-PE350 antagonism with fluazifop was the most consistent (Ferreira and Coble 1994; Jordan et al. 1993). Both Jordan et al. (1993) as well as Ferreira and Coble (1994) reported some large crabgrass and johnsongrass suppression by DPX-PE350. Sequential applications of DPX-PE350 and increasing graminicide rates helped overcome graminicide antagonism (Ferreira et al. 1994; Jordan et al. 1993). DPX-PE350 had no effect on ACCase inhibition by fluazifop or the absorption and metabolism of fluazifop-P (Ferreira et al. 1995). Fluazifop-P antagonism by DPX-PE350 on large crabgrass control was related to reduced translocation (Ferreira et al. 1995).

Environmental conditions, sequential applications, and increased graminicide rates have reduced ALS-inhibiting herbicide antagonism of the ACCase-inhibiting herbicides. Careful selection of tank mixtures can help producers avoid losses due to antagonistic herbicide mixtures. Barnwell and Cobb (1993) recently reviewed the effects of the graminicides on cellular proton gradients. These effects may help explain antagonism between the auxin herbicides and graminicides (Barnwell and Cobb 1994).

ADJUVANTS

The addition of adjuvants to a herbicide mixture has reduced antagonism (Gerwick et al. 1990; Hart et al. 1992), enhanced weed control (Foy 1993; Foy and Witt 1993; Gednalski et al. 1995; Gronwald et al. 1993; Nalewaja et al. 1990), and affected chemical stability (Bridges et al. 1992; Falb et al. 1990; McMullan 1996). Adjuvants enhance absorption by increasing spray retention and foliar penetration (Gronwald et al. 1993; Penner 1989).

Sun-It II is a modified vegetable oil containing surfactant manufactured by Agsco Inc. (Foy 1993). Foy and Witt (1993) reported that soybean injury increased when imazethapyr was applied to soybeans with adjuvants. Kochia control by imazethapyr (Nalewaja et al. 1990); giant foxtail control by primisulfuron (Hart et al. 1992); and weed control by imazethapyr (Ogg et al. 1988) or imazamox (Gednalski et al. 1995) was greater with a methylated seed oil than a nonionic surfactant. Thompson et al. (1996) reported greater absorption of ^{14}C-imazethapyr by leafy spurge (*Euphorbia esula* L.) when a methylated seed oil was applied instead of a nonionic surfactant when 28% UAN was present or absent. Hager and Renner (1994) increased common ragweed control with imazethapyr by adding 28% UAN to imazethapyr plus nonionic surfactant. Hart et al. (1992) reported enhanced ^{14}C-primisulfuron absorption by giant foxtail and less tank mixture antagonism when a methylated seed oil was included.

AMS (ammonium sulfate) improved the uptake of imazethapyr in quackgrass compared to imazethapyr with surfactant alone. AMS has been used to overcome salt antagonism with several herbicides. The ammonium ion was important for reducing Na-sethoxydim antagonism by competing with sodium for sethoxydim (Wanamarta et al. 1993). Thelen (1994) reported the nitrate from UAN was not as effective as the ammonium ion in ammonium sulfate for overcoming hard-water antagonism of glyphosate.

ENVIRONMENTAL EFFECTS ON HERBICIDE EFFICACY

Temperature, relative humidity, rainfall, and light affect weed control and crop response to a herbicide (Hammerton 1967). Successful herbicide product development strategies strive to provide weed control over a variety of environmental conditions. It is important to understand environmental effects before or when unique problems, situations, or concerns arise.

The amount and type of crop injury as well as the ability of the plant to metabolize or compensate for the injury affects the yield potential of that crop. Ateh and Harvey (1997) reported that soybean injury by contact and translocated postemergence herbicides reduced soybean yields. Soybean injury was related to the environmental conditions at the time of application (Ateh and Harvey 1997). Soybean area 22 days after treatment had a direct affect on soybean yield (yield reduction = 4 + (0.3 x area reduction 22 DAT) (Ateh and Harvey 1997). Soybean area was the product of soybean height and width. Visual injury at 8 DAT was the best indicator of yield loss (yield reduction = 4 +

0.2 x visual injury 8 DAT) (Ateh and Harvey 1997). Soybeans are more sensitive to ALS-inhibiting herbicides at low temperatures (Malefyt and Quakenbush 1991; Reed et al. 1992). Some soybean varieties have greater herbicide tolerance than others (Reed et al. 1992; Simpson and Stoller 1996). Temperature exhibited no effect on translocation or absorption of imazethapyr, but soybean metabolism was halved as the temperature decreased from 27/33 to 21/27 C and from 21/27 to 15/21 C (Malefyt and Quakenbush 1991). Soybean recovery from thifensulfuron was greater under ideal growing conditions (Reed et al. 1992). Under higher temperatures (30 C) and low relative humidity (35%), thifensulfuron had increased ivyleaf morningglory control compared to low temperature (15 C) (Reed et al. 1992), but temperature had a limited effect upon velvetleaf or common lambsquarters control by thifensulfuron (Reed et al. 1992) or pitted morningglory control by imazethapyr (Kent et al. 1991a, 1992b). Temperature (18 to 35 C) had no effect on the absorption or translocation of ^{14}C-imazethapyr (Kent et al. 1992b; Malefyt and Quakenbush 1991), but a greater distribution of ^{14}C-imazethapyr in pitted morningglory was noted at 35 C compared to 18 C (Kent et al. 1991b). However, Harker and Dekker (1988) reported more translocation ^{14}C-cloproxydim ((E,E)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) to the shoot by quackgrass at high temperatures (from 10/5 to 20/15 C or from 20/15 to 30/25 C).

Relative humidity affects weed control more than temperature (Kent et al. 1991a, 1992b; Malefyt and Quakenbush 1991; Reed et al. 1992). The relative humidity is the amount of moisture in the air relative to the greatest amount that can be present at that temperature. At a higher relative humidity, greater weed control of several weed species has been noted (Malefyt and Quakenbush 1991; Nalewaja et al. 1990; Reed et al. 1992). Pitted morningglory absorbed and translocated greater amounts of ^{14}C-imazethapyr at 100% compared to 40% relative humidity (Kent et al. 1991a, 1992b).

Drought stressed plants have a higher herbicide tolerance level than actively growing plants (Bridges 1989; Kells and Wanamarta 1987). As discussed earlier, herbicide antagonism may be greater or more severe under reduced water availability depending on the mixture and weed species evaluated. Reynolds et al. (1988) reported that the effects of induced water stress on basipetal translocation in grain sorghum was dependent on the graminicide. For instance, increased acropetal translocation of sethoxydim or fluazifop by grain sorghum was noted while there was less acropetal translocation of quizalofop (Reynolds et al. 1988). Reduced quackgrass control by fluazifop or sethoxydim was related to water stress at the time of application by Kells and Wanamarta (1987).

Plant life depends on light to generate chemical energy. Light is important for the activation of the protox herbicides, but can increase degradation of others (Bridges et al. 1992). McMullan (1994b, 1996) showed that barley control with clethodim was greater in the absence of ultraviolet light. This was partially accounted for by the pH of the solution and the selected adjuvant. As the pH decreased, there was a decrease in photodegradation (Falb et al. 1990). A narrow pH window (5 to 7) was established by McMullan (1996) for the best control of barley by clethodim. Since quizalofop and fenoxaprop are formulated as esters, they are not affected by pH like clethodim

(McMullan 1994b, 1996). It was shown that an adjuvant could affect clethodim uptake and reduce photodegradation on johnsongrass (Bridges 1989).

There are several environmental factors that interplay and affect herbicide injury of crops and weed control. These factors may influence absorption, penetration, metabolism, and the activation or degradation of herbicides. The interplay of these factors must be considered when evaluating problems or interactions between herbicides for weed control.

ROW SPACING AND WEED COMPETITION

Soybean yields are reduced when weeds are not controlled due to competition for essential plant growth factors. Coble et al. (1981) found that as few as four common ragweed plants per 10 meter of row reduced soybean yields, and if common ragweed was not controlled before it was 6 weeks old, soybean yields decreased. Similarly, Knake and Slife (1962) showed that fifty-four giant foxtail plants per foot of row reduced soybean yields 28%. The harvested giant foxtail dry weight in this study was proportional to the reduction in soybean dry weight (Knake and Slife 1962). A comprehensive review of weed interference in soybeans has been published by Stoller et al. (1987).

Narrow (usually less than or equal to 25 cm) row soybeans yielded more and decreased weed yields more than similar wide row treatments (Burnside and Colville 1964; McWorter and Sciumbato 1988; Mickelson and Renner 1997; Patterson et al. 1988; Peters et al. 1965; Wax and Pendleton 1968). Soybeans grown in narrow row spacings were more profitable than wide row soybeans for most of the post emergence herbicide applications (Mickelson and Renner 1997). Taylor (1980) reported that wide row soybean yield may equal narrow row soybean yield under severe water stressed conditions because water deficits occur first in narrow row soybeans. Patterson et al. (Taylor 1988) found that soybean yield was related to the soybean biomass in wide and narrow soybean row spacings. Soybean yield was inversely related to weed biomass yield (Burnside and Moomaw 1977). The total plant biomass by weeds and soybeans was greater than the weed free soybean biomass (Weber and Staniforth 1957). However, Legèré and Schreiber (1989) measured equal total biomass between handweeded soybeans compared to the total biomass of the untreated control.

The introduction of postemergence herbicides has facilitated the transition of producers from wide to narrow row soybeans. Limited research has evaluated postemergence herbicides in narrow row compared to wide row soybeans. Mickelson and Renner (1997) evaluated weed control in narrow and wide row soybeans using reduced herbicide rates. Postemergence herbicide treatments in narrow row soybeans had 30% less total weed biomass than the same postemergence treatments in wide row soybeans (Mickelson and Renner 1997). Split applications of postemergence herbicides at a one-fourth the recommended field rate had similar weed control compared to the recommended field rate (Mickelson and Renner 1997). Burnside and Moomaw (1977) evaluated reduced herbicide rates in wide and narrow soybeans. Several tank mixtures provided weed control that was adequate in narrow row soybeans and did not require a cultivation (Burnside and Moomaw 1977). Early timings of reduced rate herbicides were needed for adequate weed control in narrow row soybeans (Burnside and Moomaw

1977). Weeds suppressed by chloramben (3-amino-2,5-dichlorobenzoic acid) were controlled to a greater extent in narrow than wide row soybeans (Peters et al. 1965). Faster canopy closure helped control weeds that were partially controlled by a herbicide treatment.

All other factors being equal, light competition by soybean is greater in narrow than wide row soybeans. Redroot pigweed total leaf area was less in narrow (25 cm) row soybeans than wide (75 cm) (Legèré and Schreiber 1989). Canopy closure for 25, 51, 76, and 102 cm row spacing soybeans ranged from 35-36, 47-50, 56-65, and 67-80 days after planting, respectively (Burnside and Colville 1964; Wax and Pendleton 1968). Mickelson and Renner (1997) reported that the canopy closure for narrow row soybeans was 45 days earlier than wide row soybeans. Shibles and Weber (1966) reported that plants in narrow rows (25 cm) reached 95% solar interception before wide row (102 cm) soybeans. The implementation of simple adjustments in cultural practices like narrow row soybeans can enhance postemergence weed control of marginally controlled weeds, save input costs, and reduce soil erosion.

LITERATURE CITED

Ackley, J. A., H. P. Wilson, and T. E. Hines. 1996. Yellow nutsedge (*Cyperus esculentus*) control POST with acetolactate synthase-inhibiting herbicides. Weed Technol. 10:576-580.

Ahrens, W. H. ed. 1994. Herbicide Handbook. 7th ed. Weed Science Society of America, Champaign, IL. 352 p.

Anderson, D. D., A. R. Martin, and J. T. Krumm. 1996a. Broadleaf weed control in soybeans in Lincoln, NE in 1996. North Cent. Weed Sci. Soc. Res. Rep. 53:360-362.

Anderson, D. D., A. R. Martin, and J. T. Krumm. 1996b. Soybean weed control with soil applied herbicides at Lincoln, NE in 1996. North Cent. Weed Sci. Soc. Res. Rep. 53:411-413.

Anonymous a. Pursuit®. Technical information bulletin. American Cyanamid Company, Princeton, NJ. 18 p.

Anonymous b. FirstRate™ broadleaf herbicide for soybeans. Technical data bulletin. DowElanco, Indianapolis, IN. 6 p.

Anonymous. 1995a. CGA-277476 herbicide. Technical information bulletin. Ciba Crop Protection, Greensboro, NC. 4 p.

Anonymous. 1995b. Raptor™. Technical information bulletin. American Cyanamid Company, Princeton, NJ. 8 p.

Arnold, R. N., M. W. Murray, E. J. Gregory, and D. Smeal. 1993. Weed control in pinto beans (*Phaseolus vulgaris*) with imazethapyr combinations. Weed Technol. 7:361-364.

Ateh, C. M. and R. G. Harvey. 1997. Models for predicting soybean yield loss from postemergence herbicide injury. Abstr. Weed Sci. Soc. Am. 37:3.

Baerg, R. J., J. W. Gronwald, C. V. Eberlein, and R. E. Stucker. 1996. Antagonism of diclofop control of wild oat (*Avena fatua*) by tribenuron. Weed Sci. 44:461-468.

Ballard, T. O. and M. Hellmer. 1995. AC 299,263: efficacy in soybeans as influenced by postemergence timing. Proc. North Cent. Weed Sci. Soc. 50:132-133.

Ballard, T. O., M. E. Foley, and T. T. Bauman. 1995. Absorption, translocation, and metabolism of imazethapyr in common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia trifida*). Weed Sci. 43:572-577.

Ballard, T. O., M. E. Foley, and T. T. Bauman. 1996. Response of common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia trifida*) to postemergence imazethapyr. Weed Sci. 44:248-251.

Barnwell, P. and A. H. Cobb. 1993. An investigation of aryloxyphenoxypropionate antagonism of auxin-type herbicide action on proton-efflux. Pestic. Biochem. Physiol. 47:87-97.

Barnwell, P. and A. H. Cobb. 1994. Graminicide antagonism by broadleaf weed herbicides. Pestic. Sci. 41:77-85.

Bauer, T. A., S. W. Pruss, T. R. Dill, and D. Kidder. 1996. Sequential soybean herbicide programs including CGA-277476. Proc. North Cent. Weed Sci. Soc. 51:131-132.

Bauer, T. A., K. A. Renner, and D. Penner. 1995a. 'Olathe' pinto bean (*Phaseolus vulgaris*) response to postemergence imazethapyr and bentazon. Weed Sci. 43:276-282.

Bauer, T. A., K. A. Renner, and D. Penner. 1995b. Response of selected weed species to postemergence imazethapyr and bentazon. Weed Technol. 9:236-242.

Bauer, T., T. Threewitt, L. Stahlberg, A. Moses, K. Jones, D. Kidder, and P. Porpiglia. 1995c. Weed management programs in soybeans with CGA-277476. Proc. North Cent. Weed Sci. Soc. 50:140.

Bauman, T. T., M. D. White, C. C. Mowen, and S. L. Phillips. 1996. Weed control in soybeans with AC 299,263. North Cent. Weed Sci. Soc. Res. Rep. 53:384-385.

Berhane, T., A. D. Cunha, and D. L. Shaner. 1993. Differential routes of metabolism of imidazolinones: basis for soybean (*Glycine max*) selectivity. Pestic. Biochem. Physiol. 46:120-130.

Bjelk, L. A. and T. J. Monaco. 1992. Effect of chlorimuron and quizalofop on fatty acid biosynthesis. Weed Sci. 40:1-6.

Bridges, D. C. 1989. Adjuvant and pH effects on sethoxydim and clethodim activity on rhizome johnsongrass (*Sorghum halepense*). Weed Technol. 3:615-620.

Bridges, D. C., L. N. Falb, and A. E. Smith. 1992. Stability and activity of clethodim as influenced by pH, UV light, and adjuvant. Pages 215-223 *in* Foy, C. E. ed. Adjuvants for Agrichemicals. CRC Press, Boco Raton, FL.

Brooks, R. L, P. J. Porpiglia, J. W. Peek, W. Meyer, K. Gutbrod, and H. Gut. 1995. CGA-277476, a new postemergence herbicide for soybeans. Abstr. Weed Sci. Soc. Am. 35:8.

Brown, H. M. 1990. Mode of action, crop selectivity, and soil relations of the sulfonylurea herbicides. Pestic. Sci. 29:263-281.

Brown, H. M., V. A. Wittenbach, D. R. Forney, and S. D. Strachan. 1990. Basis for soybean tolerance to thifensulfuron methyl. Pestic. Biochem. Physiol. 37:303-313.

Bruns, D. E. and J. D. Nalewaja. 1995. Adjuvant type and concentration affect CGA-277476 phytotoxicity. Proc. North Cent. Weed Sci. Soc. 50:136-137.

Buhler, D. D., J. L. Gunsolus, and D. F. Ralston. 1992. Integrated weed management techniques to reduce herbicide inputs in soybean. Agron. J. 84:973-978.

Burnside, O. C. and W. L. Colville. 1964. Soybean and weed yields as affected by irrigation, row spacing, tillage, and amiben. Weeds 12:109-112.

Burnside, O. C. and R. S. Moomaw. 1977. Control of weeds in narrow-row soybeans. Agron. J. 69:793-796.

Busse, S. R. and T. J. Hartberg. 1994. Weed control and rotational crop response with AC 299,263 in soybeans. Proc. North Cent. Weed Sci. Soc. 49:132.

Cantwell, J. R., R. A. Liebl, and F. W. Slife. 1989. Imazethapyr for weed control in soybean (*Glycine max*). Weed Technol. 3:596-601.

Chen, Y. and D. Penner. 1985. Combination effects of acifluorfen with crop oil concentrates and postemergence grass herbicides. Weed Sci. 33:91-95.

Chow, P. N. P. 1988. Effect of chlorsulfuron on four graminicides for weed control and wheat yield. Weed Res. 28:145-150.

Coble, H. D., F. M. Williams, and R. L. Ritter. 1981. Common ragweed (*Ambrosia artemisiifolia*) interference in soybeans (*Glycine max*). Weed Sci. 29:339-342.

Colby, S. R. 1967. Calculating synergistic and antagonistic responses of herbicide combinations. Weeds 15:20-22.

Cole, T. A., G. R. Wehtje, J. W. Wilcut, and T. V. Hicks. 1989. Behavior of imazethapyr in soybeans (*Glycine max*), peanuts (*Arachis hypogaea*), and selected weeds. Weed Sci. 37:639-644.

Croon, K. A., M. L. Ketchersid, and M. G. Merkle. 1989. Effect of bentazon, imazaquin, and chlorimuron on the absorption and translocation of the methyl ester of haloxyfop. Weed Sci. 37:645-650.

Croon, K. A. and M. G. Merkle. 1988. Effects of bentazon, imazaquin, or chlorimuron on haloxyfop or fluazifop-P efficacy. Weed Technol. 2:36-40.

Crop Protection Chemicals Reference. 1996. 12th ed. Chemical and Pharmaceutical Press, John Wiley & Sons, Inc. 2373 p.

Derr, J. F., and J. W. Wilcut. 1993. Control of yellow and purple nutsedges (*Cyperus esculentus* and *C. rotundus*) in nursery crops. Weed Technol. 7:112-117.

Derr, J. F., T. J. Monaco, and T. J. Sheets. 1985. Uptake and translocation of fluazifop by three annual grasses. Weed Sci. 33:612-617.

Devine, M. D. and A. Rashid. 1993. Antagonism of tralkoxydim activity in *Avena fatua* by metsulfuron methyl. Weed Res. 33:97-104.

Dexter, A. G., W. E. Lueschen, and J. K. Getting. 1994. Herbicide carryover into sugarbeet. Proc. North Cent. Weed Sci. Soc. 49:114-115.

Ditmarsen, S. C., R. A. Dorich, L. B. Rowland, and M. E. Schultz. 1997. Efficacy and antagonism of tank mixtures of cloransulam-methyl with postemergence graminicides in soybeans. Abstr. Weed Sci. Soc. Am. 37:3.

Dobbles, A. F. and M. M. Loux. 1996. Postemergence control of common ragweed in soybean. North Cent. Weed Sci. Soc. Res. Rep. 53:376-377.

Duke, S. O., J. Lydon, J. M. Becerril, T. D. Sherman, L. P. Lehnen, Jr., and H. Matsumoto. 1991. Protoporphyrinogen oxidase-inhibiting herbicides. Weed Sci. 39:465-473.

Eberlein, C. V., T. L. Miller, and J. V. Wiersma. 1988. Influence of thiameturon and DPX-L5300 on wild oats (*Avena fatua*) control with barban, diclofop, AC 222,293, and difenzoquat. Weed Sci. 36:792-799.

Falb, L. N., D. C. Bridges, and A. E. Smith, Jr. 1990. Effects of pH and adjuvants on clethodim photodegradation. J. Agric. Food Chem. 38:875-878.

Fausey, J. C. and K. A. Renner. 1996. Comparing broadleaf weed control in soybeans with CGA-248757 and flumiclorac. North Cent. Weed Sci. Soc. Res. Rep. 53:336-337.

Ferreira, K. L., J. D. Burton, and H. D. Coble. 1995. Physiological basis for antagonism of fluazifop-P by DPX-PE350. Weed Sci. 43:184-191.

Ferreira, K. L. and H. D. Coble. 1994. Effect of DPX-PE350 on the efficacy of graminicides. Weed Sci. 42:222-226.

Fielding, R. J. and E. W. Stoller. 1990. Effects of additives on the efficacy, uptake, and translocation of the methyl ester of thifensulfuron. Weed Sci. 38:172-178.

Foy, C. L. 1993. Progress and developments in adjuvant use since 1989 in the USA. Pestic. Sci. 38:65-76.

Foy, C. L. and H. L. Witt. 1993. Effects of methylated crop oils and other selected adjuvants on the herbicidal efficacy and selectivity of imazethapyr in soybeans. Essex: Elsevier Applied Science Publishers 38:260-262.

Frasier, A., F. C. Roggenbuck, and D. Penner. 1995. Control of quackgrass and Canada thistle with sulfonylurea and imidazolinone herbicides. Proc. North Cent. Weed Sci. Soc. 50:32.

Friesen, G. H. 1979. Protection of snapbeans from substituted urea injury by prior treatment with dinitroaniline herbicides. Can. J. Plant Sci. 59:535-537.

Friesen, L. F., I. N. Morrison, A. Rashid, and M. D. Devine. 1993. Response of a chlorsulfuron-resistant biotype of *Kochia scoparia* to sulfonylurea and alternative herbicides. Weed Sci. 41:100-106.

Gaeddert, J. W., D. E. Peterson, and M. J. Horak. 1996. Control and cross resistance of an ALS resistant palmer amaranth (*Amaranthus palmeri* S. Wats) biotype. Abstr. Weed Sci. Soc. Am. 36:9.

Gednalski, J. V., W. G. Johnson, and G. W. Alley. 1995. Influence of various adjuvants on postemergence weed control in soybeans with AC 299,263. Proc. North Cent. Weed Sci. Soc. Am. 50:133.

Geier, P. W. and P. W. Stahlman. 1996. Evaluation of AC 299,263 in soybean. North Cent. Weed Sci. Soc. Res. Rep. 53:382-383.

Gerwick III, B. C. 1988. Potential mechanisms for bentazon antagonism with haloxyfop. Weed Sci. 36:286-290.

Gerwick, B. C., L. D. Tanguay, and F. G. Burroughs. 1990. Differential effects of UAN on antagonism with bentazon. Weed Technol. 4:620-624.

Gerwick, B. C., P. Thompson, and R. Noveroske. 1988. Potential mechanisms in antagonism with aryloxyphenoxypropionate herbicides. Abstr. Weed Sci. Soc. Am. 28:100.

Getting, J. K. and J. L. Gunsolus. 1996. Herbicide performance in soybeans at Lamberton, MN in 1996. North Cent. Weed Sci. Soc. Res. Rep. 53:422-423.

Godley, J. L. and L. M. Kitchen. 1986. Interaction of acifluorfen with fluazifop for annual grass control. Weed Sci. 34:936-941.

Gonzini, L. C., S. E. Hart, and D. J. Maxwell. 1995a. Weed control systems in glyphosate resistant soybeans. North Cent. Weed Sci. Soc. Res. Rep. 52:266-267.

Gonzini, L. C., S. E. Hart, L. M. Wax, and D. J. Maxwell. 1995b. Weed control systems in glyphosate resistant soybeans. North Cent. Weed Sci. Soc. Res. Rep. 52:302-303.

Gonzini, L. C., S. E. Hart, L. M. Wax, and D. J. Maxwell. 1996. Weed control in drilled glyphosate resistant soybeans. North Cent. Weed Sci. Soc. Res. Rep. 53:300-301.

Green, J. M. 1989. Herbicide antagonism at the whole plant level. Weed Technol. 3:217-226.

