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Notes

Sulfentrazone and Carfentrazone Accelerate Broadleaf Weed Control with Metsulfuron

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Ground ivy and khakiweed are troublesome broadleaf weeds of warm-season turfgrass. Field studies were conducted in Tennessee (TN) and Texas (TX) from 2008 to 2010 to evaluate the efficacy of sulfentrazone plus metsulfuron and carfentrazone plus metsulfuron tank mixtures compared with metsulfuron alone for control of ground ivy and khakiweed. In TN, sulfentrazone plus metsulfuron and carfentrazone plus metsulfuron provided accelerated control of ground ivy compared with metsulfuron alone. Over a 2-yr period, ground ivy control with metsulfuron at 10, 21, and 42 g ai ha^{-1} ranged from 0 to 5% 7 d after treatment (DAT) and 12 to 60% 14 DAT. Ground ivy control with mixtures of sulfentrazone plus metsulfuron ranged from 40 to 72% 7 DAT and 87 to 100% 14 DAT. Similarly, carfentrazone plus metsulfuron controlled ground ivy 5 to 32% 7 DAT and 23 to 93% 14 DAT. In TX, carfentrazone plus metsulfuron and sulfentrazone plus metsulfