Selective Star-of-Bethlehem Control with Sulfentrazone and Mixtures of Mesotrione and Topramezone with Bromoxynil and Bentazon in Cool-season Turfgrass

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SUMMARY. Star-of-bethlehem (*Ornithogalum umbellatum*) commonly invades turfgrass stands throughout the transition zone. Field experiments were conducted to evaluate sulfentrazone and mixtures of mesotrione and topramezone with bromoxynil and bentazon for selective star-of-bethlehem control in cool-season turf. At 4 weeks after treatment (WAT), applications of sulfentrazone at 0.25 and 0.38 lb/acre provided >95% control of star-of-bethlehem in 2008 and 2009. Star-of-bethlehem control following applications of commercial prepackaged mixtures containing sulfentrazone was not significantly different from applications of sulfentrazone alone, at either rate, at 4 WAT in 2008 and 2009. Control with carfentrazone-ethyl at 0.03 lb/acre measured to <75% at 4 WAT each year. Star-of-bethlehem control at 2, 3, and 4 WAT with topramezone at 0.033 lb/acre was increased by 77%, 50%, and 46%, respectively, from the addition of bromoxynil at 0.50 lb/acre. Similarly, the inclusion of bromoxynil at 0.50 lb/acre increased the level of control observed following treatment with mesotrione at 0.28 lb/acre by 77%, 30%, and 32% at 2, 3, and 4 WAT. These data suggest that sulfentrazone and mixtures of topramezone and mesotrione with bromoxynil can be used to provide postemergence control of star-of-bethlehem in cool-season turf.

Star-of-bethlehem is a perennial weed of managed turfgrass areas throughout the upper transition zone of the United States. Plants grow from bulbs that are 2 to 3 cm long, producing channeled leaves that are 3 to 8 mm in diameter. Leaves are characterized by their pale, whitish-green midrib (Goetz et al., 2003; McCarty et al., 2001). Bulbs produce lateral bulblets containing alkaloids poisonous to grazing animals (Facciola, 1990). In Tennessee, star-of-bethlehem begins to flower in early May and enters dormancy by early June (Main et al., 2004).

Star-of-bethlehem can invade open areas lacking plant competition (Haragan, 1991; Uva et al., 1997). Infestations have been reported on golf course fairways in Tennessee that have been associated with core

aerification practices (Main et al., 2004). These star-of-bethlehem infestations negatively affect the aesthetic and functional quality of golf course fairways (Main et al., 2004).

Herbicides increasing the production of reactive oxygen species have shown activity against star-of-bethlehem. Bromoxynil is a member of the nitrile herbicide family that inhibits photosystem II by occupying the Q_B-binding domain on the D1 protein, inhibiting electron flow from photosystem II to photosystem I (Senseman, 2007). This action prevents the carotenoid system from quenching reactive oxidizing energy (Hess, 2000). Main et al. (2004) reported that applications of bromoxynil at 1.11 lb/acre provided 78% control by 21 d after treatment (DAT) and

80% control at 35 DAT. Applications of imazaquin at 0.50 lb/acre, metsulfuron at 0.031 lb/acre, and halosulfuron at 0.06 lb/acre did not provide effective control (<30%) at 35 DAT when applied alone; however, when applied in combination with bromoxynil at 1.11 lb/acre, each of those treatments provided >80% control at 35 DAT (Main et al., 2004).

Carfentrazone-ethyl inhibits protoporphyrinogen IX oxidase [protox (E.C. 1.3.3.4)] in the chlorophyll biosynthesis pathway, increasing the production of reactive oxygen species in susceptible plants (Senseman, 2007). Askew and Willis (2006) reported that carfentrazone-ethyl at 0.06 lb/acre provided 96% control of star-of-bethlehem 1 month after treatment; however, this exceeds the maximum labeled use rate of 0.031 lb/acre (FMC Professional Products, 2006a). Sequential applications of carfentrazone-ethyl at 0.031 lb/acre in combination with dicamba did not increase control compared with carfentrazone alone at 0.053 lb/acre (Askew and Willis, 2006). No tall fescue (*Festuca arundinacea*) injury was observed following either treatment.