Green, J. M. 1991. Maximizing herbicide efficiency with mixtures and expert systems. Weed Technol. 5:894-897.

Grichar, W. J., P. R. Nester, and A. E. Colburn. 1992. Nutsedge (*Cyperus* spp.) control in peanuts (*Arachis hypogaea*) with imazethapyr. Weed Technol. 6:396-400.

Gronwald, J. W., S. W. Jourdan, D. L. Wyse, D. A. Somers, and M. U. Magnusson. 1993. Effect of ammonium sulfate on absorption of imazethapyr by quackgrass (*Elytrigia repens*) and maize (*Zea mays*) cell suspension cultures. Weed Sci. 41:325-334.

Hager, A. and K. Renner. 1994. Common ragweed (*Ambrosia artemisiifolia*) control in soybean (*Glycine max*) with bentazon as influenced by imazethapyr or thifensulfuron tank-mixes. Weed Technol. 8:766-771.

Hall, J. C., L. V. Edgington, and C. M. Switzer. 1982. Effects of chlorsulfuron or 2,4-D upon diclofop-methyl efficacy in oat (*Avena sativa*). Weed Sci. 30:672-676.

Hammerton, J. L. 1967. Environmental factors and susceptibility to herbicides. Weeds 15:330-336.

Harker, K. N. and J. Dekker. 1988. Temperature effects on translocation patterns of several herbicides within quackgrass (*Agropyron repens*). Weed Sci. 36:545-552.

Harris, J. R., B. J. Gossett, T. R. Murphy, and J. E. Toler. 1991. Response of broadleaf weeds and soybeans to the diphenyl ether herbicides. J. Prod. Agric. 4:407-411.

Hart, S. E., J. J. Kells, and D. Penner. 1992. Influence of adjuvants on the efficacy, absorption, and spray retention of primisulfuron. Weed Technol. 6:592-598.

Harvey, R. G., J. W. Albright, T. M. Anthon, and J. L. Kutil. 1994. Soybean herbicide studies. North Cent. Weed Sci. Soc. Res. Rep. 51:338-343.

Harvey, R. G., B. J. Williams, and S. J. Langton. 1995. Efficacy of herbicide combinations designed for use in sethoxydim-tolerant field corn (*Zea mays*). Abstr. Weed Sci. Soc. Am. 35:6.

Hatzios, K. K., and D. Penner. 1985. Interactions of herbicides with other agrochemicals in higher plants. Rev. Weed Sci. 1:1-63.

Hay, J. V. 1990. Chemistry of sulfonylurea herbicides. Pestic. Sci. 29:247-261.

Hayden, T. A., M. R. Hellmer, and C. D. Youmans. 1995. Weed control in doublecrop soybean with AC 299,263. Proc. North Cent Weed Sci. Soc. 50:133-134.

Hill, E. R., D. R. Seefield, D. Kidder, and M. P. Johnson. 1996. The chiral isomer of metolachlor--a new generation of products. Proc. North Cent. Weed Sci. Soc. 51:58.

Hinz, J. R. R. and M. D. K. Owen. 1996. Nicosulfuron and primisulfuron selectivity in corn (*Zea mays*) and two annual grass weeds. Weed Sci. 44:219-223.

Hodges, C. C., G. J. de Boer, and J. Avalos. 1990. Uptake and metabolism as mechanisms of selective herbicidal activity of the 1,2,4-triazolo[1,5-*a*]pyrimidines. Pestic. Sci. 29:365-378.

Holshouser, D. L. and H. D. Coble. 1990. Compatibility of sethoxydim with five postemergence broadleaf herbicides. Weed Technol. 4:128-133.

Hoverstad, T. R. 1995. Common ragweed control in soybeans at Waseca, MN in 1995. North Cent. Weed Sci. Soc. Res. Rep. 52:250-251.

Hoverstad, T. R. 1996a. Acifluorfen tank mixtures with imazethapyr or AC 299,263 for common ragweed control in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 53:386-387.

Hoverstad, T. R. 1996b. Common ragweed control in soybean at Waseca, MN in 1996. North Cent. Weed Sci. Soc. Res. Rep. 53:398-399.

Hoverstad, T. R. 1996c. Weed control in no-till soybeans using roundup ready technology. North Cent. Weed Sci. Soc. Res. Rep. 53:484-485.

Hoverstad, T. R., and J. L. Gunsolus. 1995. Herbicide performance in soybeans at Waseca, MN in 1995. North Cent. Weed Sci. Soc. Res. Rep. 52:262-263.

Hoverstad, T. R., and J. L. Gunsolus. 1996. Herbicide performance in soybeans at Waseca, MN in 1996. North Cent. Weed Sci. Soc. Res. Rep. 53:420-421.

Hunter, J. H., M. E. Schultz, R. K. Mann, R. C. Cordes, and R. B. Lassiter. 1994. Weed control in soybeans with cloransulam-methyl. Proc. North Cent. Weed Sci. Soc. 49:124.

Jachetta, J. J., J. C. Van Heertum, and B. C. Gerwick. 1994. Cloransulam-methyl: a new herbicide for soybeans. Proc. North Cent. Weed Sci. Soc. 49:122-123.

Jachetta, J. J., J. C. Van Heertum, and B. C. Gerwick. 1995. Cloransulam-methyl: a new herbicide for soybeans. Abstr. Weed Sci. Soc. Am. 35:8.

Jordan, D. L., R. E. Frans, and M. R. McClelland. 1993. Interactions of DPX-PE350 with fluazifop-P, sethoxydim, clethodim, and quizalofop-P. Weed Technol. 7:605-610.

Jordan, D. L. and A. C. York. 1989. Effects of ammonium fertilizers and BCH 81508 S on antagonism with sethoxydim plus bentazon mixtures. Weed Technol. 3:450-454.

Jordan, D. L., A. C. York, and F. T. Corbin. 1989. Effect of ammonium sulfate and bentazon on sethoxydim absorption. Weed Technol. 3:674-677.

Kapusta, G., J. L. Matthews, and M. R. Obermeier. 1994. Soybean weed control with preemergence and postemergence herbicides. North Cent. Weed Sci. Soc. Res. Rep. 51:257-259.

Kapusta, G., S. E. Curvey, and R. F. Krausz. 1995. Soybean weed control with AC 299,263 combinations. North Cent. Weed Sci. Soc. Res. Rep. 52:260-261.

Kells, J. J. and G. Wanamarta. 1987. Effect of adjuvant and spray volume on quackgrass (*Agropyron repens*) control with selective postemergence herbicides. Weed Technol. 1:129-132.

Kent, L. M., G. D. Wills, and D. R. Shaw. 1991a. Effect of ammonium sulfate, imazapyr, and environment on the phytoxicity of imazethapyr. Weed Technol. 5:202-205.

Kent, L. M., G. D. Wills, and D. R. Shaw. 1991b. Influence of ammonium sulfate, imazapyr, temperature, and relative humidity on the absorption and translocation of imazethapyr. Weed Sci. 39:412-416.

Kidder, D. and M. D. Johnson. 1997. Grass control in soybeans with CGA-277476; alone, in sequential, and in tankmix programs. Abstr. Weed Sci. Soc. Am. 37:1.

Kidder, D. W. and P. J. Porpiglia. 1996. CGA-277476 and CGA-248757 for broad spectrum, postemergence weed control in soybeans. Abstr. Weed Sci. Soc. Am. 36:12.

Kleven, T. W. and R. K. Zollinger. 1995. Dry edible bean response to AC 299,263. Proc. North Cent. Weed Sci. Soc. 50:132.

Klingaman, T. E., C. A. King, and L. R. Oliver. 1992. Effect of application rate, weed species, and weed stage of growth on imazethapyr activity. Weed Sci. 40:227-232.

Knake, E. L., and F. W. Slife. 1962. Competition of *Setaria faberii* with corn and soybeans. Weeds 10:26-29.

Krausz, R. F. and G. Kapusta. 1996. Evaluation of common waterhemp control with commercial and experimental herbicides in soybean. North Cent. Res. Rep. 53:294-295.

Krausz, R. F., G. Kapusta, and J. L. Matthews. 1993. The effect of giant foxtail (*Setaria faberi*) plant height on control with six postemergence herbicides. Weed Technol. 7:491-494.

Ladner, D. W. 1991. Structure-activity relationships among the imidazolinone herbicides. Pages 31-51 *in* Shaner, D. L. and S. L. O'Connor eds. The Imidazolinone Herbicides. CRC Press, Boco Raton, FL.

Langton, S. J. and R. G. Harvey. 1997. Possible physiological mechanisms of sethoxydim antagonism in sethoxydim resistant field corn. Abstr. Weed Sci. Soc. Am. 37:86.

Lassiter, Jr., R. B. and H. D. Coble. 1987. Carrier volume effects on the antagonism of sethoxydim by bentazon. Weed Sci. 35:541-546.

Lee, H. J. and S. O. Duke. 1994. Protoporphyrinogen IX-oxidizing activities involved in the mode of action of peroxidizing herbicides. J. Agric. Food Chem. 42:2610-2618.

Lee, S. D. and L. R. Oliver. 1982. Efficacy of acifluorfen on broadleaf weeds. Times and methods for application. Weed Sci. 30:520-526.

Legèré, A. and M. M. Schreiber. 1989. Competition and canopy architecture as affected by soybean (*Glycine max*) row width and density of redroot pigweed (*Amaranthus retroflexus*). Weed Sci. 37:84-92.

Leif, J. and F. Taylor. 1993. Sequential and tank mix combinations with imazethapyr for enhanced weed control and weed resistance management in soybeans. Proc. North Cent. Weed Sci. Soc. 48:81.

Lich, J. M., K. A. Renner, and D. Penner. 1997. Interaction of glyphosate with postemergence soybean herbicides. Weed Sci. 45:12-21.

Lovell, S. T., L. M. Wax, M. J. Horak, and D. E. Peterson. 1996. Imidazolinone and sulfonylurea resistance in a biotype of common waterhemp (*Amaranthus rudis*). Weed Sci. 96:789-794.

Lueschen, W. E. and J. K. Getting. 1995. Effects of time of postemergence application of herbicides on common cocklebur control in soybeans at Lamberton, MN in 1995. North Cent. Weed Sci. Soc. Res. Rep. 52:362-363.

Lueschen, W. E., J. K. Getting, and E. L. Foland. 1995. Effects of AC 299,263 and imazethapyr applied postemergence to soybeans and the residue effects on rotational sugarbeets at Hector, MN in 1994 and 1995. North Cent. Weed Sci. Soc. Res. Rep. 52:82-83.

Lueschen, W. E. and J. K. Getting. 1996. Common cocklebur control in soybeans at Lamberton, MN in 1996. North Cent. Weed Sci. Soc. Res. Rep. 53:352-354.

Lueschen, W. E., J. K. Getting, and E. L. Foland. 1997. AC 299,263 and imazethapyr carryover potential in soybean/sugarbeet rotation. Abstr. Weed Sci. Soc. Am. 37:97.

Malefyt, T. and W. B. Duke. 1981. Soybean protection from triazine injury by pendimethalin. Proc. Northeast Weed Sci. Soc. 35:56.

Malefyt, T. and L. Quakenbush. 1991. Influence of environmental factors on the biological activity of the imidazolinone herbicides. Pages 103-127 *in* Shaner, D. L. and S. L. O'Connor eds. The Imidazolinone Herbicides. CRC Press, Boca Raton, FL.

Mallory-Smith, C. A., D. C. Thill, and M. J. Dial. 1990. Identification of sulfonylurea herbicide-resistant prickly lettuce (*Lactuca serriola*). Weed Technol. 4:163-168.

McMullan, P. M. 1994a. Adjuvants with AC 299,263 for annual grass control in imidazolinone-resistant canola. North Cent. Weed Sci. Soc. Res. Rep. 51:371.

McMullan, P. M. 1994b. Effect of sodium bicarbonate on clethodim or quizalofop efficacy and the role of ultraviolet light. Weed Technol. 8:572-575.

McMullan, P. M. 1996. Grass herbicide efficacy as influenced by adjuvant, spray solution pH, and ultraviolet light. Weed Technol. 10:72-77.

McWorter, C. G. and G. L. Sciumbato. 1988. Effects of row spacing, benomyl, and duration of sicklepod (*Cassia obtusifolia*) interference on soybean (*Glycine max*) yields. Weed Sci. 36:254-259.

Menbere, H. and R. L. Ritter. 1997. Use of cloransulam-methyl in soybeans. Abstr. Weed Sci. Soc. Am. 37:2.

Michigan Department of Agriculture. 1996. Michigan Agriculture Statistics 1995-96. Lansing, MI. p. 131.

Michigan annual crop summary released. Farmers' Advance. 22 January 1997: 6-B.

Mickelson, J. A., R. G. Harvey, J. W. Albright, and T. M. Anthon. 1996a. Clethodim antagonism and efficacy and wild-proso millet and giant foxtail control in soybeans study. North Cent. Weed Sci. Soc. Res. Rep. 53:404-405.

Mickelson, J. A., R. G. Harvey, J. W. Albright, and T. M. Anthon. 1996b. Wild-proso millet control using imazethapyr and AC 299,263 in sulfonylurea-tolerant soybeans study. North Cent. Weed Sci. Soc. Res. Rep. 53:406-407.

Mickelson, J. A. and K. A. Renner. 1997. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybeans. J. Prod. Agric. In press.

Minton, B. W., M. E. Kurtz, and D. R. Shaw. 1989a. Barnyardgrass (*Echinochloa crus-galli*) control with grass and broadleaf weed herbicide combinations. Weed Sci. 37:223-227.

Minton, B. W., D. R. Shaw, and M. E. Kurtz. 1989b. Postemergence grass and broadleaf herbicide interactions for red rice (*Oryza sativa*) control in soybeans (*Glycine max*). Weed Technol. 3:329-334.

Monks, C. D., J. W. Wilcut, and J. S. Richburg, III. 1993. Broadleaf weed control in soybean (*Glycine max*) with chlorimuron plus acifluorfen or thifensulfuron mixtures. Weed Technol. 7:317-321.

Morse, P. M. 1978. Some comments on the assessment of joint action in herbicide mixtures. Weed Sci. 26:58-71.

Moyer, J. R. and R. Esau. 1996. Imidazolinone herbicide effects on following rotational crops in Southern Alberta. Weed Technol. 10:100-106.

Myers, P. F. and H. D. Coble. 1992. Antagonism of graminicide activity on annual grass species by imazethapyr. Weed Technol. 6:333-338.

Nalewaja, J. D. 1994. AC 299,263 POST in soybean. North Cent. Weed Sci. Soc. Res. Rep. 51:263.

Nalewaja, J. D., J. Palczynski, and F. Manthey. 1990. Imazethapyr efficacy with adjuvants and environments. Weed Technol. 4:765-770.

Nalewaja, J. D. and R. Matysiak. 1993. Spray carrier salts affect herbicide toxicity to kochia (*Kochia scoparia*). Weed Technol. 7:154-158.

Nandihalli, U. B., M. V. Duke, and S. O. Duke. 1992. Quantitative structure--activity relationships of protoporphyrinogen oxidase-inhibiting diphenyl ether herbicides. Pestic. Biochem. Physiol. 43:193-211.

Nash, R. G. 1981. Phytotoxic interaction studies--techniques for evaluation and presentation of results. Weed Sci. 29:147-155.

Nash, R. G. and W. G. Harris. 1973. Screening for phytotoxic pesticide interactions. J. Environ. Qual. 2:493-497.

Nelson, K. A. and K. A. Renner. 1995a. Comparing AC 299,263 and imazethapyr combinations in soybean. North Cent. Weed Sci. Soc. Res. Rep. 52:264-265.

Nelson, K. A. and K. A. Renner. 1995b. A comparison of imazethapyr and AC 299,263 for postemergence weed control in soybeans. Proc. North Cent. Weed Sci. Soc. 50:129-130.

Ogg, P. J., T. L. Arnold, S. R. Busse, K. L. Carlson, D. L. Culbertson, T. A. Hayden, T. P. Miller, S. M. Sanborn, M. E. Weiss, and W. S. Van Scoik. 1988. Methylated sunflower oil and other additives in postemergence applications of imazethapyr. Proc. North Cent. Weed Sci. Soc. 43:41.

Oliver, L. R. and J. R. Gander. 1997. Morningglory spectrum for cloransulam (FirstRate). Abstr. Weed Sci. Soc. Am. 37:2.

O'Sullivan, P. A. and K. J. Kirkland. 1984. Chlorsulfuron reduced control of wild oat (*Avena fatua*) with diclofop, difenzoquat, and flamprop. Weed Sci. 32:285-289.

Owen, M. D. K., J. F. Lux, and D. D. Franzenburg. 1995a. Evaluation of CGA-277476, CGA-248757, and imazethapyr applied postemergence for weed control in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 52:292-293.

Owen, M. D. K., J. F. Lux, and D. D. Franzenburg. 1995b. Evaluation of chlorimuron plus thifensulfuron prepackage, AC 299,263, and other ALS inhibitor herbicides for weed control in sulfonylurea tolerant soybeans. North Cent. Weed Sci. Soc. Res. Rep. 52:284-285.

Owen, M. D. K., J. F. Lux, and D. D. Franzenburg. 1995c. Evaluation of sulfentrazone, cloransulam-methyl, imazethapyr, and imazaquin for weed control in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 52:280-281.

Owen, M. D. K., J. F. Lux, and D. D. Franzenburg. 1996a. Evaluation of AC 299,263 and imazethapyr for woolly cupgrass control in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 53:388.

Owen, M. D. K., J. F. Lux, and D. D. Franzenburg. 1996b. Evaluation of AC 299,263, imazethapyr, imazaquin, and chlorimuron applied postemergence to glyphosate-resistant and sensitive soybeans. North Cent. Weed Sci. Soc. Res. Rep. 53:320-321.

Owen, M. D. K., J. F. Lux, and D. D. Franzenburg. 1996c. Evaluation of BAY FOE 5043, sulfentrazone, and AC 299,263 for weed control in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 53:389.

Owen, M. D. K., J. F. Lux, and D. D. Franzenburg. 1996d. Evaluation of CGA-277476, lactofen, fomesafen, sulfentrazone, and F-6025 for control of ALS-resistant common waterhemp in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 53:364-367.

Patterson, M. G., R. H. Walker, D. L. Colvin, G. Wehtje, and J. A. McGuire. 1988. Comparison of soybean (*Glycine max*)--weed interference from large and small plots. Weed Sci. 36:836-839.

Penner, D. 1989. The impact of adjuvants on herbicide antagonism. Weed Technol. 3:227-231.

Peters, E. J., M. R. Gebhardt, and J. F. Stritzke. 1965. Interrelations of row spacings, cultivations and herbicides for weed control in soybeans. Weeds 13:285-289.

Peterson, D. E. and D. L. Regehr. 1995. Postemergence weed control in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 52:349-350.

Peterson, D. E. and D. L. Regehr. 1996. Control of ALS-resistant common waterhemp and other weeds in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 53:350-351.

Putnam, A. R. and D. Penner. 1974. Pesticide interactions in higher plants. Residue Review. 50:73-110.

Quakenbush, L. S., T. Malefyt, and C. L. Ortlip. 1994. AC 299,263: a new broad-spectrum imidazolinone herbicide for soybeans. Proc. North Cent. Weed Sci. Soc. 49:124-125.

Reed, J. P., F. R. Hall, and S. K. Rick. 1992. Influence of temperature and relative humidity on the performance of thifensulfuron with various surfactants. Pages 255-260 *in* Foy, C. L. ed. Adjuvants for Agrichemicals. CRC Press, Boca Raton, FL.

Rendina, A. R. and J. M. Felts. 1988. Cyclohexanedione herbicides are selective and potent inhibitors of acetyl-CoA carboxylase from grasses. Plant Physiol. 86:983-986.

Renner, K. A. and G. E. Powell. 1991. Response of sugarbeet (*Beta vulgaris*) to herbicide residues in soil. Weed Technol. 5:622-627.

Reynolds, D. B., T. G. Wheless, E. Basler, and D. S. Murray. 1988. Moisture stress effects on absorption and translocation of four foliar-applied herbicides. Weed Technol. 2:437-441.

Rhodes, Jr., G. N. and H. D. Coble. 1984a. Influence of bentazon on absorption and translocation of sethoxydim in goosegrass (*Eleusine indica*). Weed Sci. 32:595-597.

Rhodes, Jr., G. N. and H. D. Coble. 1984b. Influence of application variables on antagonism between sethoxydim and bentazon. Weed Sci. 32:436-441.

Richburg, III, J. S., J. W. Wilcut, and G. R. Wehtje. 1993. Toxicity of imazethapyr to purple (*Cyperus rotundus*) and yellow nutsedges (*C. esculentus*). Weed Technol. 7:900-905.

Ritter, R. L. and H. D. Coble. 1981a. Influence of temperature and relative humidity on the activity of acifluorfen. Weed Sci. 29:480-485.

Ritter, R. L. and H. D. Coble. 1981b. Penetration, translocation, and metabolism of acifluorfen in soybean (*Glycine max*), common ragweed (*Ambrosia artemisiifolia*), and common cocklebur (*Xanthium pensylvanicum*). Weed Sci. 29:474-480.

Ritter, R. L. and H. Menbere. 1997. Use of CGA-277476 in soybeans. Abstr. Weed Sci. Soc. Am. 37:1.

Sander, K. W., T. R. Dill, D. W. Kidder, and P. J. Porpiglia. 1995. Update on the herbicidal activity of CGA-277476 and CGA-248757 in soybeans in the midwest. Proc. North Cent. Weed Sci. Soc. 50:139-140.

Sasaki, Y., T. Konishi, and Y. Nagano. 1995. The compartmentation of acetyl-coenzyme A carboxylase in plants. Plant Physiol. 108:445-449.

Schloss, J. V. 1990. Acetolactate synthase, mechanism of action and its herbicide binding site. Pestic. Sci. 29:283-292.

Schmenk, R. E., M. Barrett, and W. W. Witt. 1996. Smooth pigweed (*Amaranthus hybridus* L.) resistance to acetolactate synthase inhibiting herbicides. Abstr. Weed Sci. Soc. Am. 36:9.

Schultz, M. E., D. L. Grant, V. B. Langston, and R. A. Dorich. 1996. Cloransulam-methyl performance when applied postemergence in U.S. soybeans. Abstr. Weed Sci. Soc. Am. 36:13.

Shaner, D. L. and N. M. Mallipudi. 1991. Mechanisms of selectivity of the imidazolinones. Pages 91-102 *in* Shaner, D. L. and S. L. O'Connor eds. The Imidazolinone Herbicides. CRC Press, Boco Raton, FL.

Shaw, D. R. and M. T. Wesley. 1993. Interacting effects on absorption and translocation from tank mixtures of ALS-inhibiting and diphenyl ether herbicides. Weed Technol. 7:693-698.

Sherman, T. D., J. M. Becerril, H. Matsumoto, M. V. Duke, J. M. Jacobs, N. J. Jacobs, and S. O. Duke. 1991. Physiological basis for differential sensitivities of plant species to protoporphyrinogen oxidase-inhibiting herbicides. Plant Physiol. 97:280-287.

Shibles, R. M. and C. R. Weber. 1966. Interception of solar radiation and dry matter production by various soybean planting patterns. Crop Sci. 6:55-59.

Simpson, D. M. and E. W. Stoller. 1996. Thifensulfuron and imazethapyr interaction at the ALS enzyme in sulfonylurea-tolerant soybean (*Glycine max*). Weed Sci. 44:763-768.

Smith, M. C., D. R. Shaw, A. C. Bennett, and E. P. Webster. 1997. Efficacy of cloransulam, CGA-277476, and CGA-248757 in Mississippi and Arkansas soybean. Abstr. Weed Sci. Soc. Am. 37:2.

Sorensen, V. M., W. F. Meggitt, and D. Penner. 1987. The interaction of acifluorfen and bentazon in herbicidal combinations. Weed Sci. 35:449-456.

Stolenberg, D. E., J. W. Gronwald, D. L. Wyse, J. D. Burton, D. A. Somers, and B G. Gengenbach. 1989. Effect of sethoxydim and haloxyfop on acetyl-coenzyme A carboxylase activity in *Festuca* species. Weed Sci. 37:512-516.

Stoller, E. W., S. K. Harrison, L. M. Wax, E. E. Regnier, and E. D. Nafziger. 1987. Weed interference in soybeans (*Glycine max*). Rev. Weed Sci. 3:155-181.

Sweat, J. K., M. J. Horak, and D. E. Peterson. 1995. Herbicide efficacy on four *Amaranthus* species in soybean. Proc. North Cent. Weed Sci. Soc. 50:41.

Taylor, H. M. 1980. Soybean growth and yield as affected by row spacing and by seasonal water supply. Agron. J. 72:543-547.

Thelen, K. 1994. Applying roundup in hard water. Crops & Soils. Michigan State University Cooperative Extension Service Newsletter, No. 209. 20:6-7.

