

Chapter V

Mesotrione, imazethapyr, and imazethapyr plus imazapyr in imidazolinone-resistant corn (*Zea mays*)

Abstract: Field studies were conducted in 1999, 2000, and 2001 to evaluate mesotrione at 105 and 210 g ai/ha alone and in combinations with 70 g ai/ha imazethapyr and the pre-package mix of 47 g/ha imazethapyr plus 16 g ai/ha of imazapyr postemergence. Mesotrione combinations with imazethapyr and imazethapyr plus imazapyr controlled common ragweed, common lambsquarters, and morningglory species better than imazethapyr or imazethapyr plus imazapyr alone. Similarly, these tank mixtures of mesotrione with imidazolinone herbicides improved the control of giant foxtail over that by mesotrione alone. Crop injury was less than 11% with all treatments and appeared as transient stunting. Corn yields were variable and generally reflected variations in late-season rainfall.

Nomenclature: Imazapyr; imazethapyr; mesotrione; common lambsquarters, *Chenopodium album* L. #¹ CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; giant foxtail, *Setaria faberi* Herrm. # SETFA; morningglory species, *Ipomoea* spp. # IPOSS; corn, *Zea mays* L.

Key words: Bleaching herbicides, triketone herbicides, imidazolinone herbicides, total postemergence.

Abbreviations: ALS, acetolactate synthase; DAT, days after treatment; POST, postemergence; WAT, weeks after treatment.

¹ Letters following this symbol are a WSSA-approved computer code for Composite List of Weeds, Revised in 1989. Available from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

INTRODUCTION

Imidazolinone-resistant corn was developed through conventional breeding methods. The acetolactate synthase (ALS, EC 4.1.3.18) enzyme in imidazolinone-resistant corn is less sensitive to ALS-inhibitor herbicides than the enzyme in standard corn hybrids (Newhouse et al. 1991; Currie et al. 1995). Imazethapyr and imazapyr are currently the only imidazolinone herbicides registered for weed control in imidazolinone-resistant corn. Imazethapyr is also registered for weed control in alfalfa (*Medicago sativa* L.), peanut (*Arachis hypogaea* L.), and soybean [*Glycine max* (L.) Merr.], while imazapyr is registered for broadleaf weed and grass control in non-crop areas (Ahrens 1994; Hagood et al. 2001). Imazapyr can be applied in imidazolinone-resistant corn only in a commercial pre-package mix of imazethapyr plus imazapyr² (3:1 ratio of imazethapyr : imazapyr).

Imazethapyr controls numerous annual grasses and broadleaf weeds (Klingaman et al. 1992; Bauer et al. 1995; Ballard et al. 1996; Monks et al. 1996; Krausz and Kapusta 1998). Tank mixtures of imazethapyr with imazapyr have increased control of pitted morningglory (*Ipomoea lacunosa* L.), entireleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], and johnsongrass [*Sorghum halepense* (L.) Pers.] over that with imazethapyr alone (Riley and Shaw 1988; Shaw and Wixson 1991). The pre-package mix of imazethapyr plus imazapyr often must be tank-mixed with other corn herbicides or follow a preemergence (PRE) herbicide to broaden the spectrum of weeds controlled (Hooks et al. 1998; Askew et al. 1999; Walker et al. 1999). However, mixtures of other herbicides with imazethapyr can sometimes antagonize imazethapyr against certain weed species (Bauer et al. 1995; Hart and Wax 1996; Krausz and Kapusta 1998; Starke and Oliver 1998). Therefore, new herbicides should be evaluated in combinations with imazethapyr

² Lightning[®] Herbicide, BASF Corporation, P.O. Box 13528, Research Triangle Park, NC 27709.

and imazethapyr plus imazapyr in imidazolinone-resistant corn to investigate weed control from these mixtures.

The effectiveness of weed control programs in imidazolinone-resistant corn is also dependent on application timing. Imazethapyr and the pre-package mix of imazethapyr plus imazapyr are most effective when applied postemergence (POST) to small (generally less than 10 cm) broadleaf weeds and grasses (Klingaman et al. 1992; Monks et al. 1996; Krausz and Kapusta 1998; Bond et al. 1999). Similarly, early application of many herbicides has provided optimal weed control in total POST programs associated with conventional corn varieties (Carey and Kells 1995; Tapia et al. 1997). Therefore, herbicide combinations in imidazolinone-resistant corn should be applied early to maximize weed control.

