Evaluation of Acetolactate Synthase-inhibiting Herbicides for Weed Control in Transplanted Bell Pepper

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SUMMARY. Field and greenhouse studies were conducted in 2001 and 2002 near Painter, VA, to determine the level of weed control and pepper (*Capsicum annuum*) tolerance to postemergence applications of the acetolactate synthase (ALS) inhibitors trifloxysulfuron, halosulfuron, sulfosulfuron, cloransulam, and tribenuron. Based on measurements of visual injury, heights, dry weights, and chlorophyll content of pepper, the safest ALS inhibitor to pepper was trifloxysulfuron followed by halosulfuron, cloransulam, sulfosulfuron, and tribenuron. In addition, trifloxysulfuron was the only herbicide that provided greater than 86% control of pigweed species (*Amaranthus* spp.) and carpetweed (*Mollugo verticillata*) in both years of the field study. Trifloxysulfuron was also the only herbicide evaluated that did not reduce pepper yield compared with the control in both years of the field study.

Pepper yield is significantly impacted by weed competition. The broadleaf weeds redroot pigweed (*Amaranthus retroflexus*) and hairy galinsoga (*Galinsoga ciliata*) have reduced pepper yield by as much as 88% and 99%, respectively (Fu and Ashley, 2006). Purple nutsedge (*Cyperus rotundus*) has reduced pepper yield by as much as 70% (Morales-Payan et al., 2003). Weeds must be controlled at least through the first half of the cropping season to avoid significant yield loss in pepper, and this level of weed control may not always be achieved with the use of

herbicides applied before weed emergence (Amador-Ramirez, 2002). However, the majority of the herbicides available for weed control in pepper are only selective to pepper when applied as preplant (PP), preplant incorporated (PPI), or pre-emergence (PRE) applications applied before weed emergence. In fact, the only herbicides registered for postemergence (POST) over-the-top weed control in pepper are gramincides that control only grass weeds (Orzolek et al., 1986; Stall, 2007).

Clomazone provides control of certain annual grasses and several broadleaf weeds, including common ragweed (*Ambrosia artemisiifolia*), common lambsquarters (*Chenopodium album*), prickly sida (*Sida spinosa*), velvetleaf (*Abutilon theophrasti*), and jimsonweed (*Datura stramonium*) in pepper (Ackley et al., 1992; Stall, 2007). Pepper tolerance to PRE clomazone applications is due to lower uptake and more rapid metabolism of

clomazone to inactive metabolites in pepper compared with other more sensitive crops and weeds (Weston and Barrett, 1989). Clomazone tolerance is greatest when applied PP, PPI, or POST to transplanted pepper than when applied PRE to direct-seeded pepper (Ackley et al., 1998; Cavero et al., 1996). On the Coastal Plain soils of eastern Virginia, clomazone is often applied PP or PPI in combinations with napropamide, metolachlor, or trifluralin to improve suppression of the broadleaf weeds smooth pigweed (*Amaranthus hybridus*), carpetweed, and several annual grasses (Ackley et al., 1992). Metolachlor can also be applied with clomazone to improve control of yellow nutsedge (*Cyperus esculentus*) (Stall, 2007; Vencill, 2002). However, full-season control of all broadleaf and sedge weeds is unlikely with these clomazone programs.

Selected herbicides have been evaluated for POST over-the-top weed control in pepper. The photosystem II (PSII) inhibitor bentazon was evaluated for POST weed control in several varieties of peppers because it is currently used to control several broadleaf weeds and yellow nutsedge in minor crops like mint (*Mentha* spp.), pea (*Pisum sativum*), and bean (*Phaseolus* spp.) (Baltazar et al., 1984). However, pepper injury and yield varied greatly between pepper varieties treated with different POST rates of bentazon (Baltazar et al., 1984; Wolff et al., 1989). This variability in tolerance was due to differential detoxification of bentazon among these pepper varieties (Baltazar and Monaco, 1984). Another PSII inhibitor, metribuzin, was also evaluated as a POST treatment for weed control in pepper based on its safety in tomato (*Solanum lycopersicum*) and potato (*Solanum tuberosum*). However, metribuzin caused severe injury and yield reductions when applied POST in pepper