Sulfentrazone is a protox inhibitor in the same chemical class as carfentrazone-ethyl that can be absorbed by the roots and shoots of treated plants (Senseman, 2007). Like carfentrazone, sulfentrazone is labeled for use on several warm- and cool-season turf species (FMC Professional Products, 2008a); however, its efficacy against star-of-bethlehem is not known.

Hydroxyphenylpyruvate dioxygenase [HPPD (EC 1.13.11.27)]-inhibiting herbicides prevent the carotenoid system from quenching reactive oxidizing energy; thus, carotenoid biosynthesis is disrupted, resulting in chlorophyll destruction, lipid oxidation, and membrane breakdown (Lee et al., 1997). These herbicides act by inhibiting the enzyme *p*-HPPD responsible for converting hydroxyphenylpyruvate to homogentisate, from

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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
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha ⁻¹	0.8922
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

which α -tocopherols and plastoquinones are synthesized (Hess, 2000; Lee et al., 1997). Two commonly used HPPD-inhibiting herbicides are mesotrione and topramezone. Mesotrione, a triketone herbicide, is registered for preemergence (PRE) and postemergence (POST) control of broadleaf and grassy weeds in turf (Syngenta Professional Products, 2008b). Topramezone is a pyrazolone herbicide registered for control of broadleaf and grassy weeds in corn [*Zea mays* (AMVAC, 2006b)]. Mesotrione and topramezone cause foliar bleaching of susceptible species (Mitchell et al., 2001); however, the efficacy of these herbicides against star-of-bethlehem has not been reported.

Mixtures of HPPD and photosystem II-inhibiting herbicides, like atrazine and bromoxynil, have been reported to provide increased weed control in various cropping systems. Armel et al. (2003, 2005) found that mixtures of mesotrione at 0.09 lb/acre and atrazine at 0.250 lb/acre provided an improved level of horse-nettle (*Solanum carolinense*) and Canada thistle (*Cirsium arvense*) control over mesotrione alone at 0.09 lb/acre. Johnson et al. (2002) reported improved ivy-leaf morningglory (*Ipomoea hederacea*) and yellow nutsedge (*Cyperus esculentus*) control with mixtures of mesotrione at 0.062 lb/acre and atrazine at 0.226 lb/acre. Abendroth et al. (2006) reported a synergistic effect in sunflower (*Helianthus annuus*) control when mixing mesotrione at 0.008, 0.016, and 0.031 lb/acre with atrazine at 0.250 lb/acre and bromoxynil at 0.06 lb/acre. Synergistic responses in the control of velvetleaf (*Abutilon theophrasti*) and palmer amaranth (*Amaranthus palmeri*) have been reported for mixtures of mesotrione with atrazine or bromoxynil (Abendroth et al., 2006) as well. In turfgrass, Willis et al. (2007) reported that mixtures of mesotrione with bromoxynil and atrazine provided an improved level of white clover (*Trifolium repens*) control compared with these materials applied alone. The efficacy of mixtures containing topramezone, another HPPD-inhibiting herbicide, with photosystem II-inhibiting herbicides like atrazine and bromoxynil has not been reported.

The objectives of this research were to determine if mesotrione and

sulfentrazone provided greater control of star-of-bethlehem than the current commercial standards of carfentrazone-ethyl and bromoxynil, and to evaluate the efficacy of mesotrione and topramezone applied alone and in mixtures with photosystem II-inhibiting herbicides for control of star-of-bethlehem.