Mesotrione is a recently registered herbicide for preemergence and POST control of broadleaf weeds in corn (Anonymous 2001). This compound is the newest member of the triketone herbicide family, which also includes SC 0051, a herbicide registered in Europe for broadleaf weed control in corn (Beraud et al. 1993). Mesotrione, like other triketones, functions through inhibition of the enzyme p-hydroxyphenylpyruvate dioxygenase (HPPD, EC 1.13.11.27) (Norris et al. 1998; Pallet et al. 1998; Viviani et al. 1998).

POST mesotrione applications have controlled several annual broadleaf weeds, large crabgrass, and barnyardgrass in corn (Johnson and Young 1999; Sutton et al. 1999; Beckett and Taylor 2000; Johnson and Young 2000; Ohmes et al. 2000; Armel et al. 2001). However, POST applications generally fail to control most grass species (Ohmes et al. 2000; Armel et al. 2001). POST applications should include 1% v/v crop oil concentrate (COC) and 2.5% v/v urea ammonium nitrate (UAN) (Wichert and Pastushok 2000).

Imazethapyr and imazethapyr plus imazapyr control several annual grasses, but do not control a broad-spectrum of annual broadleaf weeds (Hagood et al. 2001). Conversely, mesotrione controls few grass species, but controls several broadleaf weeds (Beckett and

Taylor 2000; Ohmes et al. 2000). As a result, combinations of mesotrione with these imidazolinone herbicides may provide broad-spectrum weed control in imidazolinone-resistant corn. Therefore, an objective of this study was to evaluate the tolerance of imidazolinone-resistant corn to mesotrione POST alone and in combinations with imazethapyr and imazethapyr plus imazapyr. A second objective was to elucidate control of several broadleaf weeds and giant foxtail with mesotrione plus these imidazolinone herbicides.

MATERIALS AND METHODS

Field study. Studies were conducted at the Eastern Shore Agricultural Research and Extension Center near Painter, VA in 1999, 2000, and 2001. The soil type was a Bojac sandy loam (Typic Hapludults) with less than 1% organic matter and a pH of 6.1. A conventional seedbed was prepared by chisel plowing followed by tandem disking. Prior to planting, seedbeds were tilled with an S-tine field cultivator with double rolling baskets. Fertilizer was applied in accordance with current recommendations from Virginia Polytechnic Institute and State University (Donohue and Heckendorn 1994). In 1999 ‘Pioneer 3395IR’³ field corn hybrid was planted 3.8 cm deep at a rate of 56,800 seeds/ha, while in 2000 and 2001 ‘Pioneer 32Z18IR’ corn hybrid was planted at the same rate and depth. Corn was planted May 28, 1999, April 14, 2000, and April 30, 2001.

Plots were established to receive POST herbicide treatments. Each plot consisted of four rows spaced 0.76 m apart with a herbicide treated area of 2.5 m by 6.1 m; a 0.9 m untreated buffer was maintained between plots. Herbicides were applied POST with a tractor-mounted sprayer delivering 235 L/ha at 210 kPa through flat fan nozzles⁴. Herbicides were applied June 18, 1999, May 15, 2000, and May 14, 2001. These

³ Pioneer Hi-Bred International, Inc., 400 Locust Street, Suite 800, Des Moines, IA 50306-3453.

⁴ Teejet 8003 flat fan nozzle. Spraying Systems Company, North Avenue, Wheaton, IL 60188.

applications were made 21, 31, and 14 days after planting in 1999, 2000, and 2001, respectively. Mesotrione was evaluated alone at 105 and 210 g ai/ha and in combinations with 71 g/ha imazethapyr and the pre-package mix of 47 g/ha imazethapyr plus 16 g/ha imazapyr. Imazethapyr and imazethapyr plus imazapyr were applied alone at the same rates for comparison. All treatments included 1% v/v COC⁵ and 2.5% v/v UAN.

Weed species varied between years, but each species was present in at least two years in this study. Common ragweed (*Ambrosia artemisiifolia* L.) common lambsquarters (*Chenopodium album* L.), and giant foxtail (*Setaria faberi* Herrm.) were present in 2000 and 2001. In 1999, ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] was present, but in 2001 morningglory species were a mixture of ivyleaf morningglory, pitted morningglory, and tall morningglory [*Ipomoea purpurea* (L.) Roth]. Weed densities varied with species and year but were generally 5 to 80 plants / m². Herbicides were applied to weed less than 5 cm tall. Corn was 10 to 15 cm tall and in approximately the V3 to V4 stage of growth at POST herbicide applications in 1999 and 2000. In 2001, corn was about 25 cm tall and in approximately the V4 to V5 stage of growth.

