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The Potential of Sulfosulfuron to Control Troublesome Weeds in Tomato[1]

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Abstract: There are few efficient and cost-effective methods for controlling weeds in processing tomatoes. Sulfosulfuron is a sulfonylurea herbicide developed for controlling weeds in wheat. In previous studies, we have demonstrated the efficacy of sulfosulfuron in selectively controlling *Orobanche aegyptiaca* in tomato. The objective of the present study was to elucidate the potential of sulfosulfuron to selectively control troublesome, nonparasitic weeds in tomato. In the greenhouse, sulfosulfuron efficacy at 37.5, 75.0, and 112.5 g ai/ha applied preplant incorporated (PPI), preemergence (PRE), and postemergence (POST) was tested. Sulfosulfuron when applied PPI and POST was highly selective in controlling weeds without causing injury to tomato. The weeds that were efficiently controlled, even at low rates of application, included purple nutsedge, black nightshade, mustard, pigweed, and bindweed. PRE application resulted in the most efficient weed control but was phytotoxic to tomato at high rates.

Nomenclature: Sulfosulfuron; black nightshade, *Solanum nigrum* L. #[3] SOLNI; field bindweed, *Convolvulus arvensis* L., # CONAR; purple nutsedge, *Cyperus rotundus* L. # CYPRO; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; tomato, *Lycopersicon esculentum* Mill. # LYPES; wheat, *Triticum aestivum* L.; wild mustard, *Sinapis arvensis* L. # SINAR.

Additional index words: Acetolactate synthase inhibitors, sulfonylurea herbicides, weed management.

Abbreviations: ALS, acetolactate synthase; DAA, days after application; DAP, days after planting; POST, postemergence; PPI, preplant incorporated; PRE, preemergence.

INTRODUCTION

Sulfosulfuron is a sulfonylurea herbicide that is registered worldwide for preemergence (PRE) and postemergence (POST) weed control in wheat. The herbicide was first introduced as MON 37500 (Anonymous 1995) and subsequently commercially registered as "Maverick" 75% WG in the United States, "Monitor™" 75% WG in the Czech Republic and Slovakia, "Monitor™" 80% WG at Switzerland, and "Apyros™" 75% WG in Poland (Vencill 2002).

Sulfosulfuron is a selective systemic herbicide that is absorbed through foliage and roots of plants by rapid acropetallic and basipetallic translocation (Schloss 1995).

Plants can metabolize sulfonylurea herbicides through the hydroxylation of the phenyl ring by cytochrome P450 (Frear et al. 1991; Hinz et al. 1997). Selectivity of wheat and other grasses such as *Aegilops cylindria* to sulfosulfuron is due to rapid metabolism of the herbicide (Olson et al. 2000). Metabolism of sulfosulfuron rather than an insensitive site of action is reported for a downy brome (*Bromus tectorum*) sulfosulfuron-resistant biotype (Mallory Smith et al. 1999). The mechanism of tolerance of tomato to sulfosulfuron is unknown.

Sulfosulfuron at recommended application rates of 20 to 35 g ai/ha effectively controls the annual grasses *Bromus* spp., *Hordeum* spp., *Poa* spp., *Phalaris minor*, and *Avena fatua*; the perennial grasses *Eltrigia repens* and *Sorghum helpense*; and the important broadleaf plants *Amaranthus* spp., *Sinapis arvensis*, *Brassica* spp., *Matricaria* spp., *Helianthus* spp., *Stellaria media*, and *Galium aparine* (Anonymous 1995).

Although sulfosulfuron was initially developed and registered for controlling weeds in wheat, its selectivity to some broadleaf crop species has recently led to its registration under the name "Apyros" 75% WG for weed control in potato (*Solanum tuberosum* L.) in Poland. Studies conducted in Poland showed that POST application of 20 to 26.5 g ai/ha sulfosulfuron effectively controlled *Eltrigia repens*, *Galium aparine*, *Capsella*

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

bursa-pastoris, and cereal volunteers without injuring potatoes (Kutzior et al. 1999).

