Evaluation of Sulfentrazone for Weed Control and Phytotoxicity in Field-Grown Landscape Plants[1]

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Abstract

Research was conducted in 1996 and 1997 at the Horticulture Research Farm in Lexington, KY, to evaluate full season weed control and phytotoxicity for rates of sulfentrazone alone and in combination with Gallery (0.55 kg ai/ha) (0.49 lb ai/A), Treflan (2.18 kg ai/ha) (1.94 lb ai/A), and Pennant (3.27 kg ai/ha) (2.92 lb ai/A). In general, by 12 WAT, control provided by all treatments was only fair to moderate. The greatest reductions in weed cover were observed with the high rate of sulfentrazone (0.55 kg/ha) (0.49 lb ai/A), the combination of sulfentrazone (0.41 kg/ha) (0.37 lb ai/A) plus Pennant, and combinations of sulfentrazone plus Treflan. In all cases, weed control was improved with the use of a higher rate of sulfentrazone, and not necessarily associated with the presence of the partner herbicides. Phytotoxicity was mainly associated with contact of the herbicide with developing foliage, but sulfentrazone was particularly damaging to the herbaceous species *Liriope* and *Hemerocallis*, where damage was observed throughout the plants. Sulfentrazone was present in all cases where plants exhibited severe phytotoxicity in response to herbicide treatment. The most sensitive species evaluated in this study were: *Abies*, *Liriope*, and *Hemerocallis*. The most tolerant species included: *Fraxinus*, *Crataegus*, and *Euonymus*. Postemergence directed applications or shielded preemergence applications of sulfentrazone were recommended to possibly decrease phytotoxicity to sensitive species.

Index words: nursery, landscape crops, preemergence herbicides, sulfentrazone, phytotoxicity, and soil applied.

Herbicides used in this study: Sulfentrazone N-[2,4-dichloro-5-[(4-difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl] phenyl] methane sulfonamide; Gallery (isoxaben), N-[3-(1-ethyl-1-methylpropyl)-5-isoxazolyl]2,6-dimethoxy benzamide; Pennant (metolachlor), 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide; Treflan (trifluralin), (2,6-dinitro-N,N-dipropyl-4-p-triflouromethyl) benzenamine.

Species used in this study: daylily (*Hemerocallis* spp. L. cv. Stella d'Oro); liriope (*Liriope muscari* (Decne.) L. H. Bailey); burning bush (*Euonymus alata* (Thunb.) Siebold 'Compacta'); white fir (*Abies concolor* (Gord.) Lindl. ex Hildebr.); cranberrybush (*Viburnum trilobum* Marsh. 'Hahs'); Eastern redbud (*Cercis canadensis* L.); green hawthorn (*Crataegus viridis* L. 'Winter King'); white ash (*Fraxinus americana* L. 'Skyline'); red oak (*Quercus rubra* L.); and common lilac (*Syringa vulgaris* L.).

Significance to the Nursery Industry

Sulfentrazone could be a valuable herbicide for summer weed management in the nursery industry because it controls weeds such as morningglory (*Ipomoea* spp.) and yellow nutsedge (*Cyperus esculentus* L.) that are difficult to control with products currently labeled for nursery crops. It also exhibits good soil persistence, leading to potential long-term weed management. Some phytotoxicity occurs when sulfentrazone is applied to certain sensitive species; this may possibly be alleviated by a shielded application since phytotoxicity appears to be mainly due to contact activity, rather than translocation.

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Introduction

The nursery industry has limited options for effective full season weed control because few soil persistent broad-spectrum herbicides are registered for use in landscape crops. Difficult-to-control weed species, such as yellow nutsedge and morningglory spp., are often not controlled due to a lack of selective and efficacious chemistry that is labeled. An herbicide that provides season-long weed control would be extremely beneficial because it would enable nurserymen to produce high quality landscape crops with minimal weed interference using just one application. Phytotoxicity to landscape crops should also be considered. Herbicide tolerance varies with species and within cultivars of a species. As a result, new products must be evaluated with a variety of plants before they can be registered for use in landscape species (7).

Gallery (isoxaben) is a preemergence herbicide currently being used in the nursery industry to control broadleaf weeds. Gallitano and Skroch (5) and Norcini and Aldrich (6) found that Gallery (0.55 kg ai/ha) (0.49 lb ai/A) provided acceptable to good control of many broadleaf weeds in numerous landscape crops without phytotoxicity. Gallery has caused some phytotoxicity to sensitive crops, resulting in reduced dry weights of herbaceous perennials (3, 8).