Corn injury was evaluated 1 week after treatment (WAT). Weed control ratings were visually assessed approximately 8 WAT with the exception of morningglory species, which were rated approximately 4 WAT. Corn yields were determined by harvesting grain from the center two rows of each plot with a commercial combine modified for small plots and adjusting weight to 15.5% moisture prior to analysis.

Greenhouse study. A greenhouse study was conducted to evaluate corn injury with mesotrione, imazethapyr, and imazethapyr plus imazapyr alone and in combinations. Treatments applied in the greenhouse were the same as those applied in the field study. Herbicides were applied using a greenhouse cabinet sprayer at 220 L/ha with a pressure

⁵ Agridex, a mixture of 83% paraffinic mineral oil and 17% polyoxyethylene sorbitan fatty acid ester, Helena Chemical Company, 5100 Poplar Avenue, Memphis TN 38137.

of 210 kPa. A single even flow nozzle⁶ was placed 30 cm above the highest part of the treated plants. Four ‘Pioneer 3395IR’ corn seeds were planted into 9.5 cm by 9.5 cm pots⁷ filled with a high organic matter commercial potting mix⁸. Plants were watered and fertilized⁹ as needed to facilitate maximum plant growth and vigor. Prior to herbicide application, plants were thinned to three per pot. Corn plants were 12 to 18 cm tall at herbicide application.

Corn injury was visually rated 3 days after treatment (DAT). Corn heights were determined and shoot biomass was harvested 11 DAT. Corn plant heights were measured from the lowest point at the soil surface to the highest point on the corn plant and the heights were averaged over three plants per pot. After harvest, plants were dried to constant moisture and weighed. Corn plant heights and biomass ratings are represented as percent of control in comparison to the untreated check.

Treatments in the field were replicated three times and the greenhouse study was replicated four times and all studies were repeated. All studies were organized in a randomized complete block design. Crop injury and weed control was visually rated on a scale of 0 to 100% where 0 = no injury or weed control and 100 = crop death or complete weed control. Data were subjected to analysis of variance (ANOVA) and means were separated using Fisher’s Protected LSD test at the $\alpha = 0.05$ significance level. When ANOVA revealed no significant year by treatment interaction, data were pooled over years. The untreated check was not included in the statistical analysis.

⁶ Teejet 8002 EVS flat fan spray tip. Spraying Systems Co., North Avenue, Wheaton, IL 60188.

⁷ T.O. Plastics 4” Fill Pots. Inside dimensions 9.5 cm by 9.5 cm by 8.1 cm. Wetzel, Inc., 1345 Diamond Springs Road, Virginia Beach, VA 23455.

⁸ Pro-Mix BX. Premier Horticulture, Inc., Red Hill, PA 18076.

⁹ Excel All Purpose 21-5-50. Wetzel, Inc., 1345 Diamond Springs Road, Virginia Beach, VA 23455.

RESULTS and DISCUSSION

Field study. There was no year by treatment interaction with common ragweed data; therefore these data were pooled over 2000 and 2001. All other data are presented separately over years. In previous studies, common ragweed control from POST mesotrione has been variable, but tank-mixtures of mesotrione with low rates of atrazine have improved common ragweed control (Armel 2002). In this study, common ragweed was controlled 76 and 84% with mesotrione at 105 and 210 g/ha, respectively (Table 5.1). Tank mixtures of mesotrione with either imazethapyr or imazethapyr plus imazapyr controlled common ragweed similar to control observed with mesotrione alone. However, control of common ragweed with imazethapyr and imazethapyr plus imazapyr alone was lower than that with mesotrione. Ballard et al. (1996) also reported that POST applications of imazethapyr were inadequate for control of common ragweed.

Common lambsquarters was controlled 91 to 99% with mesotrione applied alone or in combinations with imazethapyr or imazethapyr plus imazapyr (Table 5.1). Others have reported better than 90% control of common lambsquarters from POST mesotrione applications (Lackey et al. 1999; Beckett and Taylor 2000; Menbere and Ritter 2001). However, when imazethapyr or imazethapyr plus imazapyr were applied alone, common lambsquarters control was variable. In 2000, imazethapyr and imazethapyr plus imazapyr controlled common lambsquarters 46 and 62%, respectively. The following year, these treatments controlled common lambsquarters 75 and 92%, respectively. Vencill et al. (1990) also reported variability in common lambsquarters control with imazethapyr and attributed this difference to variations in rainfall after application. However, in our studies, at least 2.3 cm of rainfall was received within 1 WAT in both years.