The mode of resistance of specific Solanaceae species to sulfosulfuron has not been studied, but it probably involves alteration of an acetolactate synthase (ALS) binding site or metabolism of the herbicide to nonphytotoxic products.

Tomato is an intensively grown crop that is infested by troublesome weeds such as purple nutsedge, field bindweed, and black nightshade (Branthome 1990). Nightshade belongs to the same family as that of tomato and therefore is difficult to control in tomato fields. Few new herbicides have been registered for control of weeds in processing tomato, and current weed control strategies are expensive, requiring costly herbicides and hand weeding.

In previous laboratory and field trials the effectiveness and the selectivity of sulfosulfuron and other ALS-inhibiting herbicides were demonstrated for broomrape (*Orobanche* spp.) control in tomato (Eizenberg et al. 2001a, 2001b; Hershenhorn et al. 1998) and in potato (Goldwasser et al. 2001). Rimsulfuron, a sulfonylurea herbicide similar to sulfosulfuron, is used in tomato production worldwide (Reinke et al. 1991). This herbicide lacks persistence and does not control purple nutsedge, black nightshade, and field bindweed.

In the present article, sulfosulfuron was tested for selective control of troublesome weeds in tomato.

MATERIALS AND METHODS

The effects of sulfosulfuron on 10 weed species and on the processing tomato variety 'Brigade' were tested. The following seeds were sown at a depth of 1 cm: redroot pigweed (10 seeds/pot), common wild beet (*Beta vulgaris* L.) (5 seeds/pot), field bindweed (10 seeds/pot), purple nutsedge (5 tubers/pot), jimsonweed (*Datura stramonium* L.) (10 seeds/pot), wild poinsettia (*Euphorbia geniculata* Ortega) (10 seeds/pot), bull mallow (*Malva nicaeensis* ALL.) (10 seeds/pot), black nightshade (10 seeds/pot), wild mustard (10 seeds/pot), common cocklebur (*Xanthium strumarium* L.) (4 seeds/pot), and tomato (10 seeds/pot). All weed seeds and purple nutsedge tubers were collected from fields in the northern part of Israel. Experiments were performed in the winters of 2000 and 2001 at maximum and minimum temperatures of 35 and 20 C, respectively, in a greenhouse at the Newe Ya'ar research center located in the Esdraelon Valley in northern Israel.

Sulfosulfuron (Monitor 75% WG, Monsanto) at 0 (control), 37.5, 75.0, and 112.5 g ai/ha was applied preplant incorporated (PPI), PRE, and POST. For POST applications, 0.2% v/v DX,[4] a nonionic surfactant (800 g/L alkaryl polyether alcohol), was added.

PRE and POST treatments were applied with a moving-nozzle pneumatic table sprayer equipped with an 8001E nozzle[5] placed 40 cm above the soil surface (PRE) or above the plant canopy (POST). The sprayer delivered 200 L/ha of spray solution at 300 kPa in a single pass.

The PPI application was achieved by spraying soil interface in a 10-cm-deep tray. The sprayed soil was then hand mixed and placed in the pots. Plants in the PPI and PRE treatments were planted 1 d after application (DAA), and POST treatments were applied 21 d after planting (DAP).

Predetermined numbers of seeds or tubers were planted in 250-ml pots filled with air-dried clay loam (58% clay, 22% silt, 18% sand; 2% organic matter; pH 7.1). The pots were watered from above. Using a scale of 0 (no injury) to 100 (complete kill), plant injury was recorded every week. Seedling emergence was determined at the two-true-leaf stage.

Experiments were terminated 28 DAA, 28 DAP in PPI and PRE treatments and 42 DAP in POST treatments. The plants were cut at soil level, and the fresh and dry weights of foliage (following 72 h of drying at 80 C) were determined.

Experiments were arranged in a split plot arrangement with plant species used as the main plot and application methods and herbicide rates as the sub plot in a randomized design with five replications. Because the three-way interaction between the main plot and the sub plots was significant, data were subjected to analysis of variance, and treatment means were compared using the Tukey–Kramer Honestly Significant Difference Test at the $P \leq 0.05$ level. The emergence and dry weight data were arcsine transformed. Because the statistical analysis for the transformed and the original data was similar, only the latter are presented. Similar results were obtained in two experiments, so the results were combined and presented as a mean of both experiments.

RESULTS AND DISCUSSION

Most of the weeds tested were highly susceptible to sulfosulfuron. Mustard and pigweed were 100% controlled by all application rates and methods. In contrast to the weeds, tomatoes were highly tolerant to sulfosul-

[4] Agan Chemical Manufactures Ltd., Ashdod, Israel 77102.

[5] TeeJet spraying System Co., North Avenue, Wheaton, IL 60188.

Table 1. Effects of sulfosulfuron on emergence of weeds and tomato grown in pots in the greenhouse.

	Emergence					
	PPI[a]			PRE		
Plant species	37.5	75.0	112.5	37.5	75.0	112.5
	% of control					
Tomato	96 a[b]	101 a	94 a	96 a	99 a	97 a
Cocklebur	96 a	36 b	46 b	0 d	0 d	0 d
Mustard	0 d	0 d	0 d	0 d	0 d	0 d
Bindweed	52 b	18 cd	0 d	0 d	0 d	0 d
Poinsettia	66 b	61 b	14 cd	0 d	0 d	0 d
Jimsonweed	58 b	37 b	47 b	0 d	0 d	0 d
Pigweed	0 d	0 d	0 d	0 d	0 d	0 d
Nightshade	94 a	67 b	30 bc	0 d	0 d	0 d
Mallow	95 a	105 a	102 a	100 a	96 a	105 a
Nutsedge	0 d	0 d	0 d	0 d	0 d	0 d
Wild beet	0 d	0 d	0 d	0 d	0 d	0 d

[a] Abbreviations: PPI, preplant-incorporated application 1 d before planting; PRE, preemergence application 1 d before planting.

[b] Means within the tables followed by the same letter are not significantly different, according to Tukey–Kremer Honestly Significant Difference Test, P ≤ 0.05.

Table 2. Effects of sulfosulfuron on weed and tomato injury.

	Plant injury					
	PPI[a]			POST		
Plant species	37.5	75.0	112.5	37.5	75.0	112.5
	%[b]					
Tomato	16 c[c]	12 c	8 c	0 c	8 c	24 c
Cocklebur	93 a	95 a	90 a	52 b	54 b	70 ab
Mustard	—[d]	—	—	100 a	100 a	100 a
Bindweed	20 c	56 b	—	100 a	100 a	100 a
Poinsettia	70 ab	68 ab	84 a	72 ab	80 ab	90 a
Jimsonweed	60 ab	90 a	80 ab	20 c	16 c	64 ab
Pigweed	—	—	—	100 a	100 a	100 a
Nightshade	96 a	90 a	92 a	100 a	100 a	100 a
Mallow	22 c	14 c	10 c	5 c	6 c	8 c
Nutsedge	—	—	—	85 a	85 a	90 a
Wild beet	—	—	—	90 a	95 a	98 a

[a] Abbreviations: PPI, preplant-incorporated application 1 d before planting; POST, postemergence application together with 0.2% nonionic surfactant applied 21 d after planting.

[b] Plant injury assessed 28 d after application. Injury scaled from 0, healthy plants, to 100, dead plants.

[c] Means within the tables followed by the same letter are not significantly different, according to Tukey–Kremer Honestly Significant Difference Test, P ≤ 0.05.