Treflan (trifluralin) is a preemergence herbicide used in the nursery industry to control annual grasses and broadleaf weeds (5, 8). At 4 WAT, 2.18 kg ai/ha (1.94 lb ai/A) provided effective overall weed control, but control does not generally persist much longer.

Pennant (metolachlor) is a preemergence herbicide used in the nursery industry to control annual grasses and yellow nutsedge. When applied to perennials in Kentucky (11) and Virginia (3), Pennant caused little injury to the plants tested at 4.50 (4.0 lb ai/A) and 9.00 kg ai/ha (8.0 lb ai/A), but was not as efficacious in controlling weeds as mixtures of herbicides or other herbicide treatments. It does provide acceptable to good control of yellow nutsedge, a weed that many other herbicides do not control effectively (2, 4). Some phytotoxicity has been observed with Pennant applications, especially in newly established liners (1).

Field trials in Kentucky and other states have recently been conducted with sulfentrazone (F6285), an herbicide initially developed by FMC Corporation. Sulfentrazone provides selective control of yellow nutsedge and morningglories, as well as broadleaf and annual grass weeds. Sulfentrazone controls weeds by inhibiting protoporphyrinogen oxidase in the chlorophyll biosynthetic pathway. This process causes a phytodynamic toxicant (protoporphyrin IX) to build up, which leads to membrane disruption. Plants absorb sulfentrazone from both the roots and shoots, and they turn necrotic and die shortly after exposure to light. Postemergence application resulting in foliar contact with sulfentrazone can cause rapid desiccation and necrosis in affected weeds, particularly smaller ones (9, 10).

Weston et al. (11) conducted a trial in 1994 to evaluate the use of sulfentrazone (0.37 kg ai/ha; 0.33 lb ai/A) in combination with herbicides labeled for use in woody landscape crops. The herbicides included Dimension (0.37 kg ai/ha; 0.33 lb ai/A) (dithiopyr), Goal (0.56 kg ai/ha; 0.50 lb ai/A) (oxyfluorfen), Snapshot (2.24 kg ai/ha; 2.00 lb ai/A) (isoxaben 20%, oryzalin 60%), Gallery (0.56 kg ai/ha; 0.49 lb ai/A), Pennant (3.36 kg ai/ha; 3.00 lb ai/A), and Predict (2.69 kg ai/ha; 2.40 lb ai/A) (norflurazon). Four to twelve weeks after herbicide application, sulfentrazone (0.37 kg ai/ha; 0.33 lb ai/A) plus Snapshot 80DF (2.24 kg ai/ha; 2.00 lb ai/A) provided excellent (>90%) control of morningglories,

Table 1. Weed control ratings for sulfentrazone and sulfentrazone combination treatments averaged over two years.

				% Weed control[z]											
				Annual grass			Moningglory spp.			Honeyvine milkweed			Overall rating		
Herbicide treatment	Common name	Rate (kg ai/ha)	Rate (lb ai/A)	4 WAT	8 WAT	12 WAT	4 WAT	8 WAT	12 WAT	4 WAT	8 WAT	12 WAT	4 WAT	8 WAT	12 WAT
Sulfentrazone	sulfentrazone	0.14	0.12	89a	38c	29ef	64d	53bcd	80ab	57a	73a–d	83ab	32d	41ef	26fg
Sulfentrazone	sulfentrazone	0.27	0.24	95a	78ab	43e	95ab	84a	88a	62a	53d	83ab	80abc	73ab	57a–e
Sulfentrazone	sulfentrazone	0.41	0.37	96a	88a	72bc	96a	76abc	87ab	76a	68a–d	79abc	84a	75ab	69ab
Sulfentrazone	sulfentrazone	0.55	0.49	95a	92a	81abc	94ab	86a	87ab	80a	67a–d	78a–d	86a	77ab	70ab
Gallery	isoxaben	0.55	0.49	63b	42c	13fg	39e	18ef	73abc	80a	61bcd	85ab	55cd	31f	18gh
Sulfentrazone	sulfentrazone	0.27	0.24	86a	67b	46de	91ab	79ab	81ab	83a	55cd	79abc	78abc	62bcd	43ef
Gallery	isoxaben	0.55	0.49												
Sulfentrazone	sulfentrazone	0.41	0.37	91a	81ab	65cd	91ab	82a	83ab	57a	68a–d	68cd	78abc	65bcd	52b–e
Gallery	isoxaben	0.55	0.49												
Pennant	metolachlor	3.27	2.92	95a	93a	94a	37e	41de	46d	78a	82ab	90a	56bcd	52cde	55a–e
Sulfentrazone	sulfentrazone	0.14	0.12	94a	93a	87ab	89abc	83a	83ab	63a	80ab	77a–d	77abc	78ab	68abc
Pennant	metolachlor	3.27	2.92												
Sulfentrazone	sulfentrazone	0.27	0.24	97a	93a	90ab	89abc	78ab	80ab	65a	63bcd	74bcd	72abc	73ab	73a
Pennant	metolachlor	3.27	2.92												
Sulfentrazone	sulfentrazone	0.41	0.37	96a	94a	90ab	95a	83a	80ab	88a	64a–d	64d	90a	81a	68abc
Pennant	metolachlor	3.27	2.92												
Treflan	trifluralin	2.18	1.94	94a	92a	90ab	68cd	49cd	53cd	82a	79abc	79abc	78abc	47def	45def
Treflan	trifluralin	4.36	3.89	94a	88a	95a	74bcd	64a–d	64bcd	85a	81ab	86ab	83ab	63bc	63a–d
Sulfentrazone	sulfentrazone	0.14	0.12	93a	93a	92a	78a–d	50cd	77ab	70a	81ab	81abc	81abc	64bc	49cde
Treflan	trifluralin	2.18	1.94												
Sulfentrazone	sulfentrazone	0.27	0.24	92a	93a	89ab	92ab	75abc	75abc	85a	88a	84ab	70.bc	74ab	618a–e
Treflan	trifluralin	2.18	1.94												
Sulfentrazone	sulfentrazone	0.41	0.37	90a	93a	89ab	81a–d	72abc	79ab	60a	79abc	81abc	81abc	75ab	74a
Treflan	trifluralin	2.18	1.94												
Untreated check		—	—	0c	0d	0g	0f	0f	0e	0b	0e	0e	0e	0g	0h
LSD at $p < 0.05$		—	—	10	17	20	21	28	23	32	25	14	28	16	19