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
28.3495	oz	g	0.0353
70.0532	oz/acre	g·ha ⁻¹	0.0143
6.8948	psi	kPa	0.1450

(Orzolek et al., 1986). Similarly, the ALS-inhibiting herbicide rimsulfuron was evaluated, but the level of tolerance was not commercially acceptable (Ackley et al., 1998; Stall, 1999). Another ALS inhibitor, halosulfuron, has provided reduced phytotoxicity on pepper when compared with rimsulfuron (Stall 1999).

The objective of this research was to determine if POST applications of several ALS-inhibiting herbicides would provide selective broadleaf weed control in transplanted bell peppers. An additional objective was to characterize pepper tolerance to these ALS inhibitors with visual injury evaluations and measurements of pepper height, biomass, chlorophyll content, and yield.

Materials and methods

FIELD STUDY. Studies were conducted at the Eastern Shore Agricultural Research and Extension Center near Painter, VA, in 2001 and 2002. The soil type was a Bojac sandy loam (Typic Hapludults) with less than 1% organic matter and a pH of 6.1 to 6.2. A conventional seedbed was prepared by chisel plowing followed by disking. Before planting, the experimental area was tilled with an S-tine field cultivator with double rolling baskets. Fertilizer was applied in accordance with regional recommendations (Donohue and Heckendorn, 1994). Pepper variety Camelot was transplanted 1 ft apart within each row with a single row transplanter on 14 June 2001 and 20 June 2002. A PPI application of trifluralin (Treflan®; Dow Agrosciences, Indianapolis, IN) at 8 oz/acre plus clomazone (Command®; FMC Corp., Philadelphia, PA) at 4.5 oz/acre was applied to the entire test area (including the control areas) before pepper transplant to aid in the control of grass weeds.

Plots for POST herbicide treatments consisted of two treated rows spaced 3 ft apart with a treated area of 8 × 20 ft; a single guard row of peppers separated each plot. Herbicides were applied POST with a propane-powered backpack sprayer calibrated to deliver 220 L·ha⁻¹ at 210 kPa through flat fan nozzles (Teejet 8003 flat fan nozzle; Spraying Systems, Wheaton, IL). POST applications were made on 12 July 2001 and 12 July 2002. Five ALS-inhibiting herbicides were applied at rates in which they

selectively controlled broadleaf weeds in certain broadleaf crops or at rates that provide limited herbicidal activity on Solanaceous weeds, such as black nightshade (*Solanum nigrum*), which is closely related to pepper (Stall 1999; Vencill 2002). Herbicide treatments included trifloxysulfuron (Envoke®; Syngenta Crop Protection, Greensboro, NC) at 4 g·ha⁻¹, halosulfuron (Sandea®; Gowan Co., Yuma, AZ) at 13, 20, and 27 g·ha⁻¹, sulfosulfuron (Maverick®; Monsanto Co., St. Louis, MO) at 46 g·ha⁻¹, cloransulam (First-Rate™; Dow Agrosciences) at 18 g·ha⁻¹, and tribenuron (Express®; DuPont Crop Protection, Wilmington, DE) at 17 g·ha⁻¹. All treatments in the field studies included 0.25% nonionic surfactant (Induce®; Helena Chemical Co., Memphis, TN).

Plots were established in 2001 into sites that contained pigweed species and carpetweed. Pigweed in 2001 consisted primarily of prostrate pigweed (*Amaranthus blitoides*), but in 2002, smooth pigweed was the major species present. Pigweed and carpetweed were up to 4 inches tall at POST applications in 2001; however, most of the pigweed and carpetweed were not emerged at the time of POST applications in 2002. Pepper was ≈7 to 12 inches tall at POST herbicide applications in both years.

Pepper injury from herbicide applications was evaluated 1, 2, and 4 weeks after treatment (WAT). Weed control was evaluated 4 WAT. Pepper yields were determined by hand harvesting fruit from both rows of each plot between two and three times per season.