Thelen, K. D., E. P. Jackson, and D. Penner. 1995. The basis for the hard-water antagonism of glyphosate activity. Weed Sci. 43:541-548.

Thompson, L. G., J. J. Velovitch, A. Haack, and R. A. Dorich. 1995. Tank-mix alternatives with cloransulam-methyl for postemergence control of common lambsquarters and pigweed species. Proc. North Cent. Weed Sci. Soc. 50:124.

Thompson, W. M., S. J. Nissen, and R. A. Masters. 1996. Adjuvant effects on imazethapyr, 2,4-D and picloram absorption by leafy spurge (*Euphorbia esula*). Weed Sci. 44:469-475.

United States Department of Agriculture. Agriculture Chemical Usage. Agricultural Statistics Board, NASS and ERS. March 1996. pp. 56-71.

Vidrine, P. R. 1989. Johnsongrass (*Sorghum halepense*) control in soybeans (*Glycine max*) with postemergence herbicides. Weed Technol. 3:455-458.

Wanamarta, G., J. J. Kells, and D. Penner. 1993. Overcoming antagonistic effects of Na-bentazon on sethoxydim absorption. Weed Technol. 7:322-325.

Wanamarta. G., D. Penner, and J. J. Kells. 1989. The basis of bentazon antagonism on sethoxydim absorption and activity. Weed Sci. 37:400-404.

Wax, L. M., S. E. Hart, and D. J. Maxwell. 1995. Sequential applications for weed control in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 52:294-297.

Wax, L. M., S. E. Hart, and D. J. Maxwell. 1996. Sequential applications for weed control in soybeans. North Cent. Weed Sci. Soc. Res. Rep. 53:416-418.

Wax, L. M. and J. W. Pendleton. 1968. Effect of row spacing on weed control in soybeans. Weed Sci. 16:462-465.

Weber, C. R. and D. W. Staniforth. 1957. Competitive relationships in variable weed and soybean stands. Agron. J. 49:440-444.

Wesley, M. T. and D. R. Shaw. 1992. Interactions of diphenyl ether herbicides with chlorimuron and imazaquin. Weed Tech. 6:345-351.

Westberg, D. E. and H. D. Coble. 1992. Effect of acifluorfen on the absorption, translocation, and metabolism of chlorimuron in certain weeds. Weed Technol. 1992. 6:4-12.

Whitwell, T., G. Wehtje, R. H. Walker, and J. A. McGuire. 1985. Johnsongrass (*Sorghum halepense*) control in soybeans (*Glycine max*) with postemergence grass herbicides applied alone and in mixtures. Weed Sci. 33:673-678.

Wichert, R. A. and R. E. Talbert. 1993. Soybean [*Glycine max* (L.)] response to lactofen. Weed Sci. 41:23-27.

Wichert, R. A., R. Bozsa, R. E. Talbert, and L. R. Oliver. 1992. Temperature and relative humidity effects on diphenyl ether herbicides. Weed Technol. 6:19-24.

Wilcut, J. W. 1991. Tropic Croton (*Croton glandulosus*) control in peanut (*Arachis hypogaea*). Weed Technol. 5:795-798.

Wilhm, J. L., W. F. Meggitt, and D. Penner. 1986. Effect of acifluorfen and bentazon on absorption and translocation of haloxyfop and DPX-Y6202 in quackgrass (*Agropyron repens*). Weed Sci. 34:333-337.

Young, B. G., S. E. Hart, and L. M. Wax. 1996. Interactions of sethoxydim and corn (*Zea mays*) broadleaf herbicides on three annual grasses. Weed Technol. 10:914-922.

Table 1: The ALS-inhibiting herbicides are classified by their chemical family and a description of their major use.

Chemical Family	Herbicide	Industrial or Major Crop Use
Imidazolinone	imazameth	peanuts
	imazamethabenz	cereal crops
	imazamox	soybeans
	imazapyr	industrial
	imazaquin	soybeans
	imazethapyr	soybeans
Triazolopyrimidine sulfonanilide	cloransulam-methyl	soybeans
	flumetsulam	soybeans, corn
Sulfonylurea	bensulfuron	rice
	chlorimuron	soybeans
	chlorsulfuron	cereal crops
	ethamethsulfuron	canola
	halosulfuron	corn
	metsulfuron	cereal crops, pastures
	nicosulfuron	corn
	oxasulfuron	soybeans
	primisulfuron	corn
	prosulfuron	corn
	rimsulfuron	corn
	sulfometuron	industrial
	sulfosulfuron	cereal crops
	thifensulfuron	soybeans
	triasulfuron	cereal crops
	tribenuron	cereal crops
	triflusulfuron	sugarbeet
Pyrimidinyl thiobenzoate	pyrithiobac	cotton

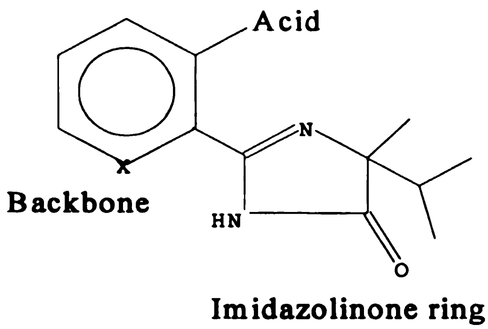

Figure 1. The imidazolinone skeleton consists of an acid, backbone, and imidazolinone ring. Imidazolinone ring termination or the conversion to an immobile structure, and alkyl hydroxylation followed by glucose conjugation are the primary mechanisms of metabolism.

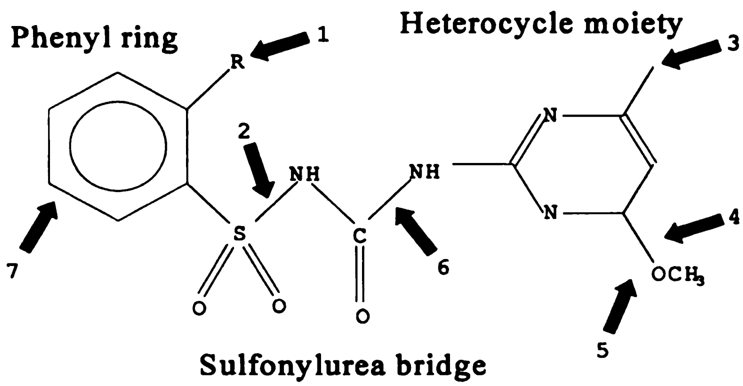

Figure 2. The sulfonylurea structure includeds a phenyl ring, sulfonylurea bridge, and heterocycle moeity. Metabolism of the sulfonylurea herbicides includes (1) de-esterification, (2 and 6) hydrolysis or cleavage of the bridge, (3) homoglutathione

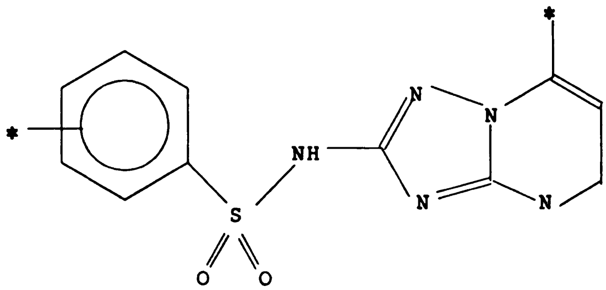

Figure 3. The triazolopyrimidine sulfonanilide herbicide skeleton. The triazolopyrimidine sulfonanilide herbicides are metabolized primarily through hydroxylation and subsequent glucose conjugation of the herbicide structure denoted with an asterisk.

CHAPTER 2

POSTEMERGENCE WEED CONTROL WITH OXASULFURON AND CLORANSULAM-METHYL IN SOYBEANS [*Glycine max* (L.) Merr][1]

Kelly A. Nelson and Karen A. Renner[2]

Abstract. Field and greenhouse experiments were conducted to evaluate postemergence soybean injury and weed control by oxasulfuron and cloransulam-methyl alone and in tank mixtures. Visual soybean injury was 12 to 14% from oxasulfuron and 9 to 13% from cloransulam-methyl 7 days after treatment in the field. Tank mixtures of either herbicide with acifluorfen or acifluorfen plus thifensulfuron were more injurious than oxasulfuron or cloransulam-methyl applied alone. Both oxasulfuron and cloransulam-methyl controlled velvetleaf, while cloransulam-methyl also controlled common ragweed. Adding acifluorfen to the spray solution enhanced common ragweed, common lambsquarters, redroot pigweed, and eastern black nightshade control with oxasulfuron and enhanced common lambsquarters, redroot pigweed, and eastern black nightshade control with cloransulam-methyl. Tank mixing thifensulfuron with oxasulfuron or cloransulam-methyl increased common lambsquarters and redroot pigweed control. In the greenhouse, oxasulfuron controlled velvetleaf at 20 g ai/ha and common ragweed

---

[1]Received for publication __________ and in revised form __________.

[2]Grad. Res. Asst. and Prof., Mich. State Univ., East Lansing, MI 48824-1325.

at 79 g/ha. The dry weight of common lambsquarters was reduced 60% by oxasulfuron at 79 g/ha. Cloransulam-methyl controlled velvetleaf at 4.4 g ai/ha and common ragweed at 8.8 g/ha. Chlorimuron reduced yellow nutsedge dry weight more than oxasulfuron or cloransulam-methyl. Oxasulfuron reduced giant foxtail control by clethodim, but not by quizalofop in the field. In the greenhouse, large crabgrass height was 42% greater when oxasulfuron was tank mixed with quizalofop compared to quizalofop alone. No reduction in johnsongrass or corn control was observed when oxasulfuron was tank mixed with quizalofop or clethodim. Grass antagonism by oxasulfuron was grass species and graminicide related. Cloransulam-methyl tank mixed with clethodim or quizalofop controlled giant foxtail.

Nomenclature: Acifluorfen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid; chlorimuron, 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid; clethodim, (*E*,*E*)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one; cloransulam-methyl, *N*-(2-carboxymethyl-6-chlorophenyl)-5-ethoxy-7-fluoro(1,2,4)triazolo-(1,5c)-pyrimidine-2-sulfonamide; oxasulfuron (CGA-277476), 2-[[[[(4,6-dimethyl-2-pyrimidinyl)-amino]carbonyl]amino]sulfonyl]benzoic acid, 3-oxetanyl ester; quizalofop, (±)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid; thifensulfuron, 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid; common lambsquarters, *Chenopodium album* L. #[3] CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; eastern black nightshade, *Solanum ptycanthum* Dun. # SOLPT; giant foxtail, *Setaria faberi* Herrm. # SETFA; johnsongrass, *Sorghum halepense* (L.) Pers. # SORHA; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; velvetleaf, *Abutilon theophrasti* Medik. # ABUTH; volunteer corn, *Zea mays* L. # ZEAMX; yellow nutsedge, *Cyperus esculentus* L. # CYPES; soybean, *Glycine max* (L.) Merr.

Additional index words: Herbicide antagonism, interaction, tank mixture.

[3]Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

INTRODUCTION

Oxasulfuron is a sulfonylurea herbicide for postemergence control of broadleaf and some grass weed species in soybeans (Anonymous 1995; Brooks et al. 1995; Kidder and Johnson 1997; Ritter and Menbere 1997). Cloransulam-methyl is a triazolopyrimidine sulfonanilide herbicide for preplant incorporated, preemergence, and postemergence broadleaf weed control in soybeans (Jachetta et al. 1995; Menbere and Ritter 1997; Oliver and Gander 1997).

Herbicide interactions have been described as synergistic, additive, or antagonistic (Hatzios and Penner 1985; Putnam and Penner 1974). Herbicides tank mixtures may enhance weed control (Green 1991; Monks et al. 1993; Sander et al. 1995), but they may increase soybean injury (Simpson and Stoller 1996; Thompson et al. 1995) or result in antagonism (Ditmarsen et al. 1997; Ritter and Menbere 1997; Wesley and Shaw 1992). Herbicides in the triazolopyrimidine sulfonanilide (Ditmarsen et al. 1997), imidazolinone (Bjelk and Monaco 1992; Croon and Merkle 1988), sulfonylurea (Ritter and Menbere 1997; Young et al. 1996), and pyrimidinyl thiobenzoate (Ferreira et al. 1995; Ferreira and Coble 1994; Jordan et al. 1993) families have antagonized the control of several grass species by the graminicides. Gerwick et al. (1988) postulated that this antagonism was based on a physiological interaction between the ALS[4]-inhibitors (E.C. 4.1.3.18) and graminicides. Tank mixtures with oxasulfuron or cloransulam-methyl have been evaluated for soybean injury and enhanced broadleaf weed control (Bauer et al. 1995;

---

[4]Abbreviation: ALS, acetolactate synthase (E.C. 4.1.3.18); UAN, 28% urea ammonium nitrate; NIS, nonionic surfactant; and DAT, days after treatment.

Kidder and Porpiglia 1996; Sander et al. 1995; Thompson et al. 1995). Graminicide antagonism by oxasulfuron was species and graminicide dependent (Kidder and Johnson 1997; Ritter and Menbere 1997). Ditmarsen et al. (1997) reported that cloransulam-methyl antagonized grass control by the aryloxyphenoxypropionate herbicides, but not the cyclohexanedione herbicides. Antagonistic mixtures are expensive with respect to reduced weed control, reduced crop yield, and increased weed seed production.

The objectives of this research were: to evaluate soybean injury and weed control from postemergence applications of oxasulfuron and cloransulam-methyl applied alone and in selected tank mixtures; to determine the sensitivity of various weed species to oxasulfuron and cloransulam-methyl; and to identify interactions of oxasulfuron with graminicides on selected monocot species.

MATERIALS AND METHODS

Field Experiments. Field experiments were conducted in 1995 and 1996 at the Michigan State University Research Farm at East Lansing, MI. The soil was a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) with 2.7% organic matter and a soil pH of 7.2 in 1995. This site was chisel plowed in the fall, and disked and field cultivated twice in the spring. In 1996, the soil was a Capac sandy clay loam with 3.4% organic matter and a soil pH of 7.8. This site was moldboard plowed in the fall and cultimulched twice in the spring.

'Conrad' soybeans were planted in 76 cm rows at 366,000 seeds per hectare in 1995 and 359,000 seeds per hectare in 1996 with a John Deere 7200 Max-Emerge®2 planter[5]. Plots were 3 meters wide and 9.1 meters long in 1995, and 3 meters wide and 12.2 meters long in 1996.

The weed control treatments included an untreated control, acifluorfen at 280 g ai/ha, thifensulfuron at 2.2 g ai/ha, and acifluorfen plus thifensulfuron which were each tank mixed with oxasulfuron at 79 g ai/ha and cloransulam-methyl at 17.5 g ai/ha (Table 2). Clethodim at 140 g ai/ha and quizalofop (1996 only) at 50 g ai/ha were included in the factorial design (Table 3). All herbicide treatments were applied with 2.6% (v/v) 28% urea ammonium nitrate (UAN)[4] and 0.25% (v/v) nonionic surfactant (NIS)[4,6].

---

[5]Deere and Co., 501 River Drive, Moline, IL 61265-1100.

[6]Nonionic surfactant was Activator-90, a mixture of alkyl polyoxyethylene ether and free fatty acids, from Loveland Industries, Inc., P.O. Box 1289, Greeley, CO 80632.

Herbicide applications were made with a tractor mounted compressed air sprayer traveling at 6.3 km/h and delivering 178 L/ha at 207 kPa of pressure on June 9, 1995 and June 23, 1996 (28 and 25 days after planting) at a standard postemergence timing. Treatments were made with 8003 flat-fan nozzles[7] on a 51 cm spacing at 48 cm above the crop and weed canopy. Air temperature was 22 C with 70 percent relative humidity in 1995, and 20 C with 62 percent relative humidity in 1996 at the time of application. Rainfall ten days prior to herbicide application was 3.1 cm in 1995 and 9.8 cm in 1996, while rainfall from one to ten days after herbicide application totaled 0.5 cm in 1995 and 0.7 cm of rain in 1996. Soybeans were at the V2 stage of development in 1995 and 1996. Weed heights, leaf number, and weed density are presented in Table 1.

Plots were evaluated for soybean injury at 3, 7, 14, and 21 days after treatment (DAT)[4]. Soybean injury was based on chlorosis, necrosis, and stunting. Injury is presented for 7 DAT. Weed control was evaluated at 7, 14, 21, and 56 DAT. Evaluations taken at 21 and 56 DAT were the most representative of herbicide effectiveness. Weed control was evaluated visually and as a percent reduction in dry weight. Visual ratings were based upon a scale of 0 (no effect) to 100 (weed or crop death) percent. Percent dry weight reduction was determined 21 DAT by harvesting the above ground plant matter of three common ragweed and three velvetleaf plants marked with plastic garden stakes[8] 1 day prior to herbicide application in each plot. Percent dry weight reduction was

---

[7]Teejet flat fan tips. Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.

[8]Pylon Plastics, Inc. 2111 Ogden Ave., P.O. Box 505, Lisle, IL 60532.

calculated as 100*[1-(plant dry weight/untreated plant dry weight)]. Giant foxtail was harvested from an 840 cm^2 quadrat. Weight per plant was first calculated and then the percent dry weight reduction was calculated as previously described.

General Methods for Greenhouse Experiments. Velvetleaf, common ragweed, yellow nutsedge, common lambsquarters, giant foxtail, johnsongrass, large crabgrass, and corn seeds were planted in BACCTO[9] potting soil in 946 ml plastic pots. Environmental conditions were maintained at 27 $\pm$ 5 C. Plants were grown in a 16 h photoperiod of natural and supplemental sodium vapor lighting that provided a photosynthetic photon flux density[10] of 120 $\mu E/m^2/s$. Midday photosynthetic photon flux density was approximately 1000 $\mu E/m^2/s$. Plants were fertilized with 0.1 g of water soluble fertilizer (20% N, 20% P_2O_2, 20% K_2O) and watered as needed.

Herbicide applications were made with a continuous belt-link sprayer traveling at 1.5 km/hr and equipped with an 8001[7] even flat fan nozzle calibrated to deliver 234 L/ha at 193 kPa of pressure. All treatments included 2.5% (v/v) UAN and 0.25% (v/v) NIS. The soil was moist and soil temperature was 26 $\pm$ 1 C at the time of herbicide application. Treatments were applied in the evening from 3:00 p.m. to dusk when the relative humidity was low (32 to 42%). Photosynthetic photon flux density was 110 to 400 $\mu E/m^2/s$ at the conclusion of the herbicide treatments. Percent dry weight reduction of the oven dried top plant growth was calculated as previously described.

[9]Baccto is a product of Michigan Peat Co. Houston, TX 77098.

[10]LI-COR. 4421 Superior Street, Lincoln, NE 68504.

Broadleaf weed sensitivity study. Velvetleaf, common ragweed, and common lambsquarters seed were purchased from V & J Seed Farms[11] and thinned to one plant per pot prior to herbicide application. Yellow nutsedge tubers were purchased from Valley Seed Service[12] and selected for plants with two shoots that arose from one tuber prior to herbicide application. Velvetleaf was 5 to 8 cm tall with three leaves, common ragweed was 3 to 5 cm tall with four to six leaves, yellow nutsedge was 10 cm tall with four to six leaves, and common lambsquarters were 3 to 5 cm tall with six leaves at the time of herbicide application. Plant top growth was harvested 28 DAT.

Velvetleaf, common ragweed, and yellow nutsedge were arranged in the experimental design described in the statistical protocol. Oxasulfuron and cloransulam-methyl were applied at three rates to velvetleaf and common ragweed (Table 4). In the yellow nutsedge study, chlorimuron was included as an ALS-inhibiting yellow nutsedge control treatment. Cloransulam-methyl was not included in the common lambsquarters experiment since no control was observed in the field; therefore, this study was arranged as a single-factor factorial experiment in a randomized complete block design. Thifensulfuron at 2.2 g ai/ha was included as an ALS-inhibiting common lambsquarters control treatment.

Giant foxtail antagonism study. Giant foxtail was thinned to ten plants per pot when plants reached 3 cm. At application, giant foxtail was 8 to 13 cm tall with four to six leaves. Plant top growth was harvested 21 DAT. Herbicide treatments consisted of an

---

[11]P.O. Box 82, Woodstock, IL 60098.

[12] P.O. Box 9335, Fresno, CA 93791.

untreated control, oxasulfuron, and four graminicides applied at three rates alone and in a tank mixture with oxasulfuron (Table 5). The mathematical method described by Colby (1967) was used to determine antagonistic interactions. An LSD at the 5% level was used to compare the observed and expected dry weight reduction.

Large crabgrass, johnsongrass, and corn interaction study. Seedling johnsongrass and large crabgrass were thinned to five plants were pot, and corn 'Pioneer 3573' was thinned to two plants per pot prior to herbicide application one and a half weeks after planting. Herbicides were applied to johnsongrass that was 13 to 15 cm tall and had four leaves, large crabgrass 5 to 8 cm tall with three leaves, and corn 15 cm tall at the two-collar growth stage. Johnsongrass and large crabgrass top growth was harvested 21 DAT while corn was harvested 14 DAT. Heights were measured by averaging the height of all the plants in the pot and oven dry weights were recorded. Percent height reduction was calculated as 100*[1-(plant height/untreated plant height)]. Herbicide treatments consisted of an untreated control, oxasulfuron, quizalofop, and clethodim applied alone and in a tank mixture with oxasulfuron (Table 6).

Statistical Protocol. All of the research was conducted as factorial experiments arranged in a randomized complete block design with four replications. An analysis of variance was conducted and experiments were combined over time. The percent data was transformed to the arc sine for an analysis of variance and means were separated with an LSD at the 5% level. Original means are reported. Soybean injury and common lambsquarters control in the field for 1995 and 1996 are presented separately due to interactions between years.

RESULTS AND DISCUSSION

Field Experiments. Soybean injury from oxasulfuron was 12 to 14%, and 9 to 13% from cloransulam-methyl alone 7 DAT (Table 2). Tank mixtures of acifluorfen or acifluorfen plus thifensulfuron with oxasulfuron or cloransulam-methyl injured soybeans more than oxasulfuron or cloransulam-methyl alone, but were no more injurious than acifluorfen or acifluorfen plus thifensulfuron alone. Thifensulfuron plus cloransulam-methyl caused more injury to soybeans than cloransulam-methyl or thifensulfuron alone in 1995, but no difference in soybean injury was detected in 1996. All treatments had less than 10% soybean injury by 14 DAT (data not presented).

Velvetleaf was controlled by oxasulfuron and cloransulam-methyl applied alone and with any tank mixture 21 DAT (Table 2). There was a 21% greater reduction in velvetleaf dry weight when cloransulam-methyl was tank mixed with thifensulfuron compared to thifensulfuron alone. Oxasulfuron reduced common ragweed dry weight 66%, and tank mixtures with acifluorfen reduced common ragweed dry weights by 98% 21 DAT. Common ragweed dry weight was reduced more when oxasulfuron was tank mixed with thifensulfuron compared to oxasulfuron and thifensulfuron applied alone. Common ragweed was controlled by cloransulam-methyl.

Common lambsquarters control by oxasulfuron alone was 81% in 1995 and 70% in 1996 21 DAT (Table 2). All tank mixtures containing oxasulfuron provided greater control of common lambsquarters than oxasulfuron alone except oxasulfuron plus acifluorfen in 1996 (Table 2). Cloransulam-methyl did not control common lambsquarters alone, but tank mixing cloransulam-methyl with thifensulfuron controlled common lambsquarters. Acifluorfen, thifensulfuron, and acifluorfen plus thifensulfuron tank mixtures provided greater control of redroot pigweed than oxasulfuron or cloransulam-methyl alone 21 or 56 DAT in 1996. Redroot pigweed control from oxasulfuron decreased by 56 DAT due to regrowth. Eastern black nightshade was not controlled by oxasulfuron or cloransulam-methyl, and required acifluorfen for adequate control (data not shown).

Oxasulfuron reduced giant foxtail dry weight by 46% 21 DAT (Table 3). Tank mixing oxasulfuron or cloransulam-methyl with clethodim did not affect giant foxtail dry weight reduction compared to clethodim alone 21 DAT. However by 56 DAT, giant foxtail regrew and control was 36 to 49% less when oxasulfuron was tank mixed with clethodim compared to clethodim applied alone. Ritter and Menbere (1997) also reported that giant foxtail control by clethodim was antagonized by oxasulfuron. In 1996, giant foxtail control by oxasulfuron tank mixed with quizalofop 56 DAT was similar to quizalofop applied alone. Tank mixtures of cloransulam-methyl with clethodim or quizalofop controlled giant foxtail.