[z]Means were separated using Fisher's protected LSD test. Means followed by the same letter were not significantly different at the (0.05) level.

yellow nutsedge, annual grasses, ragweed, and dandelion. However, the sulfentrazone (0.37 kg ai/ha; 0.33 la ai/A) plus Dimension combination (0.37 kg ai/ha; 0.33 lb ai/A) exhibited significantly reduced control in comparison to treatment combinations and sulfentrazone applied alone, providing only 58% overall control as compared to 90+ % control for other treatments. Phytotoxicity due to sulfentrazone applications was rarely observed.

The objective of this study was to evaluate summer season weed control provided by sulfentrazone alone and in combination with Gallery, Treflan, and Pennant, other commonly utilized preemergence herbicides for use on field-grown landscape crops. Efficacy and phytotoxicity was examined in a nursery setting using established landscape species over a two-year period by reapplication of the treatments to the same site.

Materials and Methods

Research was conducted at the Horticulture Research Farm in Lexington, KY, on a Maury silt loam soil (fine, mixed, mesic, typic Paleuadalf) with a pH of 6.2 and organic matter content of 3.0%. During the spring of 1994, plots measuring 160 m^2 (1800 ft^2) were planted with 10 4- to 6-foot budded tree seedlings and 15.2 cm (6 in) potted shrub species, using 3 plants of each species per plot. Species evaluated in 1996–1997 were well established and included: daylily (*Hemerocallis* spp. L.); liriope (*Liriope muscari* (Decne.) L. H. Bailey); burning bush (*Euonymus alata* (Thunb.) Siebold 'Compacta'); white fir (*Abies concolor* (Gord.) Lindl. Ex Hildebr.); cranberrybush (*Viburnum trilobum* Marsh. 'Hahs'); Eastern redbud (*Cercis canadensis* L.); green hawthorn (*Crataegus viridis* L. 'Winter King'); white ash (*Fraxinus americana* L. 'Skyline'); red oak (*Quercus rubra* L.); and common lilac (*Syringa vulgaris* L.). Each treatment was replicated 3 times and treatments were arranged in a randomized complete block design (RCBD).