Mesotrione and the combinations of mesotrione plus either imazethapyr or imazethapyr plus imazapyr controlled morningglory species 82 to 96% (Table 5.2). This was comparable to control of morningglory species by the imidazolinone herbicides in 1999 and greater than control by the imidazolinone herbicides in 2000.

Giant foxtail control with mesotrione alone was less than 32% in both 2000 and 2001 (Table 5.2). Ohmes et al. (2000) also reported low control of giant foxtail with mesotrione alone. When mesotrione was tank-mixed with imazethapyr or imazethapyr plus imazapyr, giant foxtail was controlled at least 84%. Similarly imazethapyr and imazethapyr plus imazapyr alone controlled giant foxtail at least 85% in 2000 and 2001. Imazethapyr has been previously reported to control giant foxtail (Mills and Witt 1989a; Mills and Witt 1989b). However, antagonism of giant foxtail control has been reported when imazethapyr was tank-mixed with other herbicides (Hart et al. 1997; Nelson et al. 1998). This did not occur when mesotrione was mixed with imazethapyr or imazethapyr plus imazapyr.

Imidazolinone-resistant corn was injured less than 11% with all treatments in every year. Injury generally consisted of transient stunting that usually disappeared by 3 WAT (Table 5.3). Corn yields were generally higher in 2000 and 2001 due to higher amounts of rainfall in July and August compared to rainfall in 1999. In 1999, herbicide treatments did not affect corn yield and all herbicide-treated corn produced yields of 1.07 to 2.08 Mg/ha, while the untreated check produced 1.49 Mg/ha. In 2000, yields from corn treated with mesotrione, imazethapyr, and imazethapyr plus imazapyr applied alone were similar, but corn treated with combinations of mesotrione with imazethapyr or imazethapyr plus imazapyr produced higher corn yields. Again in 2001, herbicide treatments did not affect the yields of imidazolinone-resistant corn. Herbicide-treated corn produced yields between 9.82 and 11.83 Mg/ha in 2001, while the untreated check yielded 7.39 Mg/ha.

Greenhouse study. Imidazolinone-resistant corn response to herbicide treatments in the greenhouse was also minimal. Corn injury at 3 DAT did not exceed 5% from any treatment and height reductions did not exceed 11% (Table 5.4). Further, corn biomass, although variable, was not affected by any treatment. Walker et al. (1999) previously reported negligible injury from various herbicides in imidazolinone-resistant corn.

In these studies, mesotrione tank-mixtures with imazethapyr or imazethapyr plus imazapyr controlled most broadleaf weeds and giant foxtail with minimal corn injury. Combinations of mesotrione with imazethapyr or imazethapyr plus imazapyr controlled common lambsquarters, common ragweed, and generally morningglory species better than imidazolinone herbicides alone. Similarly, imazethapyr and imazethapyr plus imazapyr controlled giant foxtail better than mesotrione applied alone. Other researchers have reported that low rates of atrazine improved mesotrione activity on larger or more difficult to control weeds (Johnson and Young 1999; Armel et al. 2000; Beckett and Taylor 2000; Johnson and Young 2000; Mueller 2000; Armel et al. 2001). Therefore, it is likely that the addition of low rates of atrazine to combinations of mesotrione plus imidazolinone herbicides may increase control of morningglory species and common ragweed over that by mesotrione plus imidazolinone herbicides.

ACKNOWLEDGEMENTS

The authors thank Syngenta Crop Protection, Inc. and the Virginia Corn Board for their support of this project. We also thank all the graduate students and technical support personnel who worked on this project, especially Rob Richardson, Brian Wilson, Brian Trader, Brian Johnson, Andy Bailey, and Art Graves.

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Table 5.1. Common ragweed and common lambsquarters control from postemergence applications of mesotrione alone or in combinations with imazethapyr or imazethapyr plus imazapyr in 2000 and 2001.

Treatments ^c	Rate — g ai/ha —	Weed control ^a		
		Common ragweed 2000 + 2001 ^b	Common lambsquarters	
			2000	2001
			%	
Mesotrione	105	76	98	96
Mesotrione	210	84	98	99
Mesotrione + imazethapyr	105 + 71	83	99	99
Mesotrione + imazethapyr	210 + 71	91	99	99
Mesotrione + imazethapyr + imazapyr	105 + 47 + 16	77	91	99
Mesotrione + imazethapyr + imazapyr	210 + 47 + 16	88	96	99
Imazethapyr	71	65	46	75
Imazethapyr + imazapyr	47 + 16	58	62	92
Untreated check ^d		0	0	0
LSD _{0.05}		7	12	11

^a Weed control ratings were made 8 weeks after treatment.

^b No year by treatment interaction occurred with common ragweed control, therefore these data are pooled over 2000 and 2001.

^c All treatments included 1% v/v crop oil concentrate and 2.5% v/v urea ammonium nitrate.

^d Untreated check not included in the statistical analysis.

Table 5.2. Control of morningglory species and giant foxtail from postemergence applications of mesotrione alone and in combinations with imazethapyr and imazethapyr plus imazapyr in 1999 and 2001.

Treatments ^b	Rate g ai/ha	Weed control ^a			
		Morningglory species		Giant foxtail	
		1999	2001	2000	2001
		%			
Mesotrione	105	88	82	3	32
Mesotrione	210	91	96	27	32
Mesotrione + imazethapyr	105 + 71	98	83	85	94
Mesotrione + imazethapyr	210 + 71	98	93	84	91
Mesotrione + imazethapyr + imazapyr	105 + 47 + 16	95	86	88	90
Mesotrione + imazethapyr + imazapyr	210 + 47 + 16	95	92	92	89
Imazethapyr	71	84	66	92	90
Imazethapyr + imazapyr	47 + 16	93	71	88	85
Untreated check ^c		0	0	0	0
LSD _{0.05}		10	10	9	8

^a Ratings for morningglory species and giant foxtail were made 4 and 8 weeks after treatment respectively.

^b All treatments included 1% v/v crop oil concentrate and 2.5% v/v urea ammonium nitrate.

^c Untreated check not included in the statistical analysis.

Table 5.3. Injury and yields of corn treated postemergence with mesotrione alone or in combinations with imazethapyr or imazethapyr plus imazapyr in 1999, 2000, and 2001.^a

Treatments ^c	Rate	Injury ^b			Yield		
		1999	2000	2001	1999	2000	2001
	g ai/ha	%			Mg/ha		
Mesotrione	105	2	4	4	1.93	1.55	11.0
Mesotrione	210	4	4	5	1.28	1.42	11.17
Mesotrione + imazethapyr	105 + 71	2	6	6	1.27	5.66	9.82
Mesotrione + imazethapyr	210 + 71	3	5	10	1.16	5.45	11.77
Mesotrione + imazethapyr + imazapyr	105 + 47 + 16	3	4	7	1.65	5.52	11.78
Mesotrione + imazethapyr + imazapyr	210 + 47 + 16	4	5	10	1.45	7.16	11.37
Imazethapyr	71	4	5	5	2.08	2.36	11.83
Imazethapyr + imazapyr	47 + 16	3	3	10	1.07	2.27	10.61
Untreated check ^d		0	0	0	1.49	0.48	7.39
LSD _{0.05}		NS	NS	3	NS	2.14	NS

^a Abbreviations: NS, not significant.

^b Corn injury was rated 1 week after treatment.

^c All treatments included 1% v/v crop oil concentrate and 2.5% v/v urea ammonium nitrate.

^d Untreated check not included in the analysis.

Table 5.4. Injury, height, and biomass reductions of corn treated with postemergence mesotrione alone or in combinations with imazethapyr or imazethapyr plus imazapyr in the greenhouse.^a

Treatments ^c	Rate g ai/ha	Injury	Height	Biomass
		3 DAT	11 DAT	11 DAT
		— % —	— % of control —	
Mesotrione	105	1	102	106
Mesotrione	210	2	103	119
Mesotrione + imazethapyr	105 + 71	5	89	103
Mesotrione + imazethapyr	210 + 71	3	106	108
Mesotrione + imazethapyr + imazapyr	105 + 47 + 16	3	93	112
Mesotrione + imazethapyr + imazapyr	210 + 47 + 16	4	99	107
Imazethapyr	71	2	102	127
Imazethapyr + imazapyr	47 + 16	2	95	101
Untreated check ^d		0	100	100
LSD _{0.05}		2	11	NS

^a Abbreviations: DAT, days after treatment; NS, not significant.

^b No block by treatment interaction occurred, therefore both 4 replication studies are presented together.

^c All treatments included 1% v/v crop oil concentrate and 2.5% v/v urea ammonium nitrate.

^d Untreated check not included in the statistical analysis.