[d] Dashes indicate no analysis (no emergence).

furon and suffered from some phytotoxic effects only at the high application rate of 112.5 g/ha in the PRE and POST treatments (Tables 1 and 2). The PRE application was the most potent because emerging plants pass through a high concentration of the herbicide on the soil surface. The observed herbicide damage comprised the inhibition of apex growth followed by necrosis and total collapse of the plants (Vencill 2002).

PPI treatments completely inhibited the emergence of mustard, pigweed, wild beet, and nutsedge, whereas they had no effect on the emergence of tomato or mallow (Table 1). Sulfosulfuron applied PPI at 112.5 g/ha reduced the emergence of nightshade to only 30%, cocklebur to 46%, and poinsettia to 14% when compared with the untreated control.

Effective control was achieved by PRE sulfosulfuron applications when all rates completely inhibited the emergence of all weeds, including nutsedge, nightshade, and jimsonweed, except for mallow, which was not affected by the herbicide. The control of nightshade and jimsonweed is particularly noteworthy because tomato was highly tolerant to PPI and PRE sulfosulfuron.

PPI application of sulfosulfuron caused > 90% injury to cocklebur and nightshade and 60 to 90% injury to poinsettia and jimsonweed at all tested rates (Table 2). Bindweed was completely controlled at a high rate of application of herbicide, but only 20% injury was observed at a low rate of application of herbicide. Sulfosulfuron damage to mallow was slight, only 10 to 22%. Mallow was inhibited (80–85% injury) by all rates of PRE applications. Tomato was completely tolerant to PPI-applied sulfosulfuron at all tested rates.

PRE sulfosulfuron at all rates controlled all weeds except for mallow in which 80 to 88% injury was observed. This impressive control was also effective for nutsedge and nightshade, two of the hardest to control weeds in tomato production. Tomato was tolerant to sulfosulfuron at the low and intermediate rates, but PRE application at 112.5 g/ha inhibited tomato development, causing 30% tomato injury.

POST application of sulfosulfuron up to 112.5 g/ha was safe for tomato, whereas it completely controlled mustard, pigweed, bindweed, and nightshade. Bindweed and nightshade (Figure 1a) were not completely controlled with the other application methods. Mallow was tolerant to POST-applied sulfosulfuron, whereas some control was achieved with the other application methods. POST applications gave 50 to 60 and 70 to 80% control of cocklebur and poinsettia, respectively. POST treatments achieved 85 to 90% and 90 to 98% control of nutsedge (Figure 1b) and wild beet, respectively, as compared with complete control by PPI and PRE applications (Table 2).

PPI-applied sulfosulfuron at all rates had no significant effects on tomato and mallow foliage dry weights (Table 3). At the high herbicide rate, weight of nightshade was reduced to 16%, poinsettia to 27%, cocklebur to 25% but that of jimsonweed only to 74%, which was