Each year the field was cultivated thoroughly in May to remove all weed and plant residue before herbicide application. Following herbicide application, trees and shrubs were pruned as needed on a yearly basis. No other fertilizer or pesticide applications were made. On May 23, 1996, herbicide treatments were applied to the plots using a CO_2 pressurized backpack sprayer calibrated to deliver 292.13 liters/ha (26.00 gal/A) using 8004 nozzles and 207 kPa (30 lbs psi) at the boom. The treatments included increasing rates of sulfentrazone alone (0.14, 0.27, 0.41 and 0.55 kg ai/ha; 0.12, 0.24, 0.37, 0.49 lb ai/A) and sulfentrazone (0.14, 0.27 and 0.41 kg ai/ha; 0.12, 0.24, 0.37 lb ai/A) in combination with Gallery (0.55 kg ai/ha; 0.49 lb ai/A), Pennant (3.27 kg ai/ha; 2.92 lb ai/A), and Treflan (2.18 kg ai/ha; 1.94 lb ai/A) (Table 1). Trifluralin treatments were incorporated to a depth of 2 cm (1 in) using a cultivator immediately after application. In the appropriate combination treatments, sulfentrazone was soil applied after trifluralin was first soil incorporated. Besides an untreated control in each replicate, untreated strips containing representative weed species were present between plots. Herbicide efficacy was evaluated on a visual basis at 4, 8, and 12 weeks after treatment (WAT), with 0 representing no control and 100 representing complete control. Moderate weed control was defined as any rating over 70%; acceptable control was defined as any rating over 80%, while excellent control was defined as any rating over 90%. Plant phytotoxicity was evaluated at 5 and 10 WAT on a 0 to 10 scale, with 0 representing no injury and 10 representing plant death.

Identical herbicide applications were repeated at the same site on May 5, 1997, and treatments were evaluated as above. Data were subjected to analysis of variance for a RCBD and were combined over the two years, where possible, if no significant difference existed over years. Treatment means were separated using Fisher's protected LSD test.

Results and Discussion

Weed control. Predominant weed species encountered in both years of the study were: giant foxtail (*Setaria faberi* Herrm.), green foxtail (*Setaria viridis* L.), ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.), and honeyvine milkweed (*Ampelamus albidis* (Nutt.) Britt.) (Table 1). However, certain weed species were encountered in only one year of the study, as weed populations shifted over the course of the study. Weeds encountered only in 1996 included velvetleaf (*Abutilon theophrastii* Medicus) and hophornbeam copperleaf (*Acalypha ostryifolia* Riddell) (Table 2). Weeds encountered only in 1997 included quackgrass (*Agropyron repens* (L.) Repens), yellow nutsedge (*Cyperus esculentus* L.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), smooth pigweed (*Amaranthus hybridus* L.), prickly sida (*Sida spinosa* L.), common lambsquarters (*Chenopodium album* L.), hairy galinsoga (*Galinsoga ciliata* (Raf.) Blake), and horsenettle (*Solanum carolinense* L.) (Table 3). Weed pres-

Table 2. Control of velvetleaf and hophornbeam copperleaf with selected herbicide applications in 1996.

Herbicide treatment	Rate (kg/ha)	Rate (lb/A)	% Weed control[z] Velvetleaf 4 WAT	Velvetleaf 8 WAT	Hophornbeam copperleaf 12 WAT
Sulfentrazone	0.14	0.12	100a	92a	92a
Sulfentrazone	0.27	0.24	98a	95a	93a
Sulfentrazone	0.41	0.37	95a	97a	95a
Sulfentrazone	0.55	0.49	97a	93a	100a
Gallery	0.55	0.49	67a	48c	87a
Sulfentrazone	0.27	0.24	100a	85ab	88a
Gallery	0.55	0.49			
Sulfentrazone	0.41	0.37	100a	82ab	83ab
Gallery	0.55	0.49			
Pennant	3.27	2.92	67a	58bc	88a
Sulfentrazone	0.14	0.12	99a	93a	88a
Pennant	3.27	2.92			
Sulfentrazone	0.27	0.24	96a	85ab	92a
Pennant	3.27	2.92			
Sulfentrazone	0.41	0.37	100a	97a	95a
Pennant	3.27	2.92			
Treflan	2.18	1.94	98a	92a	52c
Treflan	4.36	3.89	100a	100a	60bc
Sulfentrazone	0.14	0.12	70a	100a	80ab
Treflan	2.18	1.94			
Sulfentrazone	0.27	0.24	100a	97a	80ab
Treflan	2.18	1.94			
Sulfentrazone	0.41	0.37	100a	98a	93a
Treflan	2.18	1.94			
Untreated check	—	—	0b	0d	0d
LSD at $p < 0.05$	—	—	36	32	26

[z]Means were separated using Fisher's protected LSD test. Means followed by the same letter were not significantly different at the (0.05) level.

Table 3. Control of selected weed species with selected herbicide applications in 1997.