Materials and methods

Field studies designed to meet the first objective were referred to as "single product experiments" while those designed to meet objective two were referred to as "mixture experiments." These experiments were conducted in Spring 2008 and Spring 2009 on a mature stand of tall fescue turf infested with star-of-bethlehem ($\approx 60\%$) at the East Tennessee Research and Education Center-Plant Sciences Unit, Knoxville, TN. Plots were established on a Sequatchie loam soil [Fine-loamy, siliceous, semiactive, thermic humic Hapludult], measuring 6.2 in soil pH and 2.1% in organic matter content. Field trials were conducted in an area of full sunlight and maintained as a utility turf with respect to irrigation, fertility, and mowing during both years. Plots were mowed at 4 inches height-of-cut with a rotary mower twice monthly.

SINGLE PRODUCT EXPERIMENT. Treatments for the single product experiment were: 1) bromoxynil at 0.50 lb/acre; 2) mesotrione at 0.25 lb/acre plus a nonionic surfactant at a 0.25% (v/v) ratio; 3) sulfentrazone at 0.25 lb/acre; 4) sulfentrazone at 0.38 lb/acre; 5) carfentrazone-ethyl at 0.03 lb/acre; 6) sulfentrazone at 0.06 lb/acre + quinclorac at 0.50 lb/acre + 2,4-D at 0.88 lb/acre + dicamba at 0.10 lb/acre; 7) sulfentrazone at 0.03 lb/acre + 2,4-D at 0.70 lb/acre + MCPP at 0.25 lb/acre + dicamba at 0.11 lb/acre; 8) untreated control. Treatments were applied POST on 7 Apr. 2008 and 10 Mar. 2009.

MIXTURE EXPERIMENT. Treatments for the mixture experiment were: 1) topramezone at 0.033 lb/acre; 2) mesotrione at 0.25 lb/acre; 3) bentazon at 0.50 lb/acre; 4) bromoxynil at 0.50 lb/acre; 5) topramezone at 0.033 lb/acre + bentazon at 0.50 lb/acre; 6) topramezone at 0.033 lb/acre + bromoxynil at 0.50 lb/acre; 7) mesotrione at 0.25 lb/acre + bentazon at 0.50 lb/acre; 8) mesotrione at

0.25 lb/acre + bromoxynil at 0.50 lb/acre; 9) untreated control. All treatments containing mesotrione were applied with a nonionic surfactant at a 0.25% (v/v) ratio. Treatments delivering topramezone, bentazon, or bromoxynil (alone or in combination with one another) included a crop oil concentrate at a 1% (v/v) ratio. Treatments were applied POST on 10 Mar. 2009 and were replicated at an adjacent location later that spring.

TREATMENT APPLICATION AND DATA COLLECTION. All treatments were applied with a carbon dioxide-powered backpack boom sprayer calibrated to deliver 30 gal/acre of spray volume. The sprayer boom contained four flat-fan nozzles (Tee Jet XR8002 flat-fan nozzles; Spraying Systems, Roswell, GA) spaced 10 inches apart. A wheeled aluminum frame maintained the boom height at 10 inches above the surface while spraying.

Star-of-bethlehem control was rated visually from 0% (no injury) to 100% (plant death) at 1, 2, 3, and 4 WAT. Tall fescue injury was rated using the same 0% to 100% scale on the same evaluation dates. Weed control and turf injury were assessed visually, as Yelverton et al. (2009) reported that visual ratings of herbicide responses in turf were highly correlated with data collected using the line intersect method or digital image analysis.

STATISTICAL ANALYSIS. All experiments were arranged in a randomized complete block design with three replications. In each instance, the untreated control was deleted to stabilize variance (Willis et al., 2007). Data were subjected to analysis of variance using PROC GLM in SAS (version 9.1; SAS Institute, Cary, NC) with the factor "replication" analyzed as a random variable. Fisher's protected least significant difference values are reported for treatment comparisons at the $\alpha = 0.05$ level (Clever and Scarisbrick, 2001).

Results and discussion

SINGLE PRODUCT EXPERIMENT. The year by treatment interaction for the single product experiment was statistically significant; thus, data from each year are presented individually.