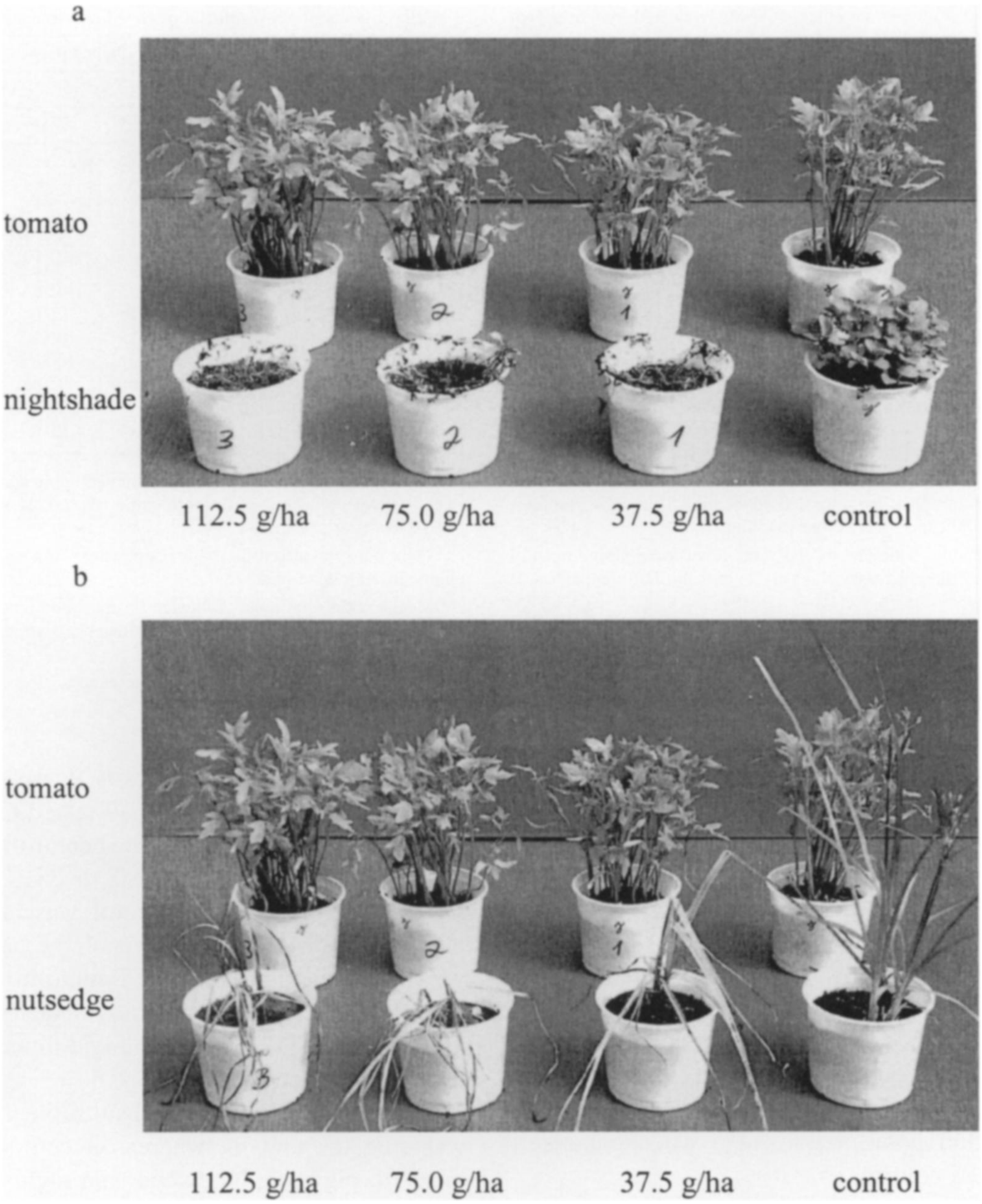

Figure 1. (a) Black nightshade and (b) purple nutsedge injury after sulfosulfuron treatments. Identically treated tomato plants are displayed behind the weeds.

not significantly different when compared with the untreated control.

PRE-applied sulfosulfuron had no effect on tomato foliage dry weight even though some injury was observed at the highest rate. At the high PRE application rate, mallow foliage dry weight was reduced to 31%. This was the lone treatment that inhibited mallow.

POST-applied sulfosulfuron had no effect on tomato and mallow foliage dry weights at any application rate but caused reductions in the dry weights of nutsedge to 10%, pigweed to 17%, cocklebur to 25%, and nightshade to 10% when compared with the untreated control. Poinsettia foliage dry weight was reduced only 70 to 76% when compared with the untreated control at all tested rates (Table 3).

Our study showed that sulfosulfuron could be highly effective in controlling noxious weeds such as purple nutsedge, black nightshade, pigweed, bindweed, and mustard.