			% Weed control[z]									
			Yellow nutsedge			Pigweed			Lambsquarter		Hairy galinsoga	
Herbicide treatment	Rate (kg/ha)	Rate (lb/A)	4 WAT	8 WAT	12 WAT	4 WAT	8 WAT	12 WAT	8 WAT	12 WAT	8 WAT	12 WAT
Sulfentrazone	0.14	0.12	100a	99a	100a	100a	90a	95ab	100a	100a	97a	98a
Sulfentrazone	0.27	0.24	100a	98a	100a	100a	99a	98a	100a	100a	99a	100a
Sulfentrazone	0.41	0.37	100a	100a	100a	100a	100a	100a	100a	100a	97a	95a
Sulfentrazone	0.55	0.49	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a
Gallery	0.55	0.49	60bc	63bc	65bc	97a	95a	96ab	90ab	93a	100a	100a
Sulfentrazone	0.27	0.24	100a	99a	100a	100a	97a	95ab	100a	100a	100a	100a
Gallery	0.55	0.49										
Sulfentrazone	0.41	0.37	100a	100a	100a	100a	98a	98a	100a	100a	100a	100a
Gallery	0.55	0.49										
Pennant	3.27	2.92	90ab	98ab	98ab	100a	65b	87c	67b	66b	98a	100a
Sulfentrazone	0.14	0.12	100a	100a	100a	100a	88ab	90bc	100a	98a	100a	99a
Pennant	3.27	2.92										
Sulfentrazone	0.27	0.24	100a	99a	100a	100a	99a	95ab	100a	100a	98a	100a
Pennant	3.27	2.92										
Sulfentrazone	0.41	0.37	100a	100a	100a	100a	100a	99a	100a	100a	99a	98a
Pennant	3.27	2.92										
Treflan	2.18	1.94	33cd	37c	33cd	97a	97a	95ab	97a	97a	80ab	90a
Treflan	4.36	3.89	60bc	53c	70ab	100a	100a	100a	100a	100a	85a	90a
Sulfentrazone	0.14	0.12	87ab	97ab	98ab	100a	100a	97ab	100a	100a	47c	33b
Treflan	2.18	1.94										
Sulfentrazone	0.27	0.24	98a	100a	100a	100a	100a	97ab	100a	100a	57bc	50b
Treflan	2.18	1.94										
Sulfentrazone	0.41	0.37	100a	100a	100a	100a	100a	99a	100a	100a	73abc	92a
Treflan	2.18	1.94										
Untreated check	—	—	0d	0d	0d	0b	0c	0d	0c	0c	0d	0c
LSD at p < 0.05	—	—	35	35	35	3	24	7	23	23	27	30

[z]Means were separated using Fisher's protected LSD test. Means followed by the same letter were not significantly different at the (0.05) level.

sures over both years at this Kentucky location could be described as heavy to very heavy.

In both study years, increasing rates of sulfentrazone provided enhanced weed control, especially with morningglory spp. and prickly sida at 8 and 12 WAT (Table 1). At the high rate of sulfentrazone (0.55 kg/ha; 0.49 lb ai/A), morningglory spp., velvetleaf, yellow nutsedge, common lambsquarters, pigweed, and other broadleaf weeds were effectively controlled (>85%). Acceptable annual grass control (81%) was also observed, even at 12 WAT.

In addition, sulfentrazone at the moderate and high rates (0.27 and 0.41 kg/ha; 0.24 and 0.37 lb ai/A) in combination with Pennant provided moderate (>70%) to acceptable (>80%) overall control up to 8 WAT (Table 1). Control ranged from 75–90% for foxtail spp., ivyleaf morningglory, and honeyvine milkweed, which were the key species infesting the experimental site. Treflan at both rates controlled annual grasses (>90%), but as expected, was only poorly to moderately effective (33–76%) in controlling yellow nutsedge and broadleaf species by 12 WAT. In comparison, combinations of sulfentrazone (0.14, 0.27 and 0.41 kg ai/ha; 0.12, 0.24, 0.37 lb ai/A) with Treflan (2.18 kg ai/ha; 1.94 lb ai/A) provided moderate (>75%) control of grasses, yellow nutsedge, morningglory, and prickly sida up to 12 WAT.