By 4 WAT, applications of sulfentrazone at 0.25 and 0.38 lb/acre provided >95% control in 2008 and 2009. While carfentrazone-ethyl at

0.03 lb/acre provided >93% control by 2 WAT in both years, control at 4 WAT had reduced to 58% and 73% in 2008 and 2009, respectively (Table 1). These results differ from those reported by Askew and Willis (2006) who reported that a single application of carfentrazone-ethyl at 0.06 lb/acre provided 96% control of star-of-bethlehem at 4 WAT.

In both years, star-of-bethlehem control following applications of commercial premixtures containing sulfentrazone was not significantly different from sulfentrazone alone at either rate at 4 WAT (Table 1). Askew and Willis (2006) reported similar results for carfentrazone-ethyl applied alone and in combination with dicamba. Since Main et al. (2004) reported that commercial premixtures of synthetic auxin herbicides only provided 15% control of star-of-bethlehem at 35 DAT in Tennessee, these results suggest that the addition of a protox-inhibiting herbicide to a premixture of synthetic auxin herbicides can improve efficacy against star-of-bethlehem.

Bromoxynil and mesotrione provided a significantly lower level of control than either of the protox-inhibiting herbicides evaluated in 2009. Bromoxynil at 0.50 lb/acre provided only 17% control of star-of-bethlehem by 4 WAT in 2009, while control following an application of mesotrione at 0.25 lb/acre only provided 43% control at the same

rating date (Table 1). These results differ from those reported by Main et al. (2004), who found applications of bromoxynil at 1.11 lb/acre to provide greater than 80% control of star-of-bethlehem at 35 DAT. However, the researcher's application rate in that study was much greater than that which was used in this study (0.50 lb/acre).

MIXTURE EXPERIMENT. No significant interactions were detected between runs of the mixture experiment; therefore, these data were combined (Table 2).

Star-of-bethlehem control following applications of topramezone at 0.033 lb/acre and mesotrione at 0.25 lb/acre measured <5% at 2 WAT (Table 2). By 4 WAT, an application of topramezone at 0.033 lb/acre provided 47% control of star-of-bethlehem, while mesotrione at 0.25 lb/acre provided 61% control on the same evaluation date. These data are similar to those reported in the single product experiment where mesotrione applications at 0.25 lb/acre only provided 50% and 43% control of star-of-bethlehem at 4 WAT in 2008 and 2009, respectively (Table 1).

Neither of the photosystem II-inhibiting herbicides provided >78% control of star-of-bethlehem. The highest level of control reported following treatment with bentazon at 0.50 lb/acre was 32% at 4 WAT, while bromoxynil only provided as

high as 78% control at 3 WAT (Table 2). Similarly, bromoxynil applications at 0.50 lb/acre only provided as high as 72% control of star-of-bethlehem at 4 WAT in the single product experiment (Table 1).

The level of control reported following treatments of topramezone and mesotrione mixed with bromoxynil at 0.50 lb/acre was significantly greater than that which was observed when either herbicide was applied alone. By adding bromoxynil at 0.50 lb/acre, star-of-bethlehem control at 2, 3, and 4 WAT with topramezone was increased 77%, 50%, and 46%, respectively (Table 2). A similar response was reported for mesotrione on each rating date. Mixtures of topramezone at 0.033 lb/acre or mesotrione at 0.25 lb/acre with bromoxynil at 0.50 lb/acre provided 93% control of star-of-bethlehem at 4 WAT (Table 2).

Mixtures of mesotrione plus bentazon at 0.50 lb/acre improved star-of-bethlehem control compared with mesotrione alone. Star-of-bethlehem control at 2 and 4 WAT with mesotrione was increased ≈22% by adding bentazon at 0.50 lb/acre (Table 2). Bentazon applied alone provided <33% control of star-of-bethlehem throughout the study. Control following applications of topramezone at 0.033 lb/acre mixed with bentazon at 0.50 lb/acre was not significantly different from topramezone alone at 0.033 lb/acre on any rating date;

Table 1. Percentage of visual control of star-of-bethlehem in the single product experiment conducted at the East Tennessee Research and Education Center-Plant Sciences Unit (Knoxville, TN) in 2008 and 2009.