Broadleaf weed sensitivity study. Velvetleaf was controlled by oxasulfuron and cloransulam-methyl at 25% of the recommended field use rate (Table 4). Common ragweed regrowth from the lateral and axillary buds was observed following the application of oxasulfuron at 20 and 40 g/ha. Ideal growing conditions and smaller common ragweed may have improved common ragweed control by oxasulfuron compared to field experiments. Cloransulam-methyl at 8.8 and 17.5 g/ha reduced common ragweed dry weight 94 and 96%, respectively. Regrowth from the lateral and axillary buds was observed only at the 4.4 g/ha rate. Chlorimuron reduced yellow nutsedge dry weights more than oxasulfuron or cloransulam-methyl. Applications of cloransulam-methyl caused crinkling of the newly emerging yellow nutsedge leaves (personal observation 3 to 7 DAT). Susceptibility of yellow nutsedge to cloransulam-methyl or oxasulfuron has not been previously reported. Thifensulfuron reduced common lambsquarters dry weight 22% more than oxasulfuron at 79 g/ha. Common lambsquarters regrew from axillary buds and numerous narrow leaves formed following the application of oxasulfuron at 70 g/ha (personal observation).

Giant foxtail antagonism. All rates of quizalofop, sethoxydim, fluazifop, and clethodim controlled giant foxtail (Table 5). Oxasulfuron reduced giant foxtail dry weight by 26%. Giant foxtail control was antagonized when oxasulfuron was tank mixed with any graminicide regardless of the graminicide application rate according to Colby's method. Quizalofop was not antagonized by oxasulfuron to the extent that sethoxydim, fluazifop, or clethodim were antagonized. Giant foxtail regrowth in the form of new tillers or continued apical meristmatic growth was not observed in the tank mixture treatments, but the grass did not die.

Large crabgrass, johnsongrass, and corn interaction study. Oxasulfuron reduced seedling johnsongrass height and dry weight by 80% and 91%, respectively (Table 6). Quizalofop or clethodim alone or tank mixed with oxasulfuron controlled johnsongrass. Oxasulfuron had limited activity on large crabgrass. However, when oxasulfuron was tank mixed with quizalofop or clethodim, large crabgrass height increased compared to quizalofop or clethodim applied alone. Large crabgrass dry weights were reduced more by quizalofop alone than quizalofop tank mixed with oxasulfuron. Large crabgrass tillered and regrew when oxasulfuron was tank mixed with quizalofop (personal observation). Oxasulfuron reduced corn height by 65% and dry weight by 75%. Control of corn by quizalofop and clethodim was not inhibited when oxasulfuron was tank mixed.

Our research indicated that tank mixtures with oxasulfuron or cloransulam-methyl were required for enhanced grass and broadleaf weed control. Grass antagonism was species and herbicide dependent. Grass species and herbicide selection should be carefully evaluated before tank mixing an ALS-inhibiting herbicide with a graminicide. None of the postemergence treatments evaluated adequately controlled both grass and broadleaf weeds. A preemergence acetanilide application followed by postemergence application of oxasulfuron or cloransulam-methyl offer broadspectrum weed control (Bauer et al. 1996; Kidder and Johnson 1997; Schultz et al. 1995). Further investigations should evaluate three-way postemergence tank mixtures for broad spectrum weed control.

LITERATURE CITED

Anonymous. 1995. CGA-277476 herbicide. Technical information bulletin. Ciba Crop Protection, Greensboro, NC. 4 p.

Bauer, T. A., S. W. Pruss, T. R. Dill, and D. Kidder. 1996. Sequential soybean herbicide programs including CGA-277476. Proc. North Cent. Weed Sci. Soc. 51:in press.

Bauer, T., T. Threewitt, L. Stahlberg, A. Moses, K. Jones, D. Kidder, and P. Porpiglia. 1995. Weed management programs in soybeans with CGA-277476. Proc. North Cent. Weed Sci. Soc. 50:140.

Bjelk, L. A. and T. J. Monaco. 1992. Effect of chlorimuron and quizalofop on fatty acid biosynthesis. Weed Sci. 40:1-6.

Brooks, R. L, P. J. Porpiglia, J. W. Peek, W. Meyer, K. Gutbrod, and H. Gut. 1995. CGA-277476, a new postemergence herbicide for soybeans. Abstr. Weed Sci. Soc. Am. 35:8.

Colby, S. R. 1967. Calculating synergistic and antagonistic responses of herbicide combinations. Weeds 15:20-22.

Croon, K. A. and M. G. Merkle. 1988. Effects of bentazon, imazaquin, or chlorimuron on haloxyfop or fluazifop-P efficacy. Weed Technol. 2:36-40.

Ditmarsen, S. C., R. A. Dorich, L. B. Rowland, and M. E. Schultz. 1997. Efficacy and antagonism of tank mixtures of cloransulam-methyl with postemergence graminicides in soybeans. Abstr. Weed Sci. Soc. Am. 37:3.

Ferreira, K. L., J. D. Burton, and H. D. Coble. 1995. Physiological basis for antagonism of fluazifop-P by DPX-PE350. Weed Sci. 43:184-191.

Ferreira, K. L. and H. D. Coble. 1994. Effect of DPX-PE350 on the efficacy of graminicides. Weed Sci. 42:222-226.

Gerwick, B. C., P. Thompson, and R. Noveroske. 1988. Potential mechanisms in antagonism with aryloxyphenoxypropionate herbicides. Abstr. Weed Sci. Soc. Am. 28:100.

Green, J. M. 1991. Maximizing herbicide efficiency with mixtures and expert systems. Weed Technol. 5:894-897.

Hatzios, K. K., and D. Penner. 1985. Interactions of herbicides with other agrochemicals in higher plants. Rev. Weed Sci. 1:1-63.

Jachetta, J. J., J. C. Van Heertum, and B. C. Gerwick. 1995. Cloransulam-methyl: a new herbicide for soybeans. Abstr. Weed Sci. Soc. Am. 35:8.

Jordan, D. L., R. E. Frans, and M. R. McClelland. 1993. Interactions of DPX-PE350 with fluazifop-P, sethoxydim, clethodim, and quizalofop-P. Weed Technol. 7:605-610.

Kidder, D. and M. D. Johnson. 1997. Grass control in soybeans with CGA-277476; alone, in sequential, and in tankmix programs. Abstr. Weed Sci. Soc. Am. 37:1.

Kidder, D. W. and P. J. Porpiglia. 1996. CGA-277476 and CGA-248757 for broad spectrum, postemergence weed control in soybeans. Abstr. Weed Sci. Soc. Am. 36:12.

Menbere, H. and R. L. Ritter. 1997. Use of cloransulam-methyl in soybeans. Abstr. Weed Sci. Soc. Am. 37:2.

Monks, C. D., J. W. Wilcut, and J. S. Richburg, III. 1993. Broadleaf weed control in soybean (*Glycine max*) with chlorimuron plus acifluorfen or thifensulfuron mixtures. Weed Technol. 7:317-321.

Oliver, L. R. and J. R. Gander. 1997. Morningglory spectrum for cloransulam (FirstRate). Abstr. Weed Sci. Soc. Am. 37:2.

Putnam, A. R. and D. Penner. 1974. Pesticide interactions in higher plants. Residue Review. 50:73-110.

Ritter, R. L. and H. Menbere. 1997. Use of CGA-277476 in soybeans. Abstr. Weed Sci. Soc. Am. 37:1.

Sander, K. W., T. R. Dill, D. W. Kidder, and P. J. Porpiglia. 1995. Update on the herbicidal activity of CGA-277476 and CGA-248757 in soybeans in the midwest. Proc. North Cent. Weed Sci. Soc. 50:139-140.

Schultz, M. E., D. L. Grant, V. B. Langston, and R. A. Dorich. 1995. Cloransulam-methyl performance when applied postemergence in U.S. soybeans. Abstr. Weed Sci. Soc. Am. 36:13.

Simpson, D. M. and E. W. Stoller. 1996. Thifensulfuron and imazethapyr interaction at the ALS enzyme in sulfonylurea-tolerant soybean (*Glycine max*). Weed Sci. 44:763-768.

Thompson, L. G., J. J. Velovitch, A. Haack, and R. A. Dorich. 1995. Tank-mix alternatives with cloransulam-methyl for postemergence control of common lambsquarters and pigweed species. Proc. North Cent. Weed Sci. Soc. 50:124.

Wesley, M. T. and D. R. Shaw. 1992. Interactions of diphenyl ether herbicides with chlorimuron and imazaquin. Weed Tech. 6:345-351.

Young, B. G., S. E. Hart, and L. M. Wax. 1996. Interactions of sethoxydim and corn (*Zea mays*) broadleaf herbicides on three annual grasses. Weed Technol. 10:914-922.

Table 1. Weed height and leaf number at the time of application for field experiments conducted in 1995 and 1996.

Weed Species	----------1995---------- height	leaf	----------1996---------- height	leaf
	cm	number	cm	number
Giant foxtail	3-8	3	3-8	3
Velvetleaf	3-5	1-3	3-5	1-3
Common ragweed	3-6	4-6	3-6	4-6
Common lambsquarters	3-4	4-6	3-4	4-6
Redroot pigweed	---	---	3-4	2-5
Eastern black nightshade	---	---	1-2	cot[a]-2

Table 2. Broadleaf weed control in the field with oxasulfuron and cloransulam-methyl alone and with selected tank mixtures.[a]

		Soybean		ABUTH[b,c]	AMBEL[c]	CHEAL	CHEAL	AMARE	AMARE
		-----7 DAT-----		---21 DAT---					56 DAT
		----- Injury -----		Dry weight reduction		----- Control -----			
Treatment[d]	Rate	1995	1996			1995	1996	1996	1996
	g ai/ha	%							
Oxasulfuron	79	14 b	12 b	82 de	66 fg	81 c	70 cd	89 b	68 b
Oxasulfuron + acifluorfen	79 + 280	29 a	24 a	94 a-c	98 a-c	94 a	83 a-c	99 a	99 a
Oxasulfuron + thifensulfuron	79 + 2.2	16 b	14 b	89 a-d	86 de	92 ab	89 a	99 a	99 a
Oxasulfuron + acifluorfen + thifensulfuron	79 + 280 + 2.2	28 a	23 a	95 ab	98 ab	94 a	87 ab	99 a	99 a
Cloransulam	17.5	9 c	13 b	82 c-e	92 b-e	0 d	18 e	56 c	55 b
Cloransulam + acifluorfen	17.5 + 280	27 a	22 a	93 a-c	99 ab	94 a	55 d	99 a	99 a
Cloransulam + thifensulfuron	17.5 + 2.2	16 b	16 b	93 a-d	79 ef	90 a-c	93 a	99 a	99 a
Cloransulam + acifluorfen + thifensulfuron	17.5 + 280 + 2.2	29 a	23 a	97 a	99 a	94 a	73 b-d	99 a	99 a
Acifluorfen	280	26 a	23 a	89 a-d	98 ab	82 c	69 cd	96 a	96 a
Thifensulfuron	2.2	0 d	12 b	72 e	57 g	83 bc	94 a	98 a	99 a
Acifluorfen + thifensulfuron	280 + 2.2	26 a	22 a	82 b-e	95 a-d	86 bc	92 a	97 a	99 a

[a]Data was combined over location except when denoted with the year above the column. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]Abbreviations: ABUTH, velvetleaf; AMARE, redroot pigweed; AMBEL, common ragweed; CHEAL, common lambsquarters; Cloransulam, cloransulam-methyl; DAT, days after treatment.
[c]Data was combined for 1995 and 1996.
[d]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) urea ammonium nitrate.

Table 3. Giant foxtail control by oxasulfuron and cloransulam-methyl alone and tank mixed with clethodim and quizalofop.

		21 DAT[a]	1995	1996
Treatment[b]	Rate	Dry weight reduction[c]	Control 56 DAT	Control 56 DAT
	g ai/ha	%		
Clethodim	140	87 a	99 a	99 a
Quizalofop	50	-----	-----	96 a
Oxasulfuron	79	46 b	13 c	25 c
Oxasulfuron + clethodim	79 + 140	79 a	50 b	63 b
Oxasulfuron + quizalofop	79 + 50	-----	-----	86 a
Cloransulam	17.5	0 c	7 d	11 c
Cloransulam + clethodim	17.5 +140	84 a	96 a	99 a
Cloransulam + quizalofop	17.5 + 50	-----	-----	96 a

[a]Abbreviations: Cloransulam, cloransulam-methyl; DAT, days after treatment.
[b]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) urea ammonium nitrate. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[c]Data was combined over 1995 and 1996.

Table 4. Weed control by oxasulfuron and cloransulam-methyl in greenhouse experiments 28 days after treatment.

Treatment[a]	Rate	ABUTH[b]	AMBEL	CYPES	CHEAL
	g ai/ha	------------- % Dry weight reduction -------------			
Oxasulfuron	20	98	69 c	21 de	37 c
	40	98	81 b	10 e	59 b
	79	98	93 a	38 cd	60 b
Cloransulam	4.4	97	84 b	18 e	----
	8.8	98	94 a	19 e	----
	17.5	98	96 a	50 bc	----
Chlorimuron	13.5	----	----	94 a	----
Thifensulfuron	2.2	----	----	----	82 a

[a]All treatments included 0.25% (v/v) nonionic surfactant and 2.5% (v/v) urea ammonium nitrate. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]Abbreviations: ABUTH, velvetleaf; AMARE, redroot pigweed; AMBEL, common ragweed; CHEAL, common lambsquarters; Cloransulam, cloransulam-methyl; CYPES, yellow nutsedge; DAT, days after treatment.

Table 5. Giant foxtail control by oxasulfuron alone and tank mixed with graminicides 21 days after treatment.

		None	Oxasulfuron	
Treatment[a]	Rate	0	79	
	g ai/ha	----------% Dry weight reduction[b]----------		
None	0	0 j	26 i	
Quizalofop	25	87 ab	82 d-g	*(90)
	50	89 a	84 c-e	*(92)
	100	89 a	86 b-d	**(92)
Sethoxydim	107	86 a-c	79 gh	*(90)
	213	86 a-c	79 e-h	*(90)
	426	88 ab	83 d-f	*(91)
Fluazifop	93	85 b-d	79 h	*(89)
	186	89 a	80 f-h	*(92)
	358	88 ab	80 f-h	*(91)
Clethodim	71	87 a-c	78 h	*(90)
	140	88 ab	77 h	*(91)
	280	88 ab	80 f-h	*(91)

[a]All treatments included 0.25% (v/v) nonionic surfactant and 2.5% (v/v) urea ammonium nitrate. Means followed by a common letter are not significantly different with an LSD at the 5% level.

[b] Comparisons between columns are valid. Values in parentheses are the calculated expected dry weight reduction for the herbicide tank mixture. A single asterisk indicates a significant antagonistic tank mixture, while two asterisks indicate actual control that was not significantly different from the graminicide applied alone.

Table 6. Johnsongrass, large crabgrass, and corn control by oxasulfuron, quizalofop, and clethodim alone and in tank mixtures.

		Johnsongrass[a]		Large crabgrass		Corn	
Treatment[b]	Rate	Height reduction	Dry weight reduction	Height reduction	Dry weight reduction	Height reduction	Dry weight reduction
	g ai/ha	%					
None	0	0 d	0 c	0 d	0 d	0 c	0 c
Oxasulfuron	79	80 c	91 b	0 d	27 c	65 b	75 b
Quizalofop	50	100 a	94 a	100 a	98 a	100 a	88 a
Oxasulfuron + quizalofop	79 + 50	100 a	93 ab	58 c	88 b	100 a	84 a
Clethodim	140	100 a	94 a	100 a	98 a	100 a	88 a
Oxasulfuron + clethodim	79 + 140	99 b	92 b	84 b	96 a	100 a	85 a

[a]Abbreviation: DAT, days after treatment.

[b]All treatments included 0.25% (v/v) nonionic surfactant and 2.5% (v/v) 28% urea ammonium nitrate. Means followed by a common letter are not significantly different with an LSD at the 5% level.

CHAPTER 3

WEED CONTROL IN SOYBEAN [*Glycine max* (L.) Merr] WITH IMAZAMOX AND IMAZETHAPYR[1]

Kelly A. Nelson, Karen A. Renner, and Donald Penner[2]

Abstract. Field and greenhouse experiments were conducted in 1995 and 1996 to determine soybean response and weed control from imazamox and imazethapyr applied alone and with selected tank mixtures applied postemergence. Imazamox injured soybean more than imazethapyr in the greenhouse, but not in the field. Applying a methylated seed oil with imazamox or imazethapyr increased soybean injury and weed control compared to the use of a nonionic surfactant. Imazethapyr provided greater yellow nutsedge control than imazamox, while imazamox provided greater control of common lambsquarters than imazethapyr in the field and greenhouse. Common lambsquarters control by imazamox was reduced when lactofen was tank mixed with imazamox in the field. Tank mixing thifensulfuron with imazethapyr increased common lambsquarters control; however, soybean response increased when thifensulfuron was tank mixed with imazamox or imazethapyr. Wild mustard, velvetleaf, redroot pigweed, and common chickweed were controlled by imazamox and imazethapyr in the field.

---

[1]Received for publication __________ and in revised form __________.

[2]Grad. Res. Asst., Prof., and Prof., Mich. State Univ., East Lansing, MI 48824-1325.

Common ragweed dry weight was reduced 61 to 64% from imazamox at 35 g ai/ha and imazethapyr at 70 g ai/ha in the field; however, imazamox provided greater common ragweed control than imazethapyr in the greenhouse. Tank mixtures of lactofen with imazamox or imazethapyr increased common ragweed control and resulted in greater soybean seed yield than when imazamox and imazethapyr were applied alone; however, tank mixtures of lactofen, acifluorfen, or fomesafen with imazamox and imazethapyr reduced giant foxtail control in the greenhouse and field. Giant foxtail control was antagonized more when diphenyl ether herbicides were tank mixed with imazethapyr than imazamox. Imazamox reduced giant foxtail dry weight more than imazethapyr in greenhouse studies, and adding urea ammonium nitrate with nonionic surfactant to imazamox or imazethapyr increased giant foxtail control and reduced tillering. Both herbicides antagonized giant foxtail control by clethodim in the greenhouse and in the field in 1995, but imazethapyr was more antagonistic than imazamox in the greenhouse.

Nomenclature: Acifluorfen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid; chlorimuron, 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid; clethodim, (*E,E*)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one; fomesafen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide; imazamox, 2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-5-(methoxymethyl) nicotinic acid; imazethapyr, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid; lactofen, (±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]2-

nitrobenzoate; thifensulfuron, 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid; common chickweed, *Stellaria media* (L.) Vill. #[3] STEME; common lambsquarters, *Chenopodium album* L. # CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; eastern black nightshade, *Solanum ptycanthum* Dun. # SOLPT; giant foxtail, *Setaria faberi* Herrm. # SETFA; wild mustard, *Sinapis arvensis* L. # SINAR; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; velvetleaf, *Abutilon theophrasti* Medik. # ABUTH; yellow nutsedge, *Cyperus esculentus* L. # CYPES; soybean, *Glycine max* (L.) Merr.

Additional index words: Adjuvant, antagonism, herbicide interaction, tank mixture.

---

[3]Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

INTRODUCTION

Imazamox and imazethapyr are imidazolinone herbicides used for postemergence grass and broadleaf weed control in soybeans. These herbicides inhibit acetolactate synthase (ALS)[4] which is essential for leucine, valine, and isoleucine synthesis (Anonymous; Anonymous 1995). The replacement of the ethyl substituent on the pyridine carboxylic acid ring of imazethapyr with a methoxymethyl characterizes the only chemical structure difference between imazamox and imazethapyr. The recommended use rate for imazamox is 35 to 45 g ai/ha compared to 70 g ai/ha for imazethapyr (Anonymous; Anonymous 1995).

There are numerous postemergence herbicide tank mixtures available to soybean producers. Tank mixture decisions depend primarily on weed pressure, weed species and size, resistance management strategies, rotational crop restrictions, interactions between herbicides, and cost effectiveness. Interactions between herbicides in a tank mixture have been classified as additive, synergistic, or antagonistic (Hatzios and Penner 1985; Putnam and Penner 1974). Thifensulfuron has been tank mixed with several herbicides to enhance common lambsquarters control (Green 1991; Monks et al. 1993), while the diphenyl ether herbicides have been tankmixed with similar herbicides to control common ragweed (Leif and Taylor 1993; Monks et al. 1993; Wilcut 1991) and ALS-resistant weeds (Gaeddert et al. 1996) in soybeans. However, tank mixtures may increase

---

[4]Abbreviations: ALS, acetolactate synthase (E.C. 4.1.3.18); MSO, methylated seed oil; NIS, nonionic surfactant; and UAN, 28% urea ammonium nitrate; DAT, days after treatment; WAT, weeks after treatment.

soybean injury (Simpson and Stoller 1996) or antagonize weed control by one or more of the herbicides in the mixture.

Adjuvants have been utilized in herbicide tank mixtures to reduce antagonism (Gerwick et al. 1990; Hart et al. 1992; Wanamarta et al. 1993) and increase weed control (Gednalski et al. 1995; Gronwald et al. 1993; Nalewaja et al. 1990). Adjuvants enhance herbicide absorption by increasing spray retention and foliar penetration (Gronwald et al. 1993; Penner 1989). Foy and Witt (1993) reported that soybean injury increased when adjuvants were applied with imazethapyr. Hager and Renner (1994) increased common ragweed control in the greenhouse by adding 28% urea ammonium nitrate (UAN)[4] to imazethapyr plus a nonionic surfactant (NIS)[4] or petroleum oil adjuvant. Kochia [*Kochia scoparia* (L.) Schrad.] control by imazethapyr (Nalewaja et al. 1990); giant foxtail control by primisulfuron (Hart et al. 1992); and weed control by imazethapyr (Ogg et al. 1988) or imazamox (Gednalski et al. 1995) was increased with a methylated seed oil (MSO)[4] compared to a NIS. Thompson et al. (1996) reported increased ^{14}C-imazethapyr absorption by leafy spurge (*Euphorbia esula* L.) when a methylated seed oil was applied instead of a nonionic surfactant with or without UAN. Hart et al. (1992) enhanced ^{14}C-primisulfuron absorption by giant foxtail and had less tank mixture antagonism when a MSO was included.

Several researchers have reported graminicide antagonism by the ALS-inhibiting herbicides. Imazethapyr antagonized giant foxtail control by sethoxydim (2-[1-ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) (Cantwell et al. 1989), broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash] control by fluazifop ((±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) and sethoxydim, and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] and fall panicum (*Panicum dichotomiflorum* Michx.) control by fluazifop, clethodim, quizalofop ((±)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid), and sethoxydim (Myers and Coble 1992). Grass antagonism by the ALS-inhibitors was greatest when plants were water stressed and not actively growing (Croon and Merkle 1988; Myers and Coble 1992; Vidrine 1989).

Giant foxtail control by imazethapyr has been antagonized by acifluorfen (Cantwell et al. 1989). Similarly, the diphenyl ether herbicides have antagonized grass control by the acetyl CoA carboxylase (ACCase) inhibitors by reducing absorption (Godley and Kitchen 1986; Holshouser and Coble 1990; Minton et al. 1989; Vidrine 1989; Whitwell et al. 1985).

Sodium cations have reduced herbicide absorption similar to bentazon (3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide) tank mixtures (Bauer et al. 1995; Wanamarta et al. 1989). Cantwell et al. (1989) reported that bentazon and acifluorfen tank mixed with imazethapyr reduced giant foxtail and smooth pigweed (*Amaranthus hybridus* L.) control. Since acifluorfen and fomesafen are formulated as sodium salts similar to bentazon, the presence of sodium cations could explain the giant foxtail antagonism reported by Cantwell et al. (1989).

Herbicide antagonism is detrimental to effective and efficient postemergence weed management. Imazamox offers an additional option for postemergence grass and broadleaf weed control for producers whose choices are limited by rotational crop restrictions (Lueschen et al. 1997). Imazamox has broadspectrum activity that may not require a herbicide tank mixture. The objectives of this research were: to evaluate postemergence applications of imazamox and imazethapyr alone and with selected tank mixtures for soybean injury and weed control; to determine soybean and weed sensitivity to imazamox and imazethapyr; to determine the influence of adjuvants on soybean injury and weed control; and to evaluate giant foxtail antagonism with imazamox and imazethapyr tank mixtures.

MATERIALS AND METHODS

Field Experiments. A field experiment was conducted in 1995 and 1996 at the Michigan State University Research Farm at East Lansing, MI on a Capac sandy clay loam (fine-loamy, mixed mesic Aeric Ochraqualfs) soil with 2.7% organic matter in 1995 and 2.4% organic matter in 1996. The soil pH was 6.6 in 1995 and 7.9 in 1996. The 1995 site was fall chisel plowed as well as cultimulched and field cultivated in the spring, while the 1996 site was disked in the fall and cultimulched twice in the spring.

'Conrad' soybeans were planted in 76 cm rows at 341,000 seeds/ha in 1995 and 395,000 seeds/ha in 1996 with a John Deere 7200 Max-Emerge® 2[5] planter. The plots were 3 m wide and 9.1 m long in 1995, and 3 m wide and 12.2 m long in 1996.