At 12 WAT, control provided by all treatments was only fair to moderate, as dense infestations of annual broadleaf and grass weeds were encountered throughout this experimental site (Table 1). Greatest reductions in weed biomass were observed with the high rate of sulfentrazone (0.55 kg/ha; 0.49 lb ai/A), the combination of sulfentrazone (0.41 kg/ha; 0.37 lb ai/A) plus Pennant (3.27 kg ai/ha; 2.92 lb ai/A), and combinations of sulfentrazone (0.27 and 0.41 kg ai/ha; 0.24 and 0.37 lb ai/A) plus Treflan (2.18 kg ai/ha; 1.94 lb ai/A). In all cases, weed control was improved with the use of a higher rate of sulfentrazone, and not necessarily associated with the combination of other herbicides. Weed control provided by all other treatments was poor at 12 WAT (<65%). This herbicide treatment was reapplied to the same plots in two consecutive years. Weed control was not maintained for longer than 16 weeks in both seasons and year effects were not significant between years for weed control, providing no evidence of carryover effects due to treatment application at the same site. FMC's data suggest limited soil persistence by this product as well. Initially, weed suppression provided by most treatments was acceptable (>80%) for 4 to 6 weeks. Between 10 and 12 weeks, control started to break. Consistent control was achieved at this later date only with the higher rates of sulfentrazone. With dense weed pressures, control was moderate (>70%) at 12 WAT when sulfentrazone (0.27 kg ai/ha; 0.24 lb ai/A) was combined with Pennant or Treflan. An early season treatment of sulfentrazone (0.41–0.55 kg ai/ha; 0.37–0.49 lb ai/A) or sulfentrazone plus a partner herbicide followed by cultivation, and reapplication at 10–14 WAT could be suggested in nurseries to obtain prolonged weed control through the fall season and following spring seasons. Lower use rates could be attempted if an acceptable partner herbicide at moderate rates was also applied.

Despite the fact that the highest level of control observed with sulfentrazone at 12 WAT was ~70% at 0.41 to 0.55 kg ai/ha; 0.37 to 0.49 lb ai/A, this herbicide could be very use-

Table 4. Phytotoxicity evaluations of field-grown landscape crops averaged over two years.

Herbicide treatment	Rate (kg/ha)	Rate (lb/A)	% Phytotoxicity[z] *Quercus* 5 WAT	*Quercus* 10 WAT	*Fraxinus* 5 WAT	*Fraxinus* 10 WAT	*Crataegus* 5 WAT	*Crataegus* 10 WAT	*Cercis* 5 WAT	*Cercis* 10 WAT	*Syringa* 5 WAT	*Syringa* 10 WAT
Sulfentrazone	0.14	0.12	0.7a	1.0a–d	0.3a	0.4a	0.3ab	0.0b	0.0b	0.0e	0.8b–g	1.0abc
Sulfentrazone	0.27	0.24	0.1b	1.1a–d	0.1b	0.0b	0.5ab	0.3ab	0.1ab	0.4a–e	1.1a–e	1.3a
Sulfentrazone	0.41	0.37	0.2ab	0.7bcd	0.0b	0.0b	0.2b	0.0b	0.1ab	0.7ab	1.6abc	1.0abc
Sulfentrazone	0.55	0.49	0.2ab	0.9a–d	0.1b	0.0b	0.9a	0.8a	0.0b	0.5a–e	1.5abc	1.1abc
Gallery	0.55	0.49	0.0b	1.1a–d	0.0b	0.0b	0.0b	0.4ab	0.0b	0.5a–e	0.4d–g	0.5bcd
Sulfentrazone	0.27	0.24	0.3ab	1.2abc	0.1b	0.0b	0.3ab	0.2ab	0.0b	0.2b–e	1.0a–f	0.9abc
Gallery	0.55	0.49										
Sulfentrazone	0.41	0.37	0.2ab	0.8a–d	0.1b	0.0b	0.1b	0.0b	0.0b	0.3a–e	1.6ab	1.2ab
Gallery	0.55	0.49										
Pennant	3.27	2.92	0.1b	0.7cde	0.1ab	0.2ab	0.3ab	0.3ab	0.0b	0.6a–d	0.2efg	0.9abc
Sulfentrazone	0.14	0.12	0.2ab	0.5de	0.1b	0.0b	0.0b	0.0b	0.0b	0.1de	1.4abc	0.6a–d
Pennant	3.27	2.92										
Sulfentrazone	0.27	0.24	0.5ab	1.3abc	0.0b	0.1b	0.0b	0.0b	0.1ab	0.6a–d	0.7c–g	0.8abc
Pennant	3.27	2.92										
Sulfentrazone	0.41	0.37	0.5ab	1.0a–d	0.1b	0.0b	0.1b	0.0b	0.3a	0.6a–d	1.5abc	0.8abc
Pennant	3.27	2.92										
Treflan	2.18	1.94	0.3ab	0.7cde	0.1b	0.2ab	0.0b	0.0b	0.0b	0.8a	0.2fg	0.4cd
Treflan	4.36	3.89	0.2ab	1.4a	0.1b	0.0b	0.3ab	0.3ab	0.0b	0.7abc	0.3d–g	0.5cd
Sulfentrazone	0.14	0.12	0.3ab	1.3ab	0.1b	0.0b	0.0b	0.0b	0.0b	0.4a–e	1.1a–d	0.9abc
Treflan	2.18	1.94										
Sulfentrazone	0.27	0.24	0.5ab	0.7bcd	0.0b	0.2ab	0.2b	0.3ab	0.2ab	0.2cde	1.1a–d	0.8abc
Treflan	2.18	1.94										
Sulfentrazone	0.41	0.37	0.2ab	0.9a–d	0.1b	0.0b	0.4ab	0.0b	0.0b	0.7abc	1.7a	1.1abc
Treflan	2.18	1.94										
Untreated check	—	—	0.0b	0.0e	0.0b	0.0b	0.0b	0.0b	0.0b	0.0e	0.0g	0.0d
LSD at $p < 0.05$	—	—	0.54	0.67	0.21	0.28	0.72	0.70	0.24	0.53	0.88	0.73