		Star-of-bethlehem control (%)							
		2008				2009			
Herbicide Treatment	Rate (lb/acre) ^y	1 WAT ^z	2 WAT	3 WAT	4 WAT	1 WAT	2 WAT	3 WAT	4 WAT
		(%)							
Bromoxynil	0.50	48	93	43	72	0	20	33	17
Carfentrazone-ethyl	0.03	82	97	27	58	60	93	90	73
Mesotrione	0.25	7	52	48	50	0	33	47	43
Sulfentrazone	0.25	83	97	93	100	40	87	100	97
Sulfentrazone	0.38	83	100	95	95	53	92	100	100
Sulfentrazone+	0.06+	40	82	68	67	33	90	98	93
Quinclorac +	0.50+								
2,4-D+	0.88+								
Dicamba	0.10								
Sulfentrazone+	0.03+	23	77	53	70	33	85	99	87
2,4-D+	0.70+								
MCPP+	0.25+								
Dicamba	0.11								
LSD _{0.05} ^x		9	21	40	32	22	11	6	11

^zWAT = weeks after treatment.

^y1 lb/acre = 1.1209 kg·ha⁻¹.

^xFisher's protected least significant difference value used to compare treatment means at the $\alpha = 0.05$ level.

Table 2. Percentage of visual control of star-of-bethlehem for treatments applied in the mixture experiment conducted at the East Tennessee Research and Education Center-Plant Sciences Unit (Knoxville, TN) in 2009.

Herbicide treatment	Rate (lb/acre) ^y	Star-of-bethlehem control (%)			
		1 WAT ^z	2 WAT	3 WAT	4 WAT
Bentazon ^x	0.50	2	9	32	32
Bromoxynil ^x	0.50	12	78	78	74
Mesotrione ^w	0.25	0	5	63	61
Mesotrione ^w + bentazon ^w	0.25 + 0.50	3	28	73	82
Mesotrione ^w + bromoxynil ^w	0.25 + 0.50	15	82	93	93
Topramezone ^x	0.033	2	5	43	47
Topramezone ^x + bentazon ^x	0.033 + 0.50	2	12	58	63
Topramezone ^x + bromoxynil ^x	0.033 + 0.50	18	82	93	93
LSD _{0.05} ^v		6	14	17	19

^xWAT = weeks after treatment.

^y1 lb/acre = 1.1209 kg·ha⁻¹.

^zMixed with crop oil concentrate at a 1% (v/v) ratio.

^wMixed with a nonionic surfactant at a 0.25% (v/v) ratio.

^vFisher's protected least significant difference value used to compare treatment means (pooled across two experimental runs of a study with three replications) at the $\alpha = 0.05$ level.

however, by 3 and 4 WAT, this mixture provided greater control than an application of bentazon alone at 0.50 lb/acre (Table 2).

Although mesotrione has been reported to temporarily injure tall fescue turf (Syngenta Professional Products, 2008b), at no time in the single product or mixture experiment was tall fescue injury observed with any treatment (data not shown). This may be because applications were made in spring under conditions of moderate temperature (<80 °F) and low humidity (<50%). Other researchers (Brosnan and Breeden, 2009; M.J. Goddard, personal communication) have observed tall fescue injury with mesotrione applications in hot, humid summer weather.

Data collected in these experiments illustrates that turfgrass managers can apply sulfentrazone to provide POST control of star-of-bethlehem in cool-season turf. Similar to what has been reported for other weed species, the inclusion of bromoxynil with topramezone and mesotrione significantly increases the level of star-of-bethlehem control provided by these herbicides. These tank mixtures may provide additional options for turfgrass managers charged with controlling star-of-bethlehem infestations in cool-season turf.

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