GREENHOUSE STUDY. Greenhouse studies were conducted in 2002 to evaluate pepper tolerance to POST applications of the ALS inhibitors halosulfuron at 27, 54, and 134 g·ha⁻¹, trifloxysulfuron at 8, 15, and 38 g·ha⁻¹, sulfosulfuron 46, 92, and 230 g·ha⁻¹, cloransulam 18, 36, and 90 g·ha⁻¹, and tribenuron 17, 34, and 84 g·ha⁻¹. Herbicide rates were selected based on the lowest registered use rate for these herbicides in their primary crop. Two additional rates of each herbicide were also included that corresponded to two and five times these primary use rates.

One 'Camelot' pepper plant was transplanted into a 4 × 4-inch pot (T.O. Plastics 4" Fill Pots; Wetzel, Virginia Beach, VA) filled with a

commercial potting mix (Pro-Mix BX; Premier Horticulture, Red Hill, PA). Plants were watered and fertilized (Excel All Purpose 21N-2.2P-41.6K; Wetzel) as needed to facilitate maximum plant growth and vigor. Pepper plants were 7 to 9 inches tall at herbicide application and similar to pepper heights when POST applications were made in the field study. Herbicides were applied using a greenhouse cabinet sprayer at a spray volume of 220 L·ha⁻¹ and 210 kPa pressure. A single even flow nozzle (Teejet 8002 EVS flat fan spray tip; Spraying Systems) was placed 12 inches above the uppermost part of the pepper plants. All treatments in the greenhouse studies included 0.25% (v/v) nonionic surfactant (Induce®; Helena Chemical Co.).

Pepper injury was visually rated 1 and 3 WAT. Chlorophyll content was measured at 1 WAT on a representative leaf in the meristematic regions of each plant with a chlorophyll meter (Spad 502; Konica Minolta, Tokyo). Pepper heights were measured 3 WAT from the potting mix surface to the uppermost point on the pepper plant. Shoot biomass was then harvested and plants were dried to constant moisture and weighed. Heights, chlorophyll content, and biomass ratings are presented as the percentage of reduction in comparison with the nontreated control.

Field and greenhouse studies were arranged in a randomized complete block design. Treatments in the field were replicated three times and greenhouse treatments were replicated four times; all studies were repeated once. Pepper injury and weed control were visually rated on a scale of 0 to 100, where 0 equals no pepper injury or weed control and 100 equals pepper death or complete weed control. Data from the field and greenhouse studies were subjected to analysis of variance (ANOVA) and Fisher's protected least significant difference (LSD) ($P = 0.05$) was used for mean separation. Data were pooled over studies when no study by treatment interaction occurred. The nontreated control was not included in the analyses of the greenhouse studies.

Results and discussion

FIELD STUDY. In the field study, no year by treatment interaction

Table 1. Pepper injury, control of pigweed species and carpetweed, and pepper yield with postemergence applications of several acetolactate synthase inhibitors.

Treatments ^v	Rate (g·ha ⁻¹) ^u	Injury (%)					Weed control (%) ^z				Yield (kg/plot) ^y	
		1 WAT ^x		2 WAT		4 WAT	Pigweed species ^w		Carpetweed		Pepper	
		2001 + 2002 ^t	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Trifloxysulfuron	4	12	9	17	5	17	87	98	96	98	17.6	15.5
Halosulfuron	13	15	8	14	10	12	60	96	80	67	8.8	14.3
Halosulfuron	20	20	12	22	6	16	68	99	81	77	11.1	11.7
Halosulfuron	27	20	14	27	13	22	75	98	92	72	11.8	10.5
Sulfosulfuron	46	28	23	49	13	52	77	99	85	99	16.2	1.3
Cloransulam	18	28	33	44	18	45	71	99	89	99	14.1	4.9
Tribenuron	17	33	40	74	42	78	85	62	68	33	4.2	0
Control		0	0	0	0	0	0	0	0	0	11.1	20.5
LSD _{0.05} ^s		5	6	5	6	22	13	4	9	12	4.5	5.3

^vWeed control ratings were made 4 weeks after herbicide treatment.