[z]Means were separated using Fisher's protected LSD test. Means followed by the same letter were not significantly different at the (0.05) level. Phytotoxicity was rated on a scale of 0 to 10, with 0 representing no injury and 10 representing complete death.

Table 5. Phytotoxicity evaluations of field-grown landscape crops averaged over two years.

Herbicide treatment	Rate (kg/ha)	Rate (lb/A)	% Phytotoxicity[z] *Viburnum* 5 WAT	*Viburnum* 10 WAT	*Abies* 5 WAT	*Abies* 10 WAT	*Euonymus* 5 WAT	*Euonymus* 10 WAT	*Liriope* 5 WAT	*Liriope* 10 WAT	*Hemerocallus* 5 WAT	*Hemerocallus* 10 WAT
Sulfentrazone	0.14	0.12	0.2d	0.3b	1.6abc	2.8cd	0.2b	0.1d	1.3d–g	1.2cd	1.4fgh	2.1a–d
Sulfentrazone	0.27	0.24	0.6cd	0.5b	1.6abc	3.9bc	0.0b	0.0d	1.4def	0.9cde	3.3a–e	2.5abc
Sulfentrazone	0.41	0.37	0.4cd	0.5b	1.9ab	5.7ab	0.3ab	0.2d	3.5b	2.2b	5.0a	2.9a
Sulfentrazone	0.55	0.49	0.6cd	0.5b	2.1ab	4.3bc	0.2b	0.0d	5.5a	4.9a	4.9ab	2.7ab
Gallery	0.55	0.49	0.2d	0.2b	0.0d	0.6e	0.8a	1.1ab	0.2fg	0.8cde	0.2h	1.9a–e
Sulfentrazone	0.27	0.24	0.4cd	1.8a	2.5ab	3.1c	0.2ab	1.2a	2.3bcd	1.2cd	4.3abc	1.3a–e
Gallery	0.55	0.49										
Sulfentrazone	0.41	0.37	0.4cd	0.7b	3.0a	3.7c	0.5ab	0.8abc	3.6b	1.6bc	4.1abc	1.9a–e
Gallery	0.55	0.49										
Pennant	3.27	2.92	0.2d	0.9ab	0.4cd	0.3e	0.4ab	0.1d	0.0fg	0.5de	0.7gh	0.7cde
Sulfentrazone	0.14	0.12	0.9bc	0.7ab	2.0ab	4.2bc	0.0b	0.0d	1.6de	0.9cde	1.4e–h	0.9b–e
Pennant	3.27	2.92										
Sulfentrazone	0.27	0.24	1.7a	0.9ab	2.5ab	4.1bc	0.3ab	0.1d	2.4bcd	1.6bc	2.8c–f	1.7a–e
Pennant	3.27	2.92										
Sulfentrazone	0.41	0.37	1.4ab	1.1ab	2.4ab	6.4a	0.2ab	0.0d	3.0bc	2.3b	4.6abc	2.1a–d
Pennant	3.27	2.92										
Treflan	2.18	1.94	0.1d	0.1b	0.3cd	1.1de	0.0b	0.3cd	0.3efg	0.3de	0.3h	0.8b–e
Treflan	4.36	3.89	0.2d	0.2b	1.3bcd	0.6e	0.1b	0.4cd	0.2fg	0.8cde	0.2h	0.2de
Sulfentrazone	0.14	0.12	0.6cd	0.8ab	2.4ab	5.7ab	0.3ab	0.5bcd	1.2d–g	1.0cde	2.1d–g	1.9a–e
Treflan	2.18	1.94										
Sulfentrazong	0.27	0.24	0.6cd	0.4b	2.2ab	4.3bc	0.0b	0.1d	2.0cd	1.2cd	3.0b–f	1.2a–e
Treflan	2.18	1.94										
Sulfentrazone	0.41	0.37	0.9bc	0.6b	2.3ab	3.3c	0.3ab	0.0d	3.4bc	2.2b	3.8a–d	1.6a–e
Treflan	2.18	1.94										
Untreated check	—	—	0.0d	0.0b	0.0d	0.0e	0.0b	0.0d	0.0g	0.0e	0.0h	0.0e
LSD at $p < 0.05$	—	—	0.63	1.16	1.51	1.90	0.63	0.60	1.38	0.98	1.84	1.98