Herbicide treatments included an untreated control, imazamox at 35 g ai/ha, and imazethapyr at 70 g ai/ha. Each of these treatments were applied alone and also in a tank mixed with clethodim at 140 g ai/ha, lactofen at 70 g ai/ha, thifensulfuron at 2.2 g ai/ha, and lactofen plus thifensulfuron (Table 2). Acifluorfen at 280 g ai/ha and fomesafen at 140 g ai/ha were included in the factorial design in 1996 to compare weed control when imazamox and imazethapyr were tank mixed with each of the three diphenyl ether herbicides (Table 8). All treatments were applied with 2.6% (v/v) UAN and 0.25% (v/v) NIS.[6]

---

[5]Deere and Co., 501 River Drive, Moline, IL 61265-1100.

[6]Nonionic surfactant was Activator-90, a mixture of alkyl polyoxyethylene ether and free fatty acids, Loveland Industries Inc., P.O. Box 1289, Greeley, CO 80632.

Herbicides were applied at a standard postemergence timing on June 9, 1995 and June 12, 1996 (29 and 26 days after planting) with a tractor mounted compressed air sprayer traveling at 6.3 km/h and delivering 178 L/ha at 207 kPa of pressure. Treatments were applied with 8003 flat fan nozzles[7] on a 51 cm spacing at 48 cm above the weed and crop canopy. At the time of herbicide application, the air temperature was 14 C with 80% relative humidity in 1995, and 27 C with 70% relative humidity in 1996. Rainfall 10 days prior to herbicide application was 0.5 cm in 1995 and 3.6 cm in 1996, while rainfall from 1 to 10 days after herbicide application totaled 0.5 cm in 1995 and 9.8 cm in 1996. Soybeans were at the V1 to V2 stage of development in 1995 and 1996. Weed heights and leaf number at the time of application are presented in Table 1.

Soybean injury was evaluated at 3, 7, 14, and 21 days after treatment (DAT)[4]. Soybean injury evaluation was based on chlorosis, necrosis, and stunting. Injury values are presented for 7 and 14 DAT. Weed control was evaluated 7, 14, 21, 28, and 56 DAT. Evaluations taken at 21, 28, and 56 DAT were most representative of herbicide effectiveness. Weed control was visually evaluated and measured as a percent reduction in dry weight. Visual ratings were based upon a scale of 0 (no effect) to 100 (complete weed or crop death) percent. Percent dry weight reduction was determined 21 DAT by harvesting the above ground plant matter of three common ragweed and three common lambsquarters plants that were marked in each plot with plastic garden stakes[8] prior to the

---

[7]Teejet flat fan tips. Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.

[8]Pylon Plastics, Inc. 2111 Ogden Ave., P.O. Box 505, Lisle, IL 60532.

herbicide application. Percent dry weight reduction was calculated as 100*[1-(plant dry weight/untreated plant dry weight)]. Yellow nutsedge control was evaluated 8 weeks after treatment (WAT)[4] in 1995 and again 56 WAT in July of 1996. Other weeds were controlled in 1996 with postemergence applications of glyphosate (*N*-(phosphonomethyl)glycine) at 840 g/ha plus 2100 g/L ammonium sulfate and 0.5% (v/v) NIS on May 2, 1996, glyphosate at 840 g/ha plus pyrazon (5-amino-4-chloro-2-phenyl-3(2*H*)-pyridazinone) at 3360 g/ha and diethatyl (*N*-(chloroacetyl)-*N*-(2,6-diethylphenyl)glycine) at 3360 g/ha on May 20, 1996, clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) at 420 g/ha on June 3, 1996, and quizalofop ((±)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid) at 49 g/ha plus crop oil concentrate[9] at 1.0% (v/v). Since no two-way interaction was observed and the effect of tank mix partners was not significant for yellow nutsedge control data, the data was averaged over these factors for the evaluation of imazamox, imazethapyr, and tank mix partners applied alone. The center two soybean rows were harvested in each plot with a Massey 10[10] small plot combine and moisture adjusted to 13%.

General Methods for Greenhouse Experiments. Yellow nutsedge tubers, common ragweed, common lambsquarters, velvetleaf, and giant foxtail seeds were planted in BACCTO[11] potting soil in 946 ml plastic pots. Environmental conditions were maintained at 27 ± 5 C. Weeds were grown in a 16 h photoperiod of natural and

---

[9]Crop oil concentrate was Herbimax, 83% petroleum oil and 17% surfactant, Loveland Industries Inc., P.O. Box 1289, Greeley, CO 80632.

[10]Kincaid Equipment Manufacturing. P.O. Box 400, Haven, KS 47543.

[11]Baccto is a product of Michigan Peat Co. Houston, TX 77098.

supplemental sodium vapor lighting that provided a photosynthetic photon flux density[12] of 120 μE/m^2/s. Midday photosynthetic photon flux density was approximately 1000 μE/m^2/s. Plants were fertilized with 0.1 g of water soluble fertilizer (20% N, 20% P_2O_2, 20% K_2O) and watered as needed.

Herbicide applications were made with a continuous belt-link sprayer traveling at 1.5 km/hr and equipped with an 8001 even flat fan nozzle[7] calibrated to deliver 234 L/ha at 193 kPa of pressure. All treatments were replicated four times and repeated in time. The soil was moist at the time of herbicide application and soil temperature was 26 $\pm$ 1 C. Percent dry weight reduction of the oven dried top plant growth was calculated as previously described. Expected control of each herbicide tank mixture was calculated by the method described by Colby (1967). An LSD at the 5% level was used to compare the observed and expected values to determine significant differences.

Weed species sensitivity and adjuvant study. Common ragweed, common lambsquarters, and velvetleaf seeds were purchased from V & J Seed Farms[13] and thinned to one plant per pot prior to herbicide application. Yellow nutsedge tubers were purchased from Valley Seed Service[14] and selected for plants with two shoots that arose from one tuber prior to herbicide application. At the time of application, common ragweed was 4 cm tall with four to six leaves, common lambsquarters were 4 cm tall with four to six leaves, velvetleaf was 7 cm tall with three leaves, and yellow nutsedge was 10

---

[12]LI-COR, 4421 Superior Street, Lincoln, NE 68504.

[13]P.O. Box 82, Woodstock, IL 60098.

[14]P.O. Box 9335, Fresno, CA 93791.

cm tall with five leaves. Air temperature was 28 ± 1 C and relative humidity was low (36 to 40%) at the time of herbicide application. All herbicide applications were made in the evening from 2:00 p.m. to dusk. Plant top growth was harvested 28 DAT. Herbicide treatments consisted of NIS or MSO[15] with imazamox or imazethapyr, each of which were applied at 18, 35, and 70 g/ha (Table 9). All treatments included 2.5% (v/v) UAN and either 1.0% (v/v) MSO or 0.25% (v/v) NIS.

Influence of adjuvants on giant foxtail control. Giant foxtail seeds were purchased from V & J Seed Farms and after emergence plants were thinned to ten per pot prior to herbicide application. Imazamox and imazethapyr were applied at 35 g/ha, and evaluated alone and with NIS at 0.25% (v/v), UAN at 2.5% (v/v), or NIS plus UAN. Treatments were applied to giant foxtail that were 10 cm tall with four to five leaves in the evening with a photon flux density of 150 $\mu E/m^2/s$ and moderate relative humidity (60%).

In addition to dry weight reduction, tiller presence was determined. Tiller presence was a measure of giant foxtail regrowth since dry weight reduction did not completely quantify the results. Tiller presence was evaluated as a 1 if more than one-half of the plants had tillered, and 0 if less than one-half of the plants had tillered. This was converted to a percentage of tillered plants (100 = tillering and regrowth, while 0 = no tillering or complete plant death).

Giant foxtail antagonism studies. Giant foxtail seeds were purchased from V & J Seed Farms and after emergence plants were thinned to ten per pot prior to herbicide

---

[15]Methylated seed oil was Sun-It II®, a modified vegetable oil containing surfactant, from Agsco, Inc., P.O. Box 13458, Grand Forks, ND 58208-3458.

application. Clethodim antagonism by imazamox and imazethapyr, imazamox and imazethapyr antagonism by the diphenyl ether herbicides, and the effects of adjuvants or sodium acetate on giant foxtail antagonism were evaluated.

Clethodim antagonism by imazamox and imazethapyr. Giant foxtail was 5 to 7 cm tall with four leaves, photosynthetic photon flux density was 300 to 320 $\mu E/m^2/s$, and relative humidity was low (39 to 55%) at the time of herbicide application. Herbicide applications included clethodim at 0, 18, and 36 g/ha; imazamox and imazethapyr at 9, 18, 35, and 70 g/ha; and an untreated control. All treatments included 0.25% (v/v) NIS and 2.5% (v/v) UAN.

Imazamox and imazethapyr antagonism by the diphenyl ether herbicides. Giant foxtail was 5 to 7 cm tall with four leaves, photosynthetic photo flux density was 175 to 450 $\mu E/m^2/s$, and relative humidity was low (40 to 52%) at the time of herbicide application. Herbicide treatments included fomesafen, acifluorfen, and lactofen each at 140 g/ha which were applied with imazamox at 35 and 70 g/ha, imazethapyr at 35 and 70 g/ha, and an untreated control. All treatments included 2.5% (v/v) UAN and 0.25% (v/v) NIS. The data presented are the means of three experiments with three replications in each.

Adjuvant effects on diphenyl ether antagonism. NIS at 0.25% (v/v) and UAN at 2.5% (v/v) were evaluated for their effect on diphenyl ether antagonism of imazamox and imazethapyr. Giant foxtail size and environmental conditions were previously described in the methods section of the influence of adjuvants on giant foxtail control study. Herbicide treatments included NIS, imazethapyr at 35 g/ha, imazamox at 35 g/ha, imazethapyr plus NIS and UAN, imazamox plus NIS and UAN, and NIS plus UAN which were applied with an untreated control, lactofen at 140 g/ha, acifluorfen at 280 g/ha, and fomesafen at 280 g/ha.

Sodium acetate effects on giant foxtail control with imazethapyr and imazamox. Giant foxtail size and environmental conditions were as previously described for the adjuvant evaluation. Herbicide treatments included an untreated control, imazamox at 35 g/ha, and imazethapyr at 35 g/ha which were combined with NIS at 0.25% (v/v), lactofen at 140 g/ha, acifluorfen at 280 g/ha, fomesafen at 280 g/ha, and sodium acetate at 19 mM. A sodium acetate concentration was calculated to provide an adequate number of sodium cations that would compete with ammonium in the imazamox or imazethapyr formulation. Means were separated with an LSD at the one percent level for control, tiller presence, and dry weight reduction.

Soybean injury study. 'Conrad' soybeans were planted and thinned to one plant per pot prior to herbicide application. Soybeans were in the V1 to V2 stage of development 17 days after planting, air temperature was 22 $\pm$ 1 C, photosynthetic photon flux density was 100-350 $\mu E/m^2/s$, and the relative humidity was low (32 to 52%) at the time of herbicide application. The average leaf area and height for each run was 16 cm^2 and 8 cm, 32 cm^2 and 10 cm, and 61 cm^2 and 10 cm, respectively. The differences between leaf areas were related to the time of the year. Herbicide treatments consisted of imazamox and imazethapyr at 0, 35, 70, 140, and 280 g/ha applied with 2.5% (v/v) UAN and NIS at 0.25% (v/v) or MSO at 1.0% (v/v).

Soybean injury was evaluated 7 DAT, while leaf area[16] was measured 21 DAT. The percent reduction in leaf area was calculated as 100*[1-(soybean leaf area/untreated soybean leaf area)]. Plants were harvested 21 DAT and the percent reduction in dry weight was calculated as previously described.

Data was combined over time since no interactions over time were detected. Soybean injury, leaf area reduction, and dry weight reduction were subjected to regression analysis. Regression curves for a logistic dose response were determined by TableCurve 2D[17] software. Averages were plotted and the LSD at the five percent level of probability was utilized to determine significant differences between treatments.

Statistical Protocol. All of the research was conducted as factorial experiments arranged in randomized complete block designs with four replications. An analysis of variance was conducted and experiments were combined over time. The percent data was transformed to the arc sine for an analysis of variance and means were separated with an LSD at the 5% level. Original means are reported. In field experiments, giant foxtail control 56 DAT, common lambsquarters control 28 DAT, and soybean yield for 1995 and 1996 are presented separately due to interactions between years.

---

[16]LI-COR, P.O. Box 4425, Lincoln, NE 68504.

[17]TableCurve 2D v. 3.1. Jandel Scientific, 2591 Kerner Boulevard, San Rafael, CA 94901.

RESULTS AND DISCUSSION

Field experiments. Soybean injury from imazamox and imazethapyr was 16 and 14% 7 DAT, respectively (Table 2). Tank mixtures with lactofen were the most injurious to soybeans. Tank mixtures of imazamox or imazethapyr plus thifensulfuron injured soybeans more than imazamox, imazethapyr, or thifensulfuron alone 7 DAT. Simpson and Stoller (1996) reported increased injury to sulfonylurea tolerant soybeans when imazethapyr was tank mixed with thifensulfuron because imazethapyr inhibited the ALS enzyme. Soybean injury 14 DAT was 13% for imazamox and 11% for imazethapyr, but by 21 DAT all treatments resulted in less than 10% injury to soybean (data not presented).

Imazamox reduced common ragweed dry weight by 64% and imazethapyr reduced common ragweed by 61% 21 DAT (Table 3). Common ragweed regrowth from the axillary and lateral buds was prominent by 21 to 28 DAT. Similar observations have been reported by Ballard et al. (1996). There was no difference in common ragweed dry weight reduction, control at 28 DAT, and control at 56 DAT between imazamox and imazethapyr alone and when tank mixed with other herbicides. In other research, imazamox at 35 and 45 g/ha provided greater common ragweed control than imazethapyr in the presence of a MSO in wide row soybean (Nelson and Renner 1996). Lactofen alone and lactofen tank mixtures with imazamox or imazethapyr effectively controlled common ragweed based on dry weight reduction and visual control 28 and 56 DAT. Tank mixtures of imazamox and imazethapyr with thifensulfuron provided greater control of common ragweed than thifensulfuron alone 28 and 56 DAT.

Giant foxtail control by imazamox was 92% and by imazethapyr was 88% 28 DAT (Table 4). Tank mixtures with clethodim did not reduce control compared to imazamox or imazethapyr alone 28 DAT; however by 56 DAT, giant foxtail control by clethodim was reduced by imazamox and imazethapyr in 1995, but not in 1996. This difference was probably due to adequate rainfall and actively growing giant foxtail prior to and after the herbicide application in 1996. Myers and Coble (1992) reported severe grass antagonism under water stressed conditions when imazethapyr was tank mixed with several graminicides. Tank mixtures with lactofen reduced giant foxtail control compared to either imazamox or imazethapyr 28 and 56 DAT. Lactofen reduced giant foxtail control by imazethapyr more than by imazamox in 1996. Giant foxtail plants treated with these tank mixtures initiated several new shoots or tillers by 14 to 21 DAT. Giant foxtail control was 30% greater 56 DAT in 1996 compared to 1995 for both imazamox and imazethapyr.

Imazamox reduced common lambsquarters dry weight by 80% and imazethapyr reduced common lambsquarters dry weight by 55% 21 DAT (Table 5). Tank mixtures of imazethapyr with lactofen plus thifensulfuron, but not thifensulfuron alone, reduced common lambsquarters dry weight more than imazethapyr alone. By 28 DAT, common lambsquarters control was 81% in 1995 and 1996 from imazamox, and 67 to 68% from imazethapyr. Imazamox and imazethapyr enhanced common lambsquarters control when tank mixed with lactofen compared to lactofen alone in 1995 and 1996. Thifensulfuron tank mixed with imazethapyr increased common lambsquarters control compared to imazethapyr alone.

Imazethapyr provided greater yellow nutsedge control than imazamox 8 WAT, and this difference was still evident 56 WAT (Table 6). Grichar et al. (1992) reported the suppression of yellow nutsedge by imazethapyr applied postemergence up to 142 DAT. Wild mustard in 1995 and 1996, velvetleaf in 1995, redroot pigweed in 1996, and common chickweed in 1996 were controlled with all treatments that included imazamox or imazethapyr (data not presented).

All herbicide treated soybeans yielded less than the handweeded control in 1995 (Table 7). Soybeans treated with tank mixtures of imazamox or imazethapyr plus clethodim, thifensulfuron, or lactofen plus thifensulfuron yielded more than plots treated with clethodim, thifensulfuron, or lactofen plus thifensulfuron alone. Yield reduction was primarily attributed to lactofen reducing giant foxtail control by imazamox and imazethapyr in 1995. Common ragweed was not controlled by imazamox and imazethapyr treatments that did not include lactofen in 1995 and 1996 and this resulted in reduced soybean yields. Plots treated with tank mixtures of imazamox or imazethapyr plus lactofen or thifensulfuron yielded the same as the handweeded control in 1996. Soybeans treated with tank mixtures of clethodim, lactofen, thifensulfuron, and lactofen plus thifensulfuron with imazamox or imazethapyr yielded more than soybeans treated with clethodim, lactofen, thifensulfuron, and lactofen plus thifensulfuron alone. Giant foxtail density was 140 plants/m^2 in 1995 and 70 plants/m^2 in 1996. Knake and Slife (1962) reported soybean yields decreased as giant foxtail density increased. Greater giant foxtail population densities could cause antagonistic interactions to have a greater effect on yields. This could explain reduced yields in plots treated with lactofen plus imazethapyr or imazamox compared to the handweeded control in 1995 that were not seen in 1996. Antagonistic tank mixtures may not affect soybean yield at low weed population densities, but weed seed production and maximum soybean productivity may not be achieved.

Tank mixing imazamox or imazethapyr with any diphenyl ether did not cause more injury than the diphenyl ether herbicide applied alone 7 and 14 DAT (Table 8). Common ragweed was controlled and giant foxtail control reduced when imazamox and imazethapyr were tank mixed with any diphenyl ether herbicide 28 and 56 DAT. Common lambsquarters control by imazamox was reduced by lactofen, while acifluorfen increased common lambsquarters control when tank mixed with imazamox or imazethapyr. All tank mixtures with acifluorfen and lactofen resulted in yields greater than imazamox or imazethapyr applied alone even though giant foxtail and common lambsquarters control was reduced by lactofen.

Weed species sensitivity and adjuvant study. Imazamox at 35 g/ha plus a MSO controlled common ragweed, while at 18 g/ha imazamox controlled common lambsquarters and velvetleaf 28 DAT (Table 9). Imazethapyr at 70 g/ha plus MSO reduced common ragweed dry weight similar to imazamox at 35 g/ha plus NIS, but common ragweed regrowth from the lateral and axillary buds was observed for all treatments except imazamox at 70 g/ha plus MSO. Ballard et al. (1995) reported metabolism and reduced basipetal translocation were the primary mechanisms for reduced common ragweed control by imazethapyr. Common ragweed control differences between imazamox and imazethapyr could be related to common ragweed metabolism differences. Imazethapyr at 35 g/ha controlled velvetleaf. Seventy g/ha of imazethapyr reduced common lambsquarters dry weight by 60% regardless of adjuvant. Yellow nutsedge was suppressed by 70 g/ha of imazamox and imazethapyr, but chlorimuron at 13 g ai/ha reduced yellow nutsedge dry weight by 94% (data not presented). In contrast, other researchers have reported similar yellow nutsedge control by imazethapyr and chlorimuron in the greenhouse (Ackley et al. 1996; Derr and Wilcut 1993).

Influence of adjuvants on giant foxtail control. Imazamox at 35 g/ha plus UAN and NIS stopped giant foxtail tillering and reduced dry weight by 93% (Table 10). Tiller number increased by 50% when UAN was not added to imazamox plus NIS. Imazethapyr plus UAN and NIS reduced giant foxtail dry weight by 91%, yet 88% of the plants tillered. Hager and Renner (1994) enhanced common ragweed control by adding UAN to imazethapyr plus NIS. Thompson et al. (1996) reported enhanced ^{14}C-imazethapyr absorption by leafy spurge when either NIS or NIS plus UAN were present.

Clethodim antagonism by imazamox and imazethapyr. Giant foxtail dry weight was reduced by 91% from imazamox at 9 g/ha and 93% from imazethapyr at 35 g/ha 21 DAT (Table 11). Imazethapyr antagonized giant foxtail control by clethodim in every treatment combination. Antagonism was significant with imazamox plus clethodim tank mixtures, but when the observed value controlled giant foxtail then a calculated value may not be of great use unless the weed species is not controlled. Giant foxtail control by clethodim tank mixtures was similar to the control observed by imazamox and imazethapyr applied alone. Cantwell et al. (1989) reported reduced giant foxtail control as the imazethapyr rate decreased when imazethapyr was tank mixed with sethoxydim.

Imazamox and imazethapyr antagonism by the diphenyl ether herbicides. Imazamox at 35 g/ha and imazethapyr at 70 g/ha controlled giant foxtail with no tillering (Table 12). Tank mixtures of lactofen, acifluorfen, or fomesafen with imazamox or imazethapyr at 35 or 70 g/ha reduced visual control and increased giant foxtail tillering. The reason for increased tillering in the presence of the diphenyl ether herbicides could be a result of reduced translocation. Chao et al. (1994) reported a reduction in main shoot fresh weight of wild oat (*Avena fatua* L.) when treated with imazamethabenz ((±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-4(and 5)-methylbenzoic acid (3:2)) because of limited translocation to the tiller buds as a result of apical dominance (Chao et al. 1993, Little and Shaner 1991). This could be the reason for increased tillering in the presence of the diphenyl ether herbicides. Giant foxtail antagonism was similar for all diphenyl ether herbicides, even though acifluorfen alone reduced giant foxtail dry weight by 84% while lactofen and fomesafen reduced giant foxtail dry weight by 45 and 41%, respectively (data not shown). Lactofen and fomesafen have some activity on grass species, but to a much lesser extent than acifluorfen (Holshouser and Coble 1990; Minton et al. 1989).

Adjuvant effects on diphenyl ether antagonism. Imazamox plus NIS and UAN reduced giant foxtail dry weight by 93% and stopped giant foxtail tillering (Table 13). Not adding UAN or adding a diphenyl ether herbicide to the spray solution did not increase giant foxtail dry weight, but increased the presence of tillers. Imazethapyr plus

NIS and UAN reduced giant foxtail dry weight by 91%, but 88% of the plants still tillered. Not using UAN or adding a diphenyl ether herbicide increased giant foxtail dry weight and this was considered antagonistic according to Colby's test. Similar dry weight reductions were observed when imazethapyr was tank mixed with lactofen, acifluorfen, or fomesafen compared to imazethapyr alone. This was unlike the previous study and was probably due to the smaller size of giant foxtail in this experiment and the lower diphenyl ether application rates which resulted in less antagonism (Table 12). Murphy and Briske (1992) reviewed numerous factors that influence tiller initiation by grass species. The biomass differences could be related to the physiological development differences of giant foxtail at the time of application.

Sodium acetate effects on giant foxtail control with imazethapyr and imazamox. The addition of sodium acetate to imazamox or imazethapyr plus NIS did not reduce giant foxtail control or increase tillering compared to imazamox or imazethapyr plus NIS (Table 14). Thus, the formation of the sodium salts of the imidazolinone herbicides did not explain the antagonism. The antagonism may be due to the difference in the timing of expression of the action of the two classes of herbicides. Godley and Kitchen (1986) as well as Westberg and Coble (1992) have proposed that the diphenyl ethers cause widespread cell membrane disruption of the epidermal cells and reduce normal absorption and translocation of systemic herbicides which results in antagonism. This may occur when imazethapyr and imazamox are tank mixed with these herbicides on giant foxtail. Since the primary sink of the imidazolinone herbicides is the main culm of grass species (Chao et al. 1993, Little and Shaner 1991), this would allow the release of lateral buds or tillers from apical dominance and allow regrowth.

Soybean injury study. Imazamox injured soybeans more than imazethapyr, regardless of adjuvant 7 DAT (Figure 1a). Imazamox at 280 g/ha plus MSO injured soybeans more than with NIS. Imazamox reduced soybean dry weight (Figure 1b) and leaf area (Figure 1c) more than imazethapyr 21 DAT. High rates of the imidazolinone herbicides were used to identify potential injury differences when imazamox or imazethapyr were combined with these adjuvants. At the recommended field rates of imazamox (35 g/ha) and imazethapyr (70 g/ha), there was no difference in soybean injury, dry weight reduction, or leaf area reduction between imazamox and imazethapyr. In other field studies, increasing the imazamox rate to 45 g/ha with a methylated seed oil injured soybeans greater than the imazamox at 35 g/ha and imazethapyr at 70 g/ha (Nelson and Renner 1996).

This research has shown the need for tank mixtures with imazethapyr for the control of common lambsquarters and common ragweed. Tank mixtures with imazamox at 35 g/ha plus NIS and UAN were needed for common ragweed control. Application rates of 45 g/ha may increase common ragweed control (Nelson and Renner 1996) with a MSO. However, increased soybean injury and reduced weed control depended upon the tank mixture and environmental conditions at the time of application. Lactofen, acifluorfen, and fomesafen enhanced common ragweed control, but reduced giant foxtail control by imazamox and imazethapyr. Imazethapyr and imazamox reduced giant foxtail control by clethodim in the field, but imazethapyr was more antagonistic in the greenhouse.

Adjuvants are an important tool to improve weed control and reduce herbicide antagonism. Giant foxtail control was increased by the addition of UAN and NIS to imazamox and imazethapyr. A MSO increased broadleaf weed control by imazamox and imazethapyr compared to NIS in the greenhouse. Thompson et al. (1996) reported greater absorption of ^{14}C-imazethapyr by leafy spurge with MSO compared to NIS when UAN was present. This could explain differences in weed control and soybean injury between MSO and NIS treatments with imazamox and imazethapyr. Sodium cations present in the diphenyl ether herbicide formulations do not appear to influence giant foxtail antagonism since sodium acetate did not affect giant foxtail control by imazamox or imazethapyr.

Imazamox with a MSO caused more soybean injury but provided greater weed control than imazethapyr (Nelson and Renner 1996). Future research evaluating soybean response to imazamox at 45 g/ha is needed (Nelson and Renner 1996). Absorption, translocation, and metabolism studies of imazamox and imazethapyr on tolerant and susceptible species could explain differences in weed control and lead to a greater understanding of imidazolinone chemistry.

LITERATURE CITED

Ackley, J. A., H. P. Wilson, and T. E. Hines. 1996. Yellow nutsedge (*Cyperus esculentus*) control POST with acetolactate synthase-inhibiting herbicides. Weed Technol. 10:576-580.

Anonymous. Pursuit®. Technical information bulletin. American Cyanamid Company, Princeton, NJ. 18 p.

Anonymous. 1995. Raptor™. Technical information bulletin. American Cyanamid Company, Princeton, NJ. 8 p.

Ballard, T. O., M. E. Foley, and T. T. Bauman. 1995. Absorption, translocation, and metabolism of imazethapyr in common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia trifida*). Weed Sci. 43:572-577.

Ballard, T. O., M. E. Foley, and T. T. Bauman. 1996. Response of common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia trifida*) to postemergence imazethapyr. Weed Sci. 44:248-251.

Bauer, T. A., K. A. Renner, and D. Penner. 1995. 'Olathe' pinto bean (*Phaseolus vulgaris*) response to postemergence imazethapyr and bentazon. Weed Sci. 43:276-282.

Cantwell, J. R., R. A. Liebl, and F. W. Slife. 1989. Imazethapyr for weed control in soybean (*Glycine max*). Weed Technol. 3:596-601.

Chao, J. F., A. I. Hsiao, and W. A. Quick. 1993. Effects of imazamethabenz on the main shoot growth and tillering of wild oat (*Avena fatua* L.). J. Plant Growth Regul. 12:141-147.

Chao, J. F., A. I. Hsiao, W. A. Quick, and J. A. Hume. 1994. Effect of decapitation on absorption, translocation, and phytotoxicity of imazemethabenz in wild oat (*Avena fatua* L.). J. Plant Growth Regul. 13:153-158.

Colby, S. R. 1967. Calculating synergistic and antagonistic responses of herbicide combinations. Weeds 15:20-22.

Croon, K. A. and M. G. Merkle. 1988. Effects of bentazon, imazaquin, or chlorimuron on haloxyfop or fluazifop-P efficacy. Weed Technol. 2:36-40.

Derr, J. F., and J. W. Wilcut. 1993. Control of yellow and purple nutsedges (*Cyperus esculentus* and *C. rotundus*) in nursery crops. Weed Technol. 7:112-117.

Foy, C. L. and H. L. Witt. 1993. Effects of methylated crop oils and other selected adjuvants on the herbicidal efficacy and selectivity of imazethapyr in soybeans. Essex: Elsevier Applied Science Publishers. 38:260-262.

Gaeddert, J. W., D. E. Peterson, and M. J. Horak. 1996. Control and cross resistance of an ALS resistant palmer amaranth (*Amaranthus palmeri* S. Wats) biotype. Abstr. Weed Sci. Soc. Am. 36:9.

Gednalski, J. V., W. G. Johnson, and G. W. Alley. 1995. Influence of various adjuvants on postemergence weed control in soybeans with AC 299,263. Proc. North Cent. Weed Sci. Soc. Am. 50:133.

Gerwick, B. C., L. D. Tanguay, and F. G. Burroughs. 1990. Differential effects of UAN on antagonism with bentazon. Weed Technol. 4:620-624.

Godley, J. L. and L. M. Kitchen. 1986. Interaction of acifluorfen with fluazifop for annual grass control. Weed Sci. 34:936-941.

Green, J. M. 1991. Maximizing herbicide efficiency with mixtures and expert systems. Weed Technol. 5:894-897.

Grichar, W. J., P. R. Nester, and A. E. Colburn. 1992. Nutsedge (*Cyperus* spp.) control in peanuts (*Arachis hypogaea*) with imazethapyr. Weed Technol. 6:396-400.

Gronwald, J. W., S. W. Jourdan, D. L. Wyse, D. A. Somers, and M. U. Magnusson. 1993. Effect of ammonium sulfate on absorption of imazethapyr by quackgrass (*Elytrigia repens*) and maize (*Zea mays*) cell suspension cultures. Weed Sci. 41:325-334.

Hager, A. and K. Renner. 1994. Common ragweed (*Ambrosia artemisiifolia*) control in soybean (*Glycine max*) with bentazon as influenced by imazethapyr or thifensulfuron tank-mixes. Weed Technol. 8:766-771.

Hart, S. E., J. J. Kells, and D. Penner. 1992. Influence of adjuvants on the efficacy, absorption, and spray retention of primisulfuron. Weed Technol. 6:592-598.

Hatzios, K. K., and D. Penner. 1985. Interactions of herbicides with other agrochemicals in higher plants. Rev. Weed Sci. 1:1-63.

Holshouser, D. L. and H. D. Coble. 1990. Compatibility of sethoxydim with five postemergence broadleaf herbicides. Weed Technol. 4:128-133.

Knake, E. L., and F. W. Slife. 1962. Competition of *Setaria faberii* with corn and soybeans. Weeds 10:26-29.

Leif, J. and F. Taylor. 1993. Sequential and tank mix combinations with imazethapyr for enhanced weed control and weed resistance management in soybeans. Proc. North Cent. Weed Sci. Soc. 48:81.

Little, D. L. and D. L. Shaner. 1991. Absorption and translocation of the imidazolinone herbicides. Pages 53-69 *in* Shaner, D. L. and S. L. O'Connor eds. The Imidazolinone Herbicides. CRC Press, Boca Raton, FL.

Lueschen, W. E., J. K. Getting, and E. L. Foland. 1997. AC 299,263 and imazethapyr carryover potential in soybean/sugarbeet rotation. Abstr. Weed Sci. Soc. Am. 37:97.

Minton, B. W., M. E. Kurtz, and D. R. Shaw. 1989. Barnyardgrass (*Echinochloa crus-galli*) control with grass and broadleaf weed herbicide combinations. Weed Sci. 37:223-227.

Monks, C. D., J. W. Wilcut, and J. S. Richburg, III. 1993. Broadleaf weed control in soybean (*Glycine max*) with chlorimuron plus acifluorfen or thifensulfuron mixtures. Weed Technol. 7:317-321.

Murphy, J. S. and D. D. Briske. 1992. Regulation of tillering by apical dominance: chronology, interpretive value, and current perspectives. J. Range Manage. 45:419-429.

Myers, P. F. and H. D. Coble. 1992. Antagonism of graminicide activity on annual grass species by imazethapyr. Weed Technol. 6:333-338.

Nalewaja, J. D., J. Palczynski, and F. Manthey. 1990. Imazethapyr efficacy with adjuvants and environments. Weed Technol. 4:765-770.

Nelson, K. A. and K. A. Renner. 1996. Weed control with AC 299,263 (imazamox), CGA-277476 (oxasulfuron), and imazethapyr in drilled and rowed soybeans. North Cent. Weed Sci. Soc. 51:121.

Ogg, P. J., T. L. Arnold, S. R. Busse, K. L. Carlson, D. L. Culbertson, T. A. Hayden, T. P. Miller, S. M. Sanborn, M. E. Weiss, and W. S. Van Scoik. 1988. Methylated sunflower oil and other additives in postemergence applications of imazethapyr. Proc. North Cent. Weed Sci. Soc. 43:41.

Penner, D. 1989. The impact of adjuvants on herbicide antagonism. Weed Technol. 3:227-231.

Putnam, A. R. and D. Penner. 1974. Pesticide interactions in higher plants. Residue Review. 50:73-110.

Simpson, D. M. and E. W. Stoller. 1996. Thifensulfuron and imazethapyr interaction at the ALS enzyme in sulfonylurea-tolerant soybean (*Glycine max*). Weed Sci. 44:763-768.

Thompson, W. M., S. J. Nissen, and R. A. Masters. 1996. Adjuvant effects on imazethapyr, 2,4-D and picloram absorption by leafy spurge (*Euphorbia esula*). Weed Sci. 44:469-475.

Vidrine, P. R. 1989. Johnsongrass (*Sorghum halepense*) control in soybeans (*Glycine max*) with postemergence herbicides. Weed Technol. 3:455-458.

Wanamarta. G., D. Penner, and J. J. Kells. 1989 The basis of bentazon antagonism on sethoxydim absorption and activity. Weed Sci. 37:400-404.

Westberg, D. E. and H. D. Coble. 1992. Effect of acifluorfen on the absorption, translocation, and metabolism of chlorimuron in certain weeds. Weed Technol. 1992. 6:4-12.

Whitwell, T., G. Wehtje, R. H. Walker, and J. A. McGuire. 1985. Johnsongrass (*Sorghum halepense*) control in soybeans (*Glycine max*) with postemergence grass herbicides applied alone and in mixtures. Weed Sci. 33:673-678.

Wilcut, J. W. 1991. Tropic Croton (*Croton glandulosus*) control in peanut (*Arachis hypogaea*). Weed Technol. 5:795-798.

Table 1. Weed height and leaf number at the time of herbicide application for field experiments conducted in 1995 and 1996.

	1995		1996	
Weed Species	Height	Leaf	Height	Leaf
	cm	number	cm	number
Common ragweed	3-4	4-8	3-4	4-8
Giant foxtail	5-8	3-4	5-8	3-4
Common lambsquarters	3-4	4-6	3-4	4-6
Wild mustard	3-8	4-6	3-8	4-6
Yellow nutsedge	5-15	5-7	---	---
Velvetleaf	3	1-3	---	---
Redroot pigweed	---	---	1-15	4-7
Common chickweed	---	---	3-8	10-18

Table 2. Soybean injury 7 and 14 days after treatment by imazamox and imazethapyr alone and when tank mixed with other herbicides in 1995 and 1996.

		Soybean injury	
Treatment[a]	Rate	7 DAT	14 DAT
	g ai/ha	------------- %	-------------
Imazamox	35	16 d	13 c-e
Imazethapyr	70	14 d	11 e
Imazamox + clethodim	35 + 140	15 d	13 c-e
Imazethapyr + clethodim	70 + 140	14 d	10 e
Clethodim	140	0 f	1 f
Imazamox + lactofen	35 + 70	29 ab	16 b-d
Imazethapyr + lactofen	70 + 70	29 ab	18 ab
Lactofen	70	27 b	15 b-d
Imazamox + thifensulfuron	35 + 2.2	19 c	12 e
Imazethapyr + thifensulfuron	70 + 2.2	17 cd	12 e
Thifensulfuron	2.2	9 e	11 e
Imazamox + lactofen + thifensulfuron	35 + 70 + 2.2	29 ab	20 a
Imazethapyr + lactofen + thifensulfuron	70 + 70 + 2.2	31 a	19 a
Lactofen + thifensulfuron	70 + 2.2	29 ab	16 bc

[a]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) 28% urea ammonium nitrate. Means followed by a common letter are not significantly different with an LSD at the 5% level.

Table 3. Common ragweed control by imazamox and imazethapyr alone and when tank mixed with other herbicides.[a]

		Common ragweed[b]		
Treatment[c]	Rate	Dry weight reduction 21 DAT	Control 28 DAT	Control 56 DAT
	g ai/ha	----------	%	----------
Imazamox	35	64 bc	79 de	39 cd
Imazethapyr	70	61 bc	76 e	35 d
Imazamox + clethodim	35 + 140	61 bc	79 de	39 cd
Imazethapyr + clethodim	70 + 140	64 bc	76 de	38 cd
Clethodim	140	0 d	0 g	0 f
Imazamox + lactofen	35 + 70	100 a	95 bc	94 b
Imazethapyr + lactofen	70 + 70	99 a	97 a	96 a
Lactofen	70	100 a	95 a-c	97 a
Imazamox + thifensulfuron	35 + 2.2	69 b	80 d	43 c
Imazethapyr + thifensulfuron	70 + 2.2	61 bc	76 de	42 c
Thifensulfuron	2.2	42 c	40 f	18 e
Imazamox + lactofen + thifensulfuron	35 + 70 + 2.2	99 a	96 a-c	93 b
Imazethapyr + lactofen + thifensulfuron	70 + 70 + 2.2	100 a	97 ab	97 a
Lactofen + thifensulfuron	70 + 2.2	100 a	94 c	95 ab

[a]All data was combined over years. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]Abreviation: DAT, days after treatment.
[c]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) 28% urea ammonium nitrate.

Table 4. Giant foxtail control by imazamox and imazethapyr alone and when tank mixed with other herbicides.[a]

		Giant foxtail[b]		
		Control 28 DAT	Control 56 DAT	
Treatment[c]	Rate		1995	1996
	g ai/ha	%	%	%
Imazamox	35	92 b	69 b	99 a
Imazethapyr	70	88 cd	69 b	99 a
Imazamox + clethodim	35 + 140	94 bc	73 b	99 a
Imazethapyr + clethodim	70 + 140	87 de	74 b	99 a
Clethodim	140	98 a	96 a	99 a
Imazamox + lactofen	35 + 70	79 f	45 d	80 c
Imazethapyr + lactofen	70 + 70	59 g	50 d	74 d
Lactofen	70	11 h	5 f	5 f
Imazamox + thifensulfuron	35 + 2.2	90 cd	66 bc	99 a
Imazethapyr + thifensulfuron	70 + 2.2	83 ef	67 bc	99 a
Thifensulfuron	2.2	4 hi	8 f	23 e
Imazamox + lactofen + thifensulfuron	35 + 70 + 2.2	82 f	45 d	83 bc
Imazethapyr + lactofen + thifensulfuron	70 + 70 + 2.2	78 f	55 cd	86 b
Lactofen + thifensulfuron	70 + 2.2	6 hi	23 e	5 f

[a]Data was combined over years except when interactions between years were observed. Means followed by a common letter are not significantly different with an LSD at the 5% level.

[b]Abreviation: DAT, days after treatment.

[c]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) 28% urea ammonium nitrate.

Table 5. Common lambsquarters control by imazamox and imazethapyr alone and when tank mixed with other herbicides.[a]

		Common lambsquarters[b]		
Treatment[c]	Rate	Dry weight reduction 21 DAT	Control 28 DAT 1995	Control 28 DAT 1996
	g ai/ha	----------------------------	%	----------------------------
Imazamox	35	80 a-e	81 c-e	81 c-e
Imazethapyr	70	55 e	68 f	67 ef
Imazamox + clethodim	35 + 140	77 a-e	82 c-e	79 d-f
Imazethapyr + clethodim	70 + 140	54 de	64 f	68 ef
Clethodim	140	0 f	0 g	0 h
Imazamox + lactofen	35 + 70	87 ab	69 ef	64 f
Imazethapyr + lactofen	70 + 70	73 b-e	74 d-f	76 d-f
Lactofen	70	61 c-e	18 g	33 g
Imazamox + thifensulfuron	35 + 2.2	84 a-c	90 a-c	87 b-d
Imazethapyr + thifensulfuron	70 + 2.2	79 a-e	87 a-c	92 a-c
Thifensulfuron	2.2	84 a-e	83 b-d	97 a
Imazamox + lactofen + thifensulfuron	35 + 70 + 2.2	92 a	92 ab	92 a-c
Imazethapyr + lactofen + thifensulfuron	70 + 70 + 2.2	92 ab	92 a-c	94 ab
Lactofen + thifensulfuron	70 + 2.2	84 a-d	94 a	65 ef

[a]Data was combined over years except when interactions between years were observed. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]Abreviation: DAT, days after treatment.
[c]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) 28% urea ammonium nitrate.

Table 6. Yellow nutsedge control by imazamox and imazethapyr 8 and 56 weeks after treatment.[a]

		Yellow nutsedge[b]	
Treatment[c]	Rate	8 WAT	56 WAT
	g ai/ha	%	
Imazamox	35	5 b	15 b
Imazethapyr	70	42 a	73 a
Alone		1 b	10 b

[a]Data was combined over all tank mixtures. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]Abreviation: WAT, weeks after treatment.
[c]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) 28% urea ammonium nitrate.

Table 7. Soybean yield in plots treated with imazamox or imazethapyr alone and when tank mixed with other herbicides in 1995 and 1996.

		Soybean yield	
Treatment[a]	Rate	1995	1996
	g ai/ha	----------- kg/ha -----------	
Imazamox	35	1820 c-f	1950 b
Imazethapyr	70	2290 b-d	2150 b
Imazamox + clethodim	35 + 140	2290 b-d	2220 b
Imazethapyr + clethodim	70 + 140	2560 bc	2220 b
Clethodim	140	1410 e-g	130 c
Imazamox + lactofen	35 + 70	2090 b-e	2890 a
Imazethapyr + lactofen	70 + 70	1680 d-f	2890 a
Lactofen	70	1140 fg	400 c
Imazamox + thifensulfuron	35 + 2.2	2890 b	2620 ab
Imazethapyr + thifensulfuron	70 + 2.2	2420 b-d	2560 ab
Thifensulfuron	2.2	870 g	130 c
Imazamox + lactofen + thifensulfuron	35 + 70 + 2.2	2290 b-d	3160 a
Imazethapyr + lactofen + thifensulfuron	70 + 70 + 2.2	1950 c-e	2960 a
Lactofen + thifensulfuron	70 + 2.2	1140 fg	200 c
Untreated	0	740 g	70 c
Handweeded	0	3970 a	2890 a

[a]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) 28% urea ammonium nitrate. Means followed by a common letter are not significantly different with an LSD at the 5% level.

Table 8. Soybean injury, common ragweed control, giant foxtail control, common lambsquarters control, and soybean yield in the field following an application of imazamox and imazethapyr alone and tank mixed with the diphenyl ether herbicides in 1996.

Treatment[b]	Rate	Soybean injury		AMBEL[a]		SETFA		CHEAL	Soybean yield
		7 DAT	14 DAT	28 DAT	56 DAT	28 DAT	56 DAT	28 DAT	
	g ai/ha	%							kg/ha
Imazamox	35	14 ef	12 c	74 c	40 e	94 a	99 a	81 b	1950 bc
Imazethapyr	70	12 f	12 c	69 c	39 e	97 a	99 a	67 cd	2150 bc
Imazamox + acif[c]	35 + 280	24 a-c	19 ab	93 b	91 cd	85 b	83 b	89 a	3030 a
Imazethapyr + acif	70 + 280	24 a-c	19 ab	98 a	97 ab	73 c	74 b	92 a	3300 a
Imazamox + fome	35 + 140	21 cd	17 b	96 ab	99 a	87 b	83 b	77 bc	2620 ab
Imazethapyr + fome	70 + 140	17 de	17 b	99 a	98 ab	77 bc	79 b	78 b	3230 a
Imazamox + lact	35 + 70	28 a	20 ab	96 ab	95 bc	83 bc	80 b	64 d	2890 a
Imazethapyr + lact	35 + 70	28 a	21 a	99 a	99 a	78 bc	74 b	76 bc	2890 a
Acif	280	24 bc	17 b	94 b	89 d	51 d	46 c	58 d	1750 c
Fome	140	18 d	17 b	98 a	99 a	28 e	29 d	41 e	610 d
Lact	70	26 ab	19 ab	98 a	99 a	21 e	5 e	33 e	400 d
Untreated	0	0 g	0 d	0 d	0 f	0 f	0 e	0 f	70 d
Handweeded	0								2890 a

[a]Abbreviations: AMBEL, common ragweed; SETFA, giant foxtail; CHEAL, common lambsquarters; DAT, days after treatment; acif, acifluorfen; fome, fomesafen; and lact, lactofen.

[b]All treatments included 0.25% (v/v) nonionic surfactant and 2.6% (v/v) 28% urea ammonium nitrate. Means followed by a common letter are not significantly different with an LSD at the 5% level.

Table 9. Common ragweed, common lambsquarters, velvetleaf, and yellow nutsedge control by imazamox and imazethapyr applied with nonionic surfactant and methylated seed oil in the greenhouse 28 days after treatment.

Treatment[a]	Rate	Common ragweed[b]	Common lambsquarters	Velvetleaf	Yellow nutsedge
	g ai/ha + % (v/v)	---------- % Dry weight reduction[c] ----------			
Imazamox + NIS	18 + 0.25	47 fg	91 b	98 a	22 f
Imazamox + NIS	35 + 0.25	84 b	95 ab	99 a	46 cd
Imazamox + NIS	70 + 0.25	90 a	97 a	99 a	72 a
Imazethapyr + NIS	18 + 0.25	32 h	24 e	83 c	3 g
Imazethapyr + NIS	35 + 0.25	56 ef	45 d	95 b	39 de
Imazethapyr + NIS	70 + 0.25	71 d	61 c	99 a	66 ab
Imazamox + MSO	18 + 1.0	72 cd	90 b	99 a	-----
Imazamox + MSO	35 +1.0	90 a	94 ab	99 a	-----
Imazamox + MSO	70 + 1.0	94 a	95 ab	99 a	-----
Imazethapyr + MSO	18 + 1.0	43 gh	39 d	91 b	-----
Imazethapyr + MSO	35 + 1.0	65 de	39 d	99 a	-----
Imazethapyr + MSO	70 + 1.0	80 bc	60 c	99 a	-----

[a]All treatments included 2.5% (v/v) 28% urea ammonium nitrate. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]Abreviations: NIS, nonionic surfactant; and MSO, methylated seed oil.
[c]Plant top growth was harvested 28 days after treatment.

Table 10. The effect of 28% urea ammonium nitrate or nonionic surfactant on giant foxtail control by imazamox and imazethapyr 21 days after treatment.

Treatment[a]	Tiller presence[b]	Dry weight reduction
	------------------------------ %	------------------------------
Imazamox	100 a	71 d
Imazamox + UAN	88 a	80 c
Imazamox + NIS	50 b	89 b
Imazamox + UAN + NIS	0 c	93 a
Imazethapyr	100 a	35 f
Imazethapyr + UAN	100 a	52 e
Imazethapyr + NIS	100 a	71 d
Imazethapyr + UAN + NIS	88 a	91 b

[a]All treatments included imazamox or imazethapyr at 35 g ai/ha, 28% urea ammonium nitrate at 2.5% (v/v), and nonionic surfactant at 0.25% (v/v). Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]Ratings evaluated tiller presence by over half of the plants in a pot as 1 and less than half was 0 (100 = tillering and regrowth, while 0 = no tillering or complete plant death).

Table 11. Giant foxtail control by imazamox and imazethapyr tank mixed with clethodim 21 days after treatment.[a]

Treatment[b]	Rate	Clethodim 0	Clethodim 18	Clethodim 36
	g ai/ha	% Dry weight reduction[c]		
None	0	0 k	90 ef	93 b-f
Imazamox	9	91 d-f	90** f (99)	90** f (99)
Imazamox	18	94 a-d	93** a-d (99)	93** a-d (99)
Imazamox	35	95 a	95 a (99)	95 ab (99)
Imazamox	70	95 a	95 a (99)	95 a (99)
Imazethapyr	9	62 i	63* i (96)	54* j (97)
Imazethapyr	18	83 g	85* g (98)	79* h (99)
Imazethapyr	35	93 a-d	92** c-f (99)	93** a-e (99)
Imazethapyr	70	94 a-c	92** c-f (99)	94** a-c (99)

[a]Comparisons between columns are valid. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]All treatments included 0.25% (v/v) nonionic surfactant and 2.5% (v/v) 28% urea ammonium nitrate.
[c]Values in parentheses are the expected dry weight reduction for the herbicide combination using Colby's method. A single asterisk denotes a significant antagonistic response and a double asterisk indicates a calculated antagonistic response, but when the observed value controlled giant foxtail then the calculated value may not be of great use.

Table 12. Giant foxtail control by imazamox and imazethapyr tank mixed with the diphenyl ethers 21 days after treatment.

Treatment[a]	Rate	Tiller presence[b]	Control	Dry weight reduction[c]
	g ai/ha	-------------------	%	-------------------
Imazamox	35	0 d	94 b	96 ab
Imazamox + lactofen	35 + 140	100 a	88 cd	95 * a-c (98)
Imazamox + acifluorfen	35 + 140	78 b	86 de	95 * b-d (99)
Imazamox + fomesafen	35 + 140	100 a	85 de	95 * a-c (98)
Imazamox	70	0 d	99 a	97 a
Imazamox + lactofen	70 + 140	33 c	93 b	96 ab (98)
Imazamox + acifluorfen	70 + 140	11 d	90 c	96** ab (99)
Imazamox + fomesafen	70 + 140	33 c	90 c	96 ab (98)
Imazethapyr	35	78 b	85 de	93 cd
Imazethapyr + lactofen	35 + 140	100 a	70 g	81* f (96)
Imazethapyr + acifluorfen	35 + 140	100 a	65 h	75* g (99)
Imazethapyr + fomesafen	35 + 140	100 a	71 g	85* f (96)
Imazethapyr	70	11 d	93 b	96 ab
Imazethapyr + lactofen	70 + 140	100 a	83 ef	92* de (97)
Imazethapyr + acifluorfen	70 + 140	100 a	80 f	90* e (99)
Imazethapyr + fomesafen	70 + 140	100 a	83 ef	93* cd (98)

[a]All treatments included imazamox or imazethapyr at 35 or 70 g ai/ha; lactofen, acifluorfen, and fomesafen at 140 g ai/ha; UAN at 2.5% (v/v); and NIS at 0.25% (v/v). Means followed by a common letter are not significantly different with an LSD at the 5% level.

[b]Ratings evaluated tiller presence by over half of the plants in a pot as 1 and less than half was 0 (100 = tillering and regrowth, while 0 = no tillering or complete plant death).

[c]Values in parentheses are the expected dry weight reduction for the herbicide combination using Colby's method. A single asterisk denotes a significant antagonistic response while a double asterisk indicates an antagonistic response, but when regrowth represented by tiller presence indicated control then this value may not be of great use.

Table 13. The effects of adjuvants on giant foxtail control by imazamox and imazethapyr tank mixed with the diphenyl ethers 21 days after treatment.

Treatment[a]	Tiller presence[b]	Dry weight reduction[c]
	------------------ %	------------------
Imazamox + NIS	50 b	89 bc
Imazamox + lactofen + NIS	100 a	87 cd (92)
Imazamox + acifluorfen + NIS	88 a	90* bc (97)
Imazamox + fomesafen + NIS	100 a	89 bc (92)
Imazamox + NIS + UAN	0 c	93 a
Imazamox + lactofen + NIS + UAN	63 b	94 a (96)
Imazamox + acifluorfen + NIS + UAN	88 a	92 ab (99)
Imazamox + fomesafen + NIS + UAN	100 a	94 a (97)
Imazethapyr + NIS	100 a	71 e-g
Imazethapyr + lactofen + NIS	100 a	73* ef (79)
Imazethapyr + acifluorfen + NIS	100 a	69* fg (93)
Imazethapyr + fomesafen + NIS	88 a	66* gh (80)
Imazethapyr + NIS + UAN	88 a	91 a-c
Imazethapyr + lactofen + NIS + UAN	100 a	89* bc (95)
Imazethapyr + acifluorfen + NIS + UAN	100 a	85* d (97)
Imazethapyr + fomesafen + NIS +UAN	100 a	89 bc (89)
NIS	100 a	0 k
Lactofen + NIS	100 a	29 j
Acifluorfen + NIS	100 a	75 e
Fomesafen + NIS	100 a	30 j
NIS + UAN	100 a	0 k
Lactofen + NIS + UAN	100 a	41 i
Acifluorfen + NIS + UAN	100 a	90 a-c
Fomesafen + NIS + UAN	100 a	62 h

[a]All treatments included imazamox or imazethapyr at 35 g ai/ha, lactofen 140 g ai/ha, acifluorfen 280 g ai/ha, fomesafen 280 g ai/ha, urea ammonium nitrate at 2.5% (v/v), and nonionic surfactant at 0.25% (v/v). Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]Ratings evaluated tiller presence by over half of the plants in a pot as 1 and less than half was 0 (100 = tillering and regrowth, while 0 = no tillering or complete plant death).
[c]Values in parentheses are the expected dry weight reduction for the herbicide combination using Colby's method. An asterisk denotes a significant antagonistic response.

Table 14. The effect of sodium acetate on giant foxtail control with imazamox and imazethapyr.

Treatment[a]	Tiller presence[b]	Control	Dry weight reduction[c]
	---------- % ----------		
Imazamox + NIS	50 b	81 ab	89 a
Imazamox + lactofen + NIS	100 a	77 bc	87 a (92)
Imazamox + acifluorfen + NIS	88 a	78 a-c	90* a (97)
Imazamox + fomesafen + NIS	100 a	74 c	89 a (92)
Imazamox + NIS + sodium acetate	38 b	83 a	91 a (90)
Imazethapyr + NIS	100 a	60 d	71 bc
Imazethapyr + lactofen + NIS	100 a	55 de	73* bc (79)
Imazethapyr + acifluorfen + NIS	100 a	58 de	69* bc (93)
Imazethapyr + fomesafen + NIS	88 a	52 e	66* c (80)
Imazethapyr + NIS + sodium acetate	100 a	59 d	71 bc (73)
NIS	100 a	0 g	0 e
Lactofen + NIS	100 a	22 f	29 d
Acifluorfen + NIS	100 a	56 de	75 b
Fomesafen + NIS	100 a	15 f	30 d
NIS + sodium acetate	100 a	0 g	8 e

[a]All treatments included imazamox or imazethapyr at 35 g ai/ha, lactofen at 140 g ai/ha, acifluorfen at 280 g ai/ha, fomesafen at 280 g ai/ha, and nonionic surfactant at 0.25% (v/v). Sodium acetate was applied at 19 mM. Means followed by a common letter are not significantly different with an LSD at the 1% level.
[b]Ratings evaluated tiller presence by over half of the plants in a pot as 1 and less than half was 0 (100 = tillering and regrowth, while 0 = no tillering or complete plant death).
[c]Values in parentheses are the expected dry weight reduction for the herbicide combination using Colby's method. An asterisk denotes a significant antagonistic response.

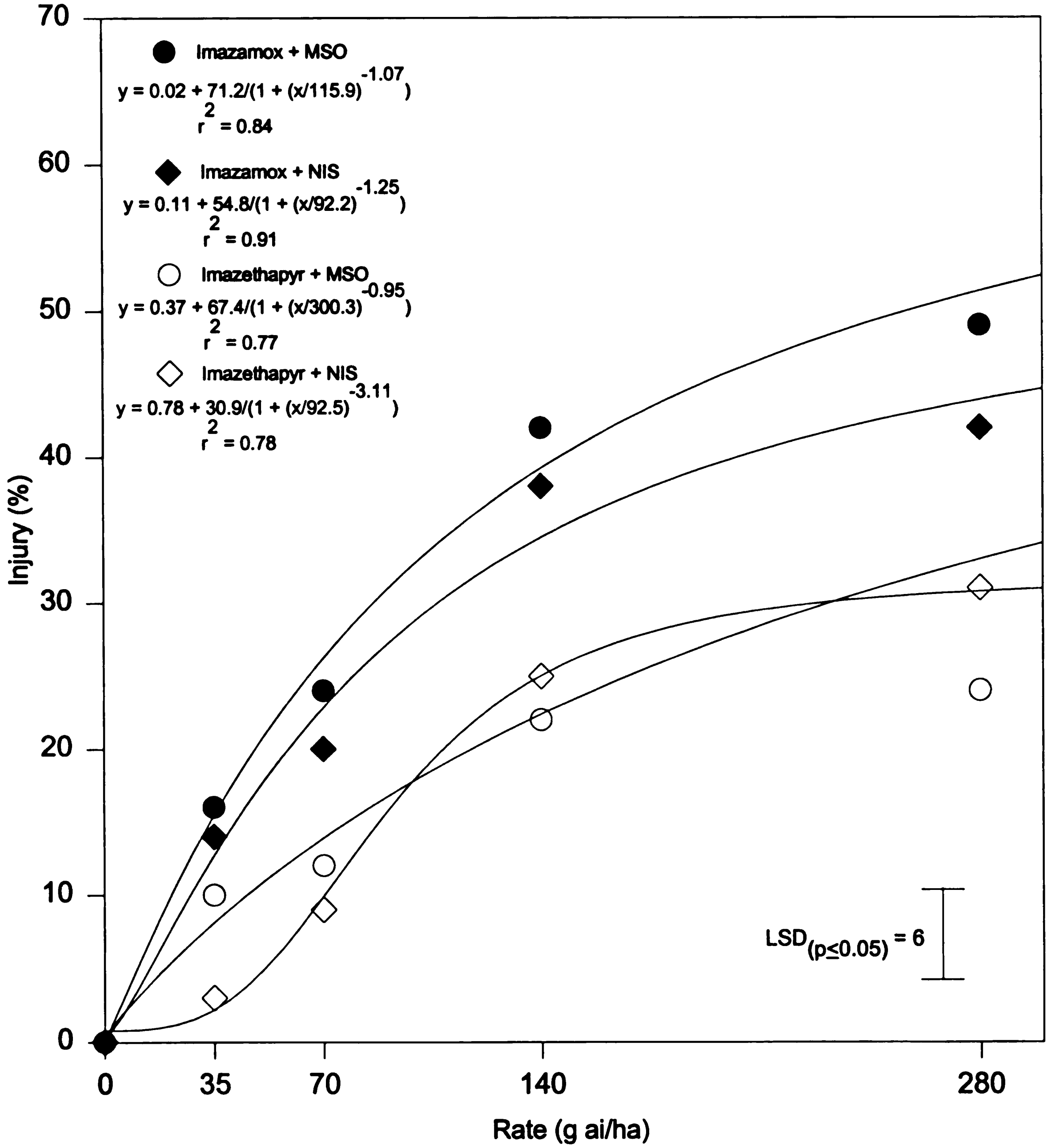

Figure 1a. Soybean injury by imazamox and imazethapyr applied with a nonionic surfactant or a methylated seed oil 7 DAT. All treatments included 2.5% (v/v) 28% urea ammonium nitrate and methylated seed oil at 1.0% (v/v) or nonionic surfactant at 0.25% (v/v).

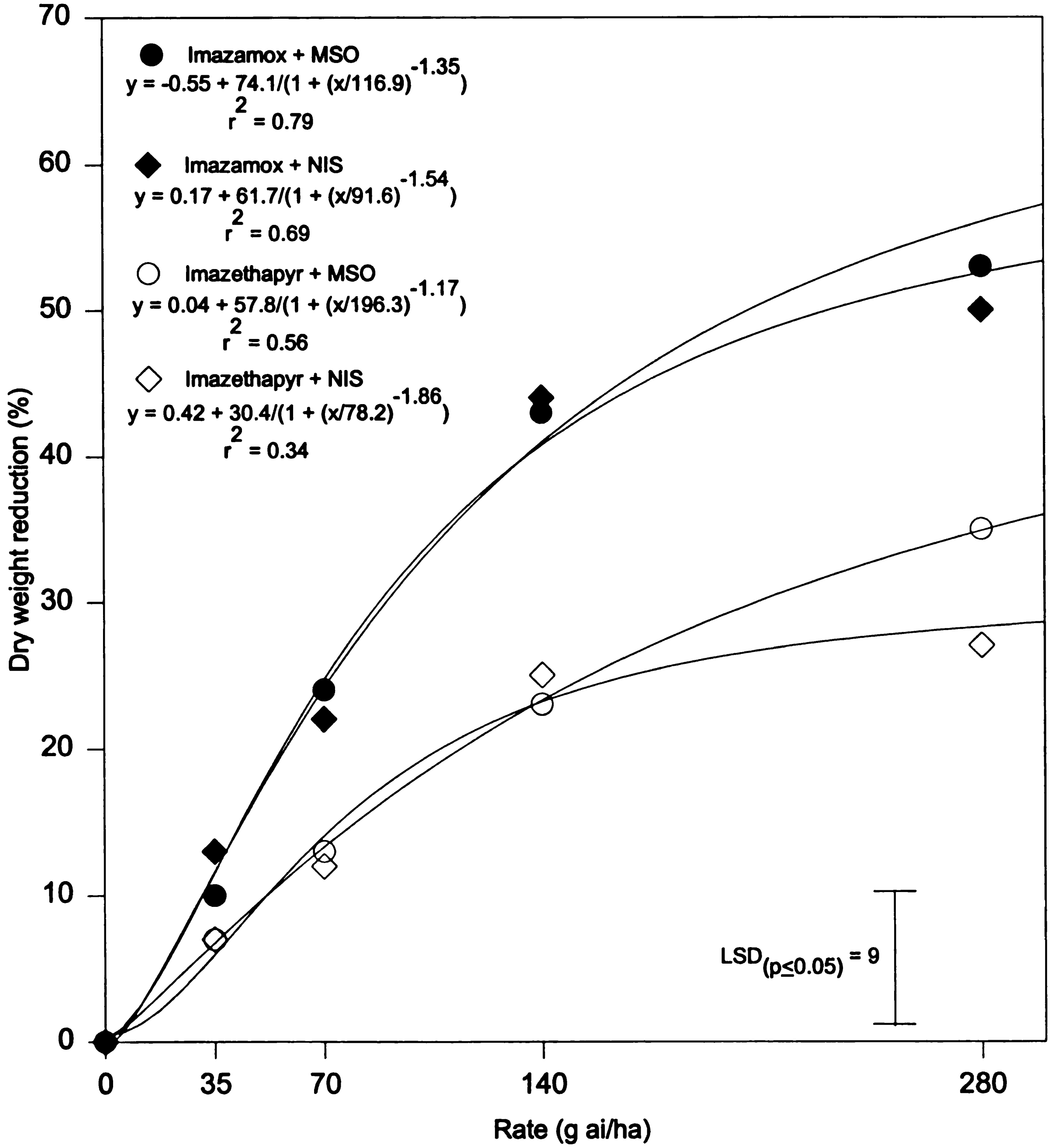

Figure 1b. Soybean dry weight reduction by imazamox and imazethapyr applied with a nonionic surfactant or a methylated seed oil 21 DAT. All treatments included 2.5% (v/v) 28% urea ammonium nitrate and methylated seed oil at 1.0% (v/v) or nonionic surfactant at 0.25% (v/v).

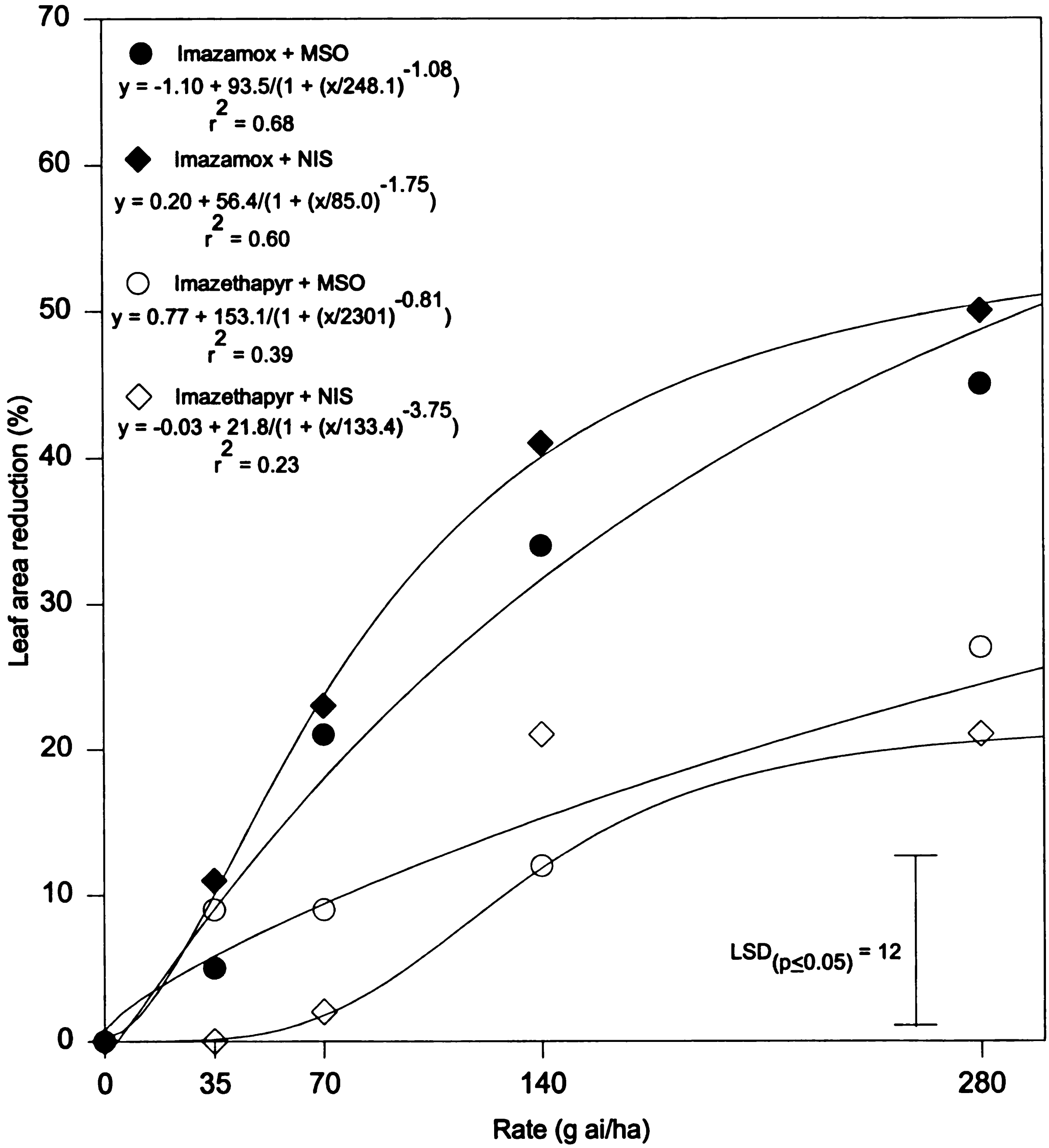

Figure 1c. Soybean leaf area reduction by imazamox and imazethapyr applied with a nonionic surfactant or methylated seed oil 21 DAT. All treatments included 2.5% (v/v) 28% urea ammonium nitrate and methylated seed oil at 1.0% (v/v) or nonionic surfactant at 0.25% (v/v).

CHAPTER 4

WEED CONTROL IN WIDE AND NARROW ROW SOYBEAN [*Glycine max* (L.) Merr] WITH IMAZAMOX, IMAZETHAPYR, AND OXASULFURON[1]

Kelly A. Nelson and Karen A. Renner[2]

Abstract. Field experiments were conducted at East Lansing and Clarksville, MI to evaluate the efficacy of imazamox, imazethapyr, and oxasulfuron applied postemergence in wide (76 cm) and narrow (19 cm) row soybean. Soybean injury from all herbicides was minimal 14 days after treatment except for oxasulfuron plus quizalofop which injured soybean 30% at the Clarksville location. Imazamox, imazethapyr, and oxasulfuron controlled velvetleaf, wild mustard, and common chickweed. Imazamox and imazethapyr also controlled eastern black nightshade. Adding CGA-248757 to oxasulfuron reduced common ragweed control, but increased redroot pigweed control compared to oxasulfuron alone. Imazamox at 35 and 45 g ai/ha provided greater common ragweed and common lambsquarters control than imazethapyr at 70 g ai/ha 28 days after treatment. Common ragweed, common lambsquarters, and redroot pigweed control was enhanced in narrow compared to wide row soybean 56 days after treatment. Total weed biomass and soybean yield in wide row soybean treated with imazamox at

---

[1]Received for publication __________ and in revised form __________.

[2]Grad. Res. Asst. and Prof., Mich. State Univ., East Lansing, MI 48824-1325.

45 g/ha was similar to that of the handweeded control. In narrow row soybean, total weed biomass and soybean yield was similar to the handweeded control for imazamox at both the 35 and 45 g/ha rate as well as imazethapyr at 70 g/ha. These postemergence herbicide treatments resulted in less weed biomass and greater soybean yield in narrow compared to wide row soybean. **Nomenclature:** CGA-248757, (proposed fluthiacet-methyl) methyl [[2-chloro-4-fluoro-5-[(tetrahydro-3-oxo-1*H*,3*H*-[1,3,4]thiadiazolo[3,4-a]pyridazin-1-ylidene)amino]phenyl]thio]acetate; imazamox, 2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-5-(methoxymethyl) nicotinic acid; imazethapyr, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid; oxasulfuron (CGA-277476), 2-[[[[(4,6-dimethyl-2-pyrimidinyl)-amino]carbonyl]amino]sulfonyl]benzoic acid, 3-oxetanyl ester; quizalofop, (±)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid; common chickweed, *Stellaria media* (L.) Vill. #[3] STEME; common lambsquarters, *Chenopodium album* L. # CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; eastern black nightshade, *Solanum ptycanthum* Dun. # SOLPT; giant foxtail, *Setaria faberi* Herrm. # SETFA; wild mustard, *Sinapis arvensis* L. # SINAR; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; velvetleaf, *Abutilon theophrasti* Medik. # ABUTH; soybean, *Glycine max* (L.) Merr.

Additional index words: Row spacing, postemergence.

[3]Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

INTRODUCTION

It has been well documented that soybean planted in narrow rows reduce weed yield and have potentially greater soybean yield than soybean planted in wide rows (Burnside and Collville 1964; Burnside and Moomaw 1977; McWorter and Sciumbato 1988; Mickelson and Renner 1997; Patterson et al. 1988; Peters et al. 1965; Wax and Pendleton 1968). Faster canopy closure in narrow row soybean can increase weed suppression by herbicides. Soybean planted in narrow rows (25 cm) reached 95% solar interception 11 to 17 days before wide row (102 cm) soybean depending upon soybean density (Shibles and Weber 1966). Canopy closure has been reported from 35 to 50 and 56 to 90 days after planting for soybean in 19 to 25 cm and 76 cm rows, respectively (Burnside and Colville 1964; Mickelson and Renner 1997; Wax and Pendleton 1968). An earlier canopy closure can enhance weed control and broaden the use of a herbicide or allow a herbicide to be applied at a reduced rate.

Burnside and Moomaw (1977) showed that reduced rates of preemergence herbicides provided adequate weed control in narrow row soybean. Chloramben (3-amino-2,5-dichlorobenzoic acid) provided greater control of weeds in narrow than wide row soybean (Peters et al. 1965). Postemergence herbicide treatments in narrow row soybean had 30% less weed biomass than the same postemergence treatments in wide rows, and narrow row soybean were more profitable for most of the postemergence herbicide programs evaluated (Mickelson and Renner 1997).

Imazamox and imazethapyr are imidazolinone herbicides for broadspectrum postemergence weed control in soybean (Anonymous; Anonymous 1995; Ballard and

Hellmer 1995). A methylated seed oil adjuvant improved control of several weed species by imazethapyr and imazamox (Gednalski et al. 1995; Nalewaja et al. 1990; Thompson et al. 1996). Oxasulfuron is a sulfonylurea herbicide for broadleaf weed control and grass suppression (Kidder and Johnson 1997; Kidder and Porpiglia 1996; Ritter and Menbere 1997). Quizalofop has been tank mixed with oxasulfuron for giant foxtail control and and CGA-248757 has been tank mixed with oxasulfuron for enhanced broadleaf weed control (Bauer et al. 1995; Bauer et al. 1996; Kidder and Porpiglia 1996; Nelson and Renner 1997). The objectives of this research were to evaluate soybean injury, weed control, and soybean yield following postemergence applications of imazamox, imazethapyr, and oxasulfuron in wide and narrow row soybean.

MATERIALS AND METHODS

Field experiments were conducted in 1996 at the Michigan State University Research Farm at East Lansing, MI and the Michigan State University Experiment Station at Clarksville, MI. The soil was a Capac clay loam (fine-loamy, mixed mesic Aeric Ochraqualfs) with a pH of 7.0 and 3.5% organic matter at the East Lansing location. This site was disked in the fall and cultimulched twice in the spring. The Clarksville soil was a Lapeer loam (coarse-loamy, mixed, mesic Mollic Haplaquepts) with a the soil pH of 6.8 and 1.2% organic matter. The site was field cultivated once in the spring.

'Conrad' soybean were planted in 76 cm rows at 358,000 seeds/ha with a John Deere 7200 Max-Emerge®2[4] planter and at 469,000 seeds/ha in 19 cm wide rows with a Great Plains Solid Stand 10[5] grain drill at East Lansing. The plots were 3 m wide and 12.2 m long. At Clarksville, soybean were planted in 76 cm rows at 371,000 seeds/ha with a John Deere 7200® planter, while 19 cm wide row soybean were planted at 508,000 seeds/ha with an International 5100[6] grain drill. At this site, plots were 12.2 m long and wide row plots were 4.6 m wide, while the narrow row plots were 2.3 m wide.

This research was arranged as a split plot design with four replications. The main plots were row spacing and subplots were herbicide treatments. Herbicide treatments included imazamox at 35 and 45 g ai/ha, imazethapyr at 70 g ai/ha, oxasulfuron at 79 g

---

[4]Deere and Co., 501 River Drive, Moline, IL 61265-1100.

[5]Great Plains Manufacturing Inc., P.O. Box 218, Assaria, KS 67416.

[6]Concord, 3000 7th Ave. North, Fargo, ND 58102.

ai/ha tank mixed with quizalofop at 69 g ai/ha, and oxasulfuron at 65 g/ha tank mixed with CGA-248757 at 4 g ai/ha and quizalofop at 69 g/ha. Imazamox and imazethapyr treatments included methylated seed oil[7] (MSO)[8] at 1.0% (v/v), while oxasulfuron tank mixtures included nonionic surfactant[9] (NIS)[8] at 0.25% (v/v). All herbicide treatments were applied with 2.6% (v/v) 28% urea ammonium nitrate (UAN)[8].

Herbicide treatments were applied at a standard postemergence timing on June 23, 1996 at East Lansing and June 20, 1996 at Clarksville (25 and 26 days after planting) with a tractor mounted compressed air sprayer traveling at 6.3 km/h and delivering 178 L/ha at 207 kPa of pressure. At the time of application, soybean were at the V1 to V2 stage of development at both locations. Weed heights, leaf number, and weed density are presented in Table 1. Herbicides were applied with 8003 flat fan nozzles[10] on a 51 cm spacing at 48 cm above the weed and crop canopy. At East Lansing, the air temperature was 21 C with 67% relative humidity and 15% cloud cover at 9:00 a.m., and at Clarksville the air temperature was 27 C with 71% relative humidity and 80% cloud cover at 6:00 p.m. at the time of application. Rainfall ten days prior to herbicide application was 9.8 cm at East Lansing and 11.5 cm at Clarksville, while rainfall from 1

---

[7]Methylated seed oil was Sun-It II®, a modified vegetable oil containing surfactant, from Agsco, Inc., P.O. Box 13458, Grand Forks, ND 58208-3458.

[8]Abbreviations: MSO, methylated seed oil; NIS, nonionic surfactant; UAN, 28% urea ammonium nitrate; DAT, days after treatment.

[9]Nonionic surfactant was Activator-90, a mixture of alkyl polyoxyethylene ether and free fatty acids, Loveland Industries Inc., P.O. Box 1289, Greeley, CO 80632.

[10]Teejet flat fan tips. Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.

to 10 days after herbicide application totaled 0.7 cm at East Lansing and 1.0 cm at Clarksville.

Soybean injury was evaluated 3, 7, 14, and 21 days after treatment (DAT)[8]. Soybean injury data is presented for 7 and 14 DAT. Weed control was evaluated 7, 14, 21, 28, and 56 DAT. Evaluations at 28 and 56 DAT were the most representative of weed control. Visual evaluations were based upon a scale of 0 (no effect) to 100 (complete weed or crop death) percent. Three days prior to herbicide application, 30 by 76 cm long quadrats were placed in every plot, and soybean and weeds were counted. The weeds and soybean in these quadrats were harvested, separated, and oven dried 56 DAT. Total weed and soybean biomass reduction was calculated as: total weed biomass reduction = 100*(1-(total weed biomass/untreated wide row total weed biomass) and soybean biomass reduction = 100*(1-(total soybean biomass/handweeded wide row soybean biomass). Total weed biomass percent was the quotient of the weed biomass and total plant biomass multiplied by 100. Two rows of the wide row soybean and a 1.5 m width of the narrow row soybean were harvested with a Massey 10[11] small plot combine and moisture adjusted to 13%.

The percent data was transformed to the arc sine for an analysis of variance and means were separated with an LSD at the 5% level, but reported as the original means. Due to interactions between location and herbicide treatments for soybean injury and weed control 28 DAT, data are presented for the East Lansing and Clarksville locations separately, but were combined over row spacing. Redroot pigweed control is presented

---

[11]Kincaid Equipment Manufacturing, P.O. Box 400, Haven, KS 47543.

for location, row spacing, and herbicide treatment since there were interactions between these factors 28 and 56 DAT. By 56 DAT, data were combined over locations, and interactions between row spacing and herbicide treatments are presented for all responses except soybean biomass reduction, where only the herbicide treatment effects were significant.

RESULTS AND DISCUSSION

Imazamox at 45 g/ha caused more soybean injury than the other herbicide treatments at East Lansing; however, oxasulfuron tank mixtures were the most injurious at Clarksville 7 DAT (Table 2). Injury symptoms on soybean treated with oxasulfuron tank mixed with CGA-248757 plus quizalofop were primarily leaf necrosis, while oxasulfuron tank mixed with quizalofop caused more stunting and reddening of soybean leaf veins. By 14 DAT, there was no difference in soybean response to herbicide treatments at East Lansing. However at Clarksville, soybean treated with imazamox at 45 g/ha were injured more than soybean treated with imazamox at 35 g/ha, while oxasulfuron tank mixed with quizalofop severely injured soybean 14 DAT (Table 2). This injury was still greater than 10% 21 DAT (data not shown). Malefyt and Quakenbush (1991) reported that tolerant species like soybean metabolize imidazolinone herbicides slower at lower temperatures. This could explain more injury from the imidazolinones at the East Lansing site. Other environmental factors may have caused increased soybean injury from oxasulfuron at the Clarksville site.

Common ragweed control by all treatments was reduced at East Lansing compared to the Clarksville location because the population density of common ragweed was greater at East Lansing and some larger common ragweed (6 to 8 cm) were not controlled by oxasulfuron or 35 g/ha of imazamox (personal observation). Imazamox at 45 g/ha provided the best common ragweed control at East Lansing, while at Clarksville both imazamox rates provided similar common ragweed control (Table 3). Common ragweed control was reduced at East Lansing and Clarksville when CGA-248757 was tank mixed with oxasulfuron.

Imazamox at 45 g/ha controlled common lambsquarters at East Lansing, while both 35 and 45 g/ha of imazamox controlled common lambsquarters at Clarksville (Table 3). Imazamox provided greater common lambsquarters control than imazethapyr at both locations. The population density of common lambsquarters was greater at Clarksville. Larger (4 to 8 cm) common lambsquarters were not controlled by oxasulfuron tank mixtures (personal observation).

Imazamox and imazethapyr controlled giant foxtail 28 DAT at both locations (Table 3). Oxasulfuron plus quizalofop tank mixtures did not adequately control giant foxtail at East Lansing possibly due to larger giant foxtail (8 to 13 cm) and higher giant foxtail population density. Eastern black nightshade was controlled by imazamox and imazethapyr, but not by oxasulfuron tank mixtures at East Lansing (Table 3). All treatments controlled velvetleaf, wild mustard, and common chickweed (data not shown).

Redroot pigweed was controlled by imazamox and imazethapyr regardless of row spacing or location (Table 4). Redroot pigweed control from oxasulfuron plus quizalofop increased 24% at the East Lansing site in narrow compared to wide row soybean 28 DAT. Redroot pigweed control was enhanced at both sites when CGA-248757 was tank mixed with oxasulfuron in wide row soybean. By 56 DAT, oxasulfuron plus CGA-248757 provided greater control of redroot pigweed than oxasulfuron alone in both row spacings at Clarksville and in the wide row spacing at East Lansing. Oxasulfuron provided less redroot pigweed control at East Lansing because of a greater pigweed population density and a few larger pigweed (10 cm) that were not controlled (personal observation).

By 56 DAT, common ragweed control was greater in narrow than in wide row soybean for all herbicide treatments (Table 5). In narrow rows, common ragweed control was similar for both rates of imazamox, imazethapyr, and oxasulfuron plus quizalofop; however, imazamox and oxasulfuron plus quizalofop provided the greatest common ragweed control in wide rows. Common lambsquarters were controlled by all treatments in narrow row soybean and control was increased in narrow compared to wide row soybean for all treatments except imazamox at 35 g/ha.

Both imazamox rates reduced total weed biomass similar to that of the handweeded control in wide and narrow row soybean (Table 5). Imazamox at 45 g/ha reduced total weed biomass more than imazethapyr and oxasulfuron tank mixtures in wide row soybean. Adding CGA-248757 to oxasulfuron reduced weed biomass in narrow row soybean comparable to oxasulfuron alone, but not in wide rows.

There was no interaction between row spacing and herbicide treatment for soybean biomass reduction 56 DAT; therefore, the effect of herbicide treatment is presented (Table 5). Soybean biomass was reduced 15 to 21% by the weeds present in the oxasulfuron and imazethapyr treatments. Soybean biomass was similar to the hand weeded control where 45 g/ha of imazamox was applied. Soybean biomass was reduced 18% more in wide than in narrow row soybean when data was combined over all herbicide treatments (data not shown).

Soybean yielded more in narrow compared to wide rows in all herbicide treatments except the handweeded control and imazamox at 45 g/ha (Table 5). All treatments in wide row soybean yielded less than the handweeded control except imazamox at 45 g/ha. Increased soybean yield in the herbicide treated plots of narrow row soybean was due to weed control differences, since the soybean yield of the handweeded control did not differ between narrow and wide row soybean.

Total weed biomass was evaluated as a percentage of the total plant biomass harvested from each plot 56 DAT (Figure 1). Both imazamox treatments in wide and narrow row soybean had a very low total weed biomass percent that was similar to the handweeded control. The weed biomass was greater in wide than narrow row soybean for imazethapyr, oxasulfuron tank mixtures, and the untreated control. Common ragweed contributed to the total weed biomass in all treatments, giant foxtail and common lambsquarters contributed in the imazethapyr treatments, and common lambsquarters and redroot pigweed contributed in the oxasulfuron treatments.

Our research indicated that weed competition was reduced and soybean yield increased in narrow compared to the wide row soybean when a total postemergence weed control strategy was used. Canopy closure dates were approximately 45 days after planting for narrow row soybean and 80 days after planting for wide row soybean at both sites. The advantage of narrow row spacing for increased weed control was not evident 28 DAT (56 days after planting) except for redroot pigweed control by oxasulfuron tank mixtures. Between 28 and 56 DAT, soybean competition was greater in narrow than in wide soybean due to canopy closure in narrow but not wide row soybean during this time period. Earlier canopy closure in narrow row soybean is an important factor that allow soybean a competitive advantage to weeds that are marginally suppressed by a postemergence herbicide treatment.

Imazamox at 45 g/ha provided broad spectrum postemergence weed control in wide and narrow row soybean. Imazamox provided increased common ragweed and common lambsquarters control compared to imazethapyr 28 and 56 DAT in wide row soybean. Imazamox has controlled common lambsquarters greater than imazethapyr in other research (Nelson and Renner 1995). Narrow row soybean treated with imazamox at 35 g/ha or imazethapyr controlled a broad spectrum of broadleaf weeds as well as giant foxtail, and soybean yields were equal to the handweeded control. Ballard and Hellmer (1995) reported a tendency for increased common ragweed and common lambsquarters control by imazamox at 45 compared to the 35 g/ha in wide row soybean. Other research has found no difference in common ragweed control with imazamox at 35 g/ha and imazethapyr at 70 g/ha in wide row soybean (Nelson and Renner 1995).

Utilization of narrow row soybean can prove beneficial in years when weed sizes and environmental conditions are not as favorable for postemergence weed control. Postemergence broadleaf weed control with oxasulfuron tank mixtures had variable weed control that appeared extremely sensitive to the weed size at the time of application. Additional cost effective weed management strategies are needed to enhance redroot pigweed, eastern black nightshade, and common ragweed control. Other researchers have evaluated early postemergence applications of oxasulfuron and preemergence acetanilide followed by oxasulfuron postemergence as methods to broaden the spectrum of weeds controlled with oxasulfuron in the weed management system (Bauer et al. 1996, Kidder and Johnson 1997).

LITERATURE CITED

Anonymous. Pursuit®. Technical information bulletin. American Cyanamid Company, Princeton, NJ. 18 p.

Anonymous. 1995. Raptor™. Technical information bulletin. American Cyanamid Company, Princeton, NJ. 8 p.

Ballard, T. O. and M. Hellmer. 1995. AC 299,263: efficacy in soybeans as influenced by postemergence timing. Proc. North Cent. Weed Sci. Soc. 50:132-133.

Bauer, T. A., S. W. Pruss, T. R. Dill, and D. Kidder. 1996. Sequential soybean herbicide programs including CGA-277476. Proc. North Cent. Weed Sci. Soc. 51:131-132.

Bauer, T., T. Threewitt, L. Stahlberg, A. Moses, K. Jones, D. Kidder, and P. Porpiglia. 1995. Weed management programs in soybeans with CGA-277476. Proc. North Cent. Weed Sci. Soc. 50:140.

Burnside, O. C. and W. L. Colville. 1964. Soybean and weed yields as affected by irrigation, row spacing, tillage, and amiben. Weeds 12:109-112.

Burnside, O. C. and R. S. Moomaw. 1977. Control of weeds in narrow-row soybeans. Agron. J. 69:793-796.

Gednalski, J. V., W. G. Johnson, and G. W. Alley. 1995. Influence of various adjuvants on postemergence weed control in soybeans with AC 299,263. Proc. North Cent. Weed Sci. Soc. Am. 50:133.

Kidder, D. and M. D. Johnson. 1997. Grass control in soybeans with CGA-277476; alone, in sequential, and in tankmix programs. Abstr. Weed Sci. Soc. Am. 37:1.

Kidder, D. W. and P. J. Porpiglia. 1996. CGA-277476 and CGA-248757 for broad spectrum, postemergence weed control in soybeans. Abstr. Weed Sci. Soc. Am. 36:12.

Malefyt, T. and L. Quakenbush. 1991. Influence of environmental factors on the biological activity of the imidazolinone herbicides. Pages 103-127 *in* Shaner, D. L. and S. L. O'Connor eds. The Imidazolinone Herbicides. CRC Press, Boca Raton, FL.

McWorter, C. G. and G. L. Sciumbato. 1988. Effects of row spacing, benomyl, and duration of sicklepod (*Cassia obtusifolia*) interference on soybean (*Glycine max*) yields. Weed Sci. 36:254-259.

Mickelson, J. A. and K. A. Renner. 1997. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybeans. J. Prod. Agric. In press.

Nalewaja, J. D., J. Palczynski, and F. Manthey. 1990. Imazethapyr efficacy with adjuvants and environments. Weed Technol. 4:765-770.

Nelson, K. A. and K. A. Renner. 1995. A comparison of imazethapyr and AC 299,263 for postemergence weed control in soybeans. Proc. North Cent. Weed Sci. Soc. 50:129-130.

Nelson, K. A. and K. A. Renner. 1997. Postemergence weed control in soybean with CGA-277476 and cloransulam-methyl. Abstr. Weed Sci. Soc. Am. 37:1.

Patterson, M. G., R. H. Walker, D. L. Colvin, G. Wehtje, and J. A. McGuire. 1988. Comparison of soybean (*Glycine max*)--weed interference from large and small plots. Weed Sci. 36:836-839.

Peters, E. J., M. R. Gebhardt, and J. F. Stritzke. 1965. Interrelations of row spacings, cultivations and herbicides for weed control in soybeans. Weeds 13:285-289.

Ritter, R. L. and H. Menbere. 1997. Use of CGA-277476 in soybeans. Abstr. Weed Sci. Soc. Am. 37:1.

Shibles, R. M. and C. R. Weber. 1966. Interception of solar radiation and dry matter production by various soybean planting patterns. Crop Sci. 6:55-59.

Thompson, W. M., S. J. Nissen, and R. A. Masters. 1996. Adjuvant effects on imazethapyr, 2,4-D and picloram absorption by leafy spurge (*Euphorbia esula*). Weed Sci. 44:469-475.

Wax, L. M. and J. W. Pendleton. 1968. Effect of row spacing on weed control in soybeans. Weed Sci. 16:462-465.

Table 1. Weed height, leaf number, and population density at the time of herbicide application for field experiments conducted at East Lansing and Clarksville, MI.

	East Lansing			Clarksville		
Weed species	Height	Leaf	Density	Height	Leaf	Density
	cm	number	plants/m^2	cm	number	plants/m^2
Giant foxtail	3-10	3-5	300	3-8	3-4	75
Redroot pigweed	3-10	3-7	400	1-8	3-8	290
Common ragweed	3-9	4-8	75	3-6	4-6	20
Common lambsquarters	3-4	4	30	3-8	4-6	65
Velvetleaf	3-5	2	10	3-5	2	10
Wild mustard	3-15	4-6	10	---	---	---
Eastern black nightshade	0.5-1	1	65	---	---	---
Common chickweed	---	---	---	3-15	6-30	40

Table 2. Soybean injury by imazamox, imazethapyr, and oxasulfuron tank mixtures 7 and 14 days after treatment at East Lansing and Clarksville, MI.[a]

		Soybean injury			
		7 DAT		14 DAT	
Treatment[b]	Rate	East Lansing	Clarksville	East Lansing	Clarksville
	g ai/ha	% Injury			
Imazamox	35	17 b	11 bc	4 ab	4 d
Imazamox	45	22 a	14 b	6 a	9 b
Imazethapyr	70	19 b	12 bc	6 a	7 b-d
Oxasulfuron + quizalofop	79 + 69	17 b	19 a	4 ab	30 a
Oxasulfuron + CGA-248757 + quizalofop	65 + 4 + 69	18 b	22 a	4 ab	8 bc

[a]Treatment means were combined over row spacing. Means followed by a common letter are not significantly different with an LSD at the 5% level.
[b]All treatments included 2.6% (v/v) 28% urea ammonium nitrate. Imazamox and imazethapyr treatments included 1.0% (v/v) methylated seed oil and oxasulfuron tank mixtures included 0.25% (v/v) nonionic surfactant.

Table 3. Common ragweed, common lambsquarters, giant foxtail, and eastern black nightshade control at East Lansing and Clarksville 28 days after treatment.[a]

		Common ragweed[b]		Common lambsquarters		Giant foxtail		Eastern black nightshade
Treatment[b]	Rate	East Lansing	Clarksville	East Lansing	Clarksville	East Lansing	Clarksville	East Lansing
	g ai/ha	%						
Imazamox	35	78 b	88 b	82 b	88 a	94 ab	99 a	99 a
Imazamox	45	84 a	93 ab	90 a	90 a	95 a	99 a	99 a
Imazethapyr	70	71 c	76 c	67 c	69 bc	88 bc	99 a	99 a
Oxasulfuron + quizalofop	79 + 69	73 c	93 a	81 b	67 c	77 d	98 a	13 b
Oxasulfuron + CGA-248757 + quizalofop	65 + 4 + 69	53 d	78 c	83 ab	73 b	84 cd	99 a	13 b

[a]Treatment means were combined over row spacing. Means followed by a common letter are not significantly different with an LSD at the 5% level.

[b]All treatments included 2.6% (v/v) 28% urea ammonium nitrate. Imazamox and imazethapyr treatments included 1.0% (v/v) methylated seed oil and oxasulfuron tank mixtures included 0.25% (v/v) nonionic surfactant.

Table 4. Redroot pigweed control 28 and 56 days after treatment at East Lansing and Clarksville, MI in wide and narrow row soybean.

		Control 28 DAT			Control 56 DAT			
		East Lansing		Clarksville[b]	East Lansing		Clarksville	
Treatment[a]	Rate	Wide	Narrow		Wide	Narrow	Wide	Narrow
	g ai/ha	%						
Imazamox	35	99 a	99 a	99 a	99 a	99 a	99 a	99 a
Imazamox	45	99 a	98 a	99 a	92 b	99 a	99 a	99 a
Imazethapyr	70	99 a	98 a	99 a	99 a	99 a	97 ab	99 a
Oxasulfuron + quizalofop	79 + 69	60 d	84 b	60 c	18 d	45 c	36 e	77 c
Oxasulfuron + CGA-248757 + quizalofop	65 + 4 + 69	75 c	71 cd	68 b	53 c	50 c	60 d	92 b

[a]All treatments included 2.6% (v/v) 28% urea ammonium nitrate. Imazamox and imazethapyr treatments included 1.0% (v/v) methylated seed oil and oxasulfuron tank mixtures included 0.25% (v/v) nonionic surfactant. Comparisons within East Lansing or Clarksville columns are valid.
[b]Treatment means were combined over row spacing. Means followed by a common letter are not significantly different with an LSD at the 5% level.

Table 5. Common ragweed and common lambsquarters control, total weed biomass reduction, soybean biomass reduction, and soybean yield in wide and narrow row soybean.

		Common ragweed		Common lambsquarters		Total weed biomass reduction		Soybean biomass reduction[b]	Soybean yield[c]	
Treatment[a]	Rate	Wide	Narrow	Wide	Narrow	Wide	Narrow		Wide	Narrow
	g ai/ha	%							kg/ha	
Imazamox	35	77 b	90 a	89 bc	96 ab	94 c-e	98 bc	16 b	2960	3300
Imazamox	45	79 b	93 a	89 bc	99 a	98 bc	99 ab	10 bc	3030	3230
Imazethapyr	70	63 c	91 a	68 e	94 ab	84 f	95 b-d	15 b	2880	3230
Oxasulfuron + quizalofop	79 + 69	73 b	91 a	79 d	94 ab	69 g	92 de	21 b	2290	3090
Oxasulfuron + CGA-248757 + quizalofop	65 + 4 + 69	50 d	69 b	83 cd	95 ab	81 f	87 ef	16 b	2290	2690
Untreated		---	---	---	---	0 i	25 h	63 a	807	1140
Handweeded		---	---	---	---	100 a	100 a	0 c	3230	3430
LSD ($p \leq 0.05$)									--- 270 ---	

[a]All treatments included 2.6% (v/v) 28% urea ammonium nitrate. Imazamox and imazethapyr treatments included 1.0% (v/v) methylated seed oil and oxasulfuron tank mixtures included 0.25% (v/v) nonionic surfactant. All data was evaluated 56 days after treatment except soybean seed yield.
[b]Treatment means were combined over location. Means followed by a common letter are not significantly different with an LSD at the 5% level. Comparisons within columns and between row spacings are valid.
[c]Moisture was adjusted to 13%.

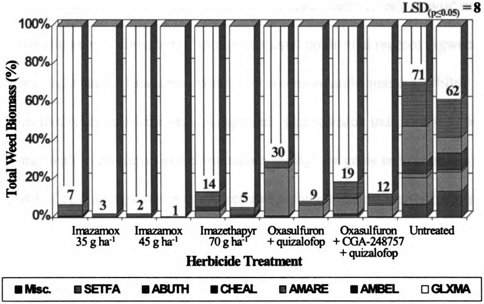

Figure 1. The percent of total weed biomass 56 days after treatment for wide and narrow row herbicide treatments. Wide row soybean treatments have vertical lines through the soybean portion of the vertical bars. White portions of the histogram bars indicate the percent soybean biomass and textured portions indicate the percent weed biomass. Numbers above the textured lines are the sum of the weed biomass percentages. Miscellaneous (Misc.) weeds included common chickweed, wild mustard, and eastern black nightshade.

SUMMARY

Imazamox, imazethapyr, oxasulfuron, and cloransulam-methyl injured soybean 7 days after treatment, but soybean recovered by 21 days after treatment. Imazamox, imazethapyr, oxasulfuron, and cloransulam-methyl controlled velvetleaf, wild mustard, and common chickweed. Imazamox and imazethapyr controlled redroot pigweed and eastern black nightshade. Imazamox controlled common lambsquarters, while cloransulam-methyl controlled common ragweed. Our research indicated the need for tank mixtures with oxasulfuron and cloransulam-methyl for grass and enhanced broadleaf weed control. Grass antagonism was species and herbicide dependent with oxasulfuron. Tank mixtures enhanced, but were not always needed for common ragweed control with imazamox, while tank mixtures with imazethapyr were needed for common lambsquarters and common ragweed control in wide row soybean. Imazamox at 35 and 45 g/ha controlled a broadspectrum of broadleaf weeds and giant foxtail in narrow row soybean. The diphenyl ether herbicides enhanced common ragweed control, but increased tillering and antagonized giant foxtail control by imazamox and imazethapyr. Soybean yield in wide rows was greater when a diphenyl ether was tank mixed with imazamox or imazethapyr, while yields were similar in narrow row soybeans without a tank mixture. Sodium cations similar to the ones present in the diphenyl ether herbicide formulations did not reduce giant foxtail control by imazamox or imazethapyr.