^u1 kg = 2.2046 lb.

^xWAT = weeks after treatment.

^wPigweed in 2001 primarily consisted of prostrate pigweed; in 2002, smooth pigweed was the primary species present.

^yAll treatments included 0.25% (v/v) nonionic surfactant.

^z1 g·ha⁻¹ = 0.0143 oz/acre.

^tNo year by treatment interaction occurred for pepper injury at 1 WAT, therefore, these data are pooled over years.

^sLSD_{0.05} = Fisher's protected least significant difference at $P = 0.05$.

occurred for pepper injury 1 WAT; therefore, these data were pooled over years (Table 1). All other data from these field studies are presented by year.

All herbicides except tribenuron provided greater than 95% control of pigweed species in 2002 (Table 1). This low control of pigweed species with tribenuron is likely due to its limited soil residual activity in comparison with the other ALS inhibitors evaluated (Vencill, 2002). When prostrate pigweed was the predominant species in 2001, only tribenuron at 17 g·ha⁻¹ and trifloxysulfuron at 4 g·ha⁻¹ provided 85% or greater control of pigweed species. This type of differential response of ALS inhibitors to pigweed species has been previously reported (Nelson and Renner, 1998; Trader et al., 2007; Umeda, 1999).

Carpetweed was controlled 85% to 99% with trifloxysulfuron, sulfosulfuron, and cloransulam (Table 1). Halosulfuron controlled emerged carpetweed 80% to 92% in 2001, but only 67% to 72% in 2002 when most carpetweed had not emerged at the time of POST herbicide applications. POST halosulfuron applied alone or in sequential applications at rates greater than 25 g·ha⁻¹ provided better control of carpetweed in other studies (MacRae et al., 2008). Tribenuron controlled carpetweed 33% to 68%, which was not considered commercially acceptable.

Pepper injury differed greatly with the herbicides applied and the year in which these herbicides were applied. Halosulfuron at 20 and 27 g·ha⁻¹, sulfosulfuron at 46 g·ha⁻¹, and tribenuron 17 g·ha⁻¹ caused 20% to 30% injury to pepper by 1 WAT (Table 1). Halosulfuron at 13 g·ha⁻¹ and trifloxysulfuron 4 g·ha⁻¹ injured pepper 15% and 12%, respectively. In 2001, pepper injury generally declined over time with the exception of pepper treated with tribenuron, which caused 42% injury by 4 WAT. In 2002, pepper injury generally increased over time, except for pepper treated with halosulfuron at 13 and 20 g·ha⁻¹. This differential injury over years is likely due to the increased amount of rainfall received within 8 d after treatment in 2002 (6.1 cm) compared with 2001 (0.38 cm), and therefore likely enhanced herbicide root absorption. By 4 WAT, the lowest amount of injury was observed on pepper treated with trifloxysulfuron at 4 g·ha⁻¹ and halosulfuron at 13 and 20 g·ha⁻¹.

Pepper treated with halosulfuron and cloransulam produced yields similar to those in the control in 2001 (Table 1). Trifloxysulfuron and sulfosulfuron treated pepper yielded 17.6 and 16.2 kg/plot, respectively, which was greater than pepper yield in the control (11.1 kg/plot) in 2001. When crop injury was most pronounced among all treatments in 2002, trifloxysulfuron was the only treatment that did not reduce pepper yield in

comparison with the control. Tribenuron was the only treatment that produced lower pepper yield than the control in both years of this study.

GREENHOUSE STUDY. In the greenhouse study, no repetition by treatment interaction occurred for 1 and 3 WAT pepper injury, percentage of chlorophyll reductions, and percentage of height reductions; therefore, these data were pooled over repetition (Table 2). However, there was a repetition by treatment interaction for percentage of dry weight reductions, and these data are presented by repetition.