The best control was achieved with PRE treatments, but these also were inhibiting tomato at the highest rate of application, 112.5 g/ha, as shown in Table 3. It is

Table 3. Effects of sulfosulfuron on weed and tomato foliage dry weight at 28 d after application.

	Plant dry weight					
	PPI[a]			POST[b]		
Plant species	37.5	50.0	112.5	37.5	50.0	112.5
	Percentage of control[c]					
Tomato[d]	94 a[e]	103 a	96 a	86 a	85 a	95 a
Cocklebur	22 c	19 c	25 c	22 c	24 c	25 c
Mustard	0 d[b]	0 d	0 d	0 d	0 d	0 d
Bindweed	90 a	85 a	0 d	3 cd	0 d	0 d
Poinsettia	79 ab	77 ab	27 c	76 ab	70 b	71 b
Jimsonweed	78 ab	77 ab	74 ab	90 a	87 a	81 ab
Pigweed	0 d	0 d	0 d	19 c	2 cd	17 c
Nightshade	67 b	13 cd	16 c	5 cd	7 cd	10 cd
Mallow[f]	91 a	84 a	84 a	100 a	98 a	94 a
Nutsedge	0 d	0 d	0 d	36 c	26 c	33 c
Wild beet	0 d	0 d	0 d	0 d	0 d	0 d

[a] Abbreviations: PPI, preplan-incorporated application 1 d before planting; POST, postemergence application together with 0.2% nonionic surfactant applied 21 d after planting.

[b] Value smaller than 0.01%.

[c] Plant dry weight was calculated as percentage of control plant's dry weight.

[d] Tomato dry weights in PRE applications as a percentage of dry weight of tomatoes from control plants were 105, 95, and 82% at rates of 37.5, 75.0, and 112.5, respectively.

[e] Means within the tables followed by the same letter are not significantly different according to Tukey–Kremer Honestly Significant Difference Test, $P \leq 0.05$.

[f] Mallow dry weights in PRE applications as a percentage of mallow from control plants were 19, 26, and 31% at rates of 37.5, 75.0, and 112.5, respectively.

theorized that this was because the emerging apex of the plants passes through a concentrated herbicide layer on the soil surface.

Sulfosulfuron applied PPI and POST resulted in a wider safety range for tomato, with no reduction in control efficacy of cocklebur, bindweed, poinsettia, jimsonweed, pigweed, nightshade, nutsedge, and wild beet.

Especially interesting is that sulfosulfuron selectively controls nightshade in tomato. Rimsulfuron, a sulfonylurea herbicide, is registered at 5 to 15 g/ha for weed control in tomato but does not control nightshade at these rates. In our study, field bindweed was found to be highly susceptible to POST applications of sulfosulfuron at rates of 37.5 to 112.5 g/ha, whereas a previous study with lower rates of 20 to 35 g/ha found field bindweed to be tolerant (Anonymous 1995).

The advantages of sulfosulfuron over other herbicides registered for tomato are its persistence in soil and high tomato tolerance so that it provides weed control throughout the growing season. In this study, we demonstrated that sulfosulfuron acts on weeds through either foliar or soil application.

The long persistence of the herbicide presents a residual danger to subsequent crops, but this can be overcome by a crop rotation system in which wheat (Anonymous 1995) or potato (Kuzior et al. 1999) follows tomato cropping. Preliminary studies on the residual effects of sulfosulfuron indicated tolerance of Malvaceae crops such as cotton that follow tomato cropping (H. Eizenberg, unpublished data). These preliminary results are consistent with the observation in the present study that mallow is tolerant to sulfosulfuron in PPI and POST applications.

The present study suggests that sulfosulfuron, applied by several methods, effectively controlled troublesome weeds in tomato. Preliminary trials in tomato fields indicate that sulfosulfuron applied PPI or POST controls nightshade under field condition without injuring tomatoes. The precise mechanisms of nightshade susceptibility and tomato tolerance to sulfosulfuron require further investigation.

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