[z]Means were separated using Fisher's protected LSD test. Means followed by the same letter were not significantly different at the (0.05) level. Phytotoxicity was rated on a scale of 0 to 10, with 0 representing no injury and 10 representing complete death.

ful for the nursery industry. Weed infestations in this study were quite dense due to large reserves of propagules in the weed seed bank, making weed management considerably more complex than that usually encountered in a well-managed nursery. In addition, sulfentrazone was able to effectively control many difficult to manage weed species, including yellow nutsedge, morningglory spp., honeyvine milkweed, as well as annual grasses. Currently, there are not many herbicide options for effective control of these species. If a potential user has a moderate weed problem, sulfentrazone at the highest rates (0.41 and 0.55 kg ai/ha; 0.37 and 0.49 lb ai/A) may be able to provide adequate control alone or in combination with Pennant (3.27 kg ai/ha; 2.92 lb ai/A) for 12-14 weeks.

Crop injury. Although sulfentrazone is a preemergence soil-applied herbicide, it has also demonstrated significant postemergence contact activity. Crop phytotoxicity in this study was observed shortly after application only in sensitive species and occasionally at 5 and 10 WAT. Sensitive species exhibiting phytotoxicity were *Syringa* (10–15%), *Abies* (15–50%), *Liriope* (10–50%) and *Hemerocallis* (10–50%) and symptoms generally included tissue chlorosis and discoloration and necrosis. Phytotoxicity was mainly associated with contact of the herbicide with developing foliage. Sulfentrazone was particularly injurious to *Liriope* (10–50%) and *Hemerocallis* (10–50%), where damage was observed throughout the entire plant. It is possible that sulfentrazone spray contacting foliage of these plants accumulated into the crown of the plant and caused significant injury of both old and new foliage due to concentration at this sensitive site.

Phytotoxicity symptoms from sulfentrazone application varied somewhat depending on species of plant material. In herbaceous species like *Liriope*, chlorosis occurred throughout the foliage, with tip necrosis observed at the highest rates (0.41 and 0.55 kg ai/ha; 0.37 and 0.49 lb ai/A). Most woody species exhibited leaf necrosis in response to sulfentrazone application. An exception was *Abies*, which was extremely sensitive to sulfentrazone at all rates (0.14, 0.27, 0.41 and 0.55 kg ai/ha; 0.12, 0.24, 0.37 and 0.49 lb ai/A). Foliage and stems of *Abies* directly contacted by the herbicide were completely necrotic. Several *Abies* plants on the edge of plots were green on one side and brown on the other, indicating damage by spray contact.

Phytotoxicity ratings are shown in Tables 4 and 5. Sulfentrazone was present in all cases where plants exhibited severe phytotoxicity in response to herbicide treatment. A general decrease in visual phytotoxicity symptoms was observed from 5 to 10 WAT (in all sulfentrazone treatments) with the exception of *Abies*, *Quercus*, and *Cercis*. *Abies* was extremely sensitive to sulfentrazone at all rates (0.14, 0.27, 0.41 and 0.55 kg ai/ha ; 0.12, 0.24, 0.37 and 0.49 lb ai/A), and many plants were near death by 10 WAT. In *Quercus* and *Cercis*, toxicity was mostly apparent in new foliage and side shoots, which may be more sensitive than the older, more mature shoots. The most sensitive species evaluated in this study were *Abies*, *Liriope*, and *Hemerocallis* (with ratings up to 6.4, 5.5, and 5.0, respectively). *Fraxinus*, *Crataegus*, and *Euonymus* were the most tolerant species. All other species exhibited only moderate sensitivity. Our own laboratory findings have shown that differential sensitivity of weed seedlings to sulfentrazone is also not correlated with differential translocation or metabolism within the weed itself. At this point, mechanisms explaining differential sensitivity to sulfentrazone in higher plants are not well understood.

Based on these findings, one might recommend application of sulfentrazone as a soil-applied preemergent, but in a shielded manner rather than over the top of the ornamentals to protect developing tissue from herbicide contact. Since phytotoxicity appears mainly due to contact and not translocation, one would expect good weed control at higher rates of sulfentrazone with a shielded application, (or when it is used in combination with partners), with limited phytotoxicity. It appears from this study that younger, less well-established plants are more sensitive to injury. This may be partly due to their smaller size and thorough coverage as well as enhanced sensitivity due to physical or other physiological differences.

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