Pepper injury from these ALS inhibitors was generally a combination of stunting and chlorosis and ranged from 11% to 34% with all treatments by 1 WAT (Table 2). Injury increased with all treatments by 3 WAT. Trifloxysulfuron at 8 g·ha⁻¹ caused the lowest level of pepper injury (18%), which was similar to trifloxysulfuron at 15 g·ha⁻¹ and halosulfuron at 27 and 54 g·ha⁻¹. In addition, all herbicide treatments reduced chlorophyll content 35% to 69%. Chlorophyll reduction was least in pepper treated with trifloxysulfuron at 8 and 15 g·ha⁻¹, halosulfuron at 27 g·ha⁻¹, and cloransulam at 18 g·ha⁻¹.

Trifloxysulfuron at 8 and 15 g·ha⁻¹ and halosulfuron at 27, 54, and 134 g·ha⁻¹ caused the least amount of pepper height reductions (Table 2). All other treatments reduced pepper heights between 23% and 33%. Pepper dry weights were

Table 2. Pepper injury, percentage of height reductions, percentage of dry weight reductions, and percentage of chlorophyll reductions from postemergence applications of acetolactate synthase inhibitors in the greenhouse.

Treatments ^y	Rate (g·ha ⁻¹) ^x	Injury (%)		Chlorophyll reduction (%)	Ht reduction (%)	Dry wt reduction (%) ^z	
		Study 1 + Study 2		Study 1 + Study 2	Study 1 + Study 2	Study 1	Study 2
		1 WAT ^w	3 WAT	1 WAT	3 WAT	3 WAT	3 WAT
Trifloxysulfuron	8	11	18	39	11	39	43
Trifloxysulfuron	15	14	22	35	15	52	63
Trifloxysulfuron	38	19	41	58	23	65	66
Halosulfuron	27	15	21	45	12	48	61
Halosulfuron	54	19	25	48	15	68	62
Halosulfuron	134	26	39	58	19	79	79
Sulfosulfuron	46	24	38	63	27	75	79
Sulfosulfuron	92	25	44	62	25	78	79
Sulfosulfuron	230	30	58	65	29	85	86
Cloransulam	18	24	39	47	27	76	77
Cloransulam	36	26	45	50	25	86	83
Cloransulam	90	34	63	58	31	88	85
Tribenuron	17	32	61	56	30	86	89
Tribenuron	34	32	68	63	28	88	89
Tribenuron	84	34	75	69	33	92	89
Nontreated control ^y		0	0	0	0	0	0
LSD _{0.05} ^u		5	9	12	7	12	8

^zA block by treatment interaction occurred for pepper dry weight reduction data, therefore, these data are presented by test. No block by treatments interaction occurred for any other data, therefore, these data are pooled.

^yAll treatments included 0.25% (v/v) nonionic surfactant.

^x1 g·ha⁻¹ = 0.0143 oz/acre.

^wWAT = weeks after treatment.

^yNontreated control not included in statistical analysis.

^uLSD_{0.05} = Fisher's protected least significant difference at $P = 0.05$.

reduced 39% to 92% by all herbicide treatments. Trifloxysulfuron at 8 g·ha⁻¹ provided the lowest amount of pepper dry weight reductions over both repetitions of this study.

Variations in weed control and pepper injury, chlorophyll content, heights, dry weights, and yield were observed depending on the rate of each ALS inhibitor applied POST to pepper. Greater rainfall in 2002 likely increased pepper injury and yield loss from several herbicide treatments by increasing herbicide uptake through the roots. Trifloxysulfuron was the only herbicide that provided greater than 86% control of pigweed species and carpetweed in both years of the field study. In addition, trifloxysulfuron provided the lowest levels of injury and chlorophyll, height, and dry weight reductions when compared with most other treatments. Similarly, trifloxysulfuron was the only herbicide that did not reduce pepper yield in both years in comparison with the control. Therefore, future studies should include evaluations of trifloxysulfuron at different rates for safety to several varieties of pepper. In addition, future studies should include trifloxysulfuron treat-

ments applied PP, PPI, PRE, or POST-directed to pepper for potential improvements in weed control while limiting potential pepper injury, as has been observed with other ALS inhibitors in vegetable crops (Dittmar et al., 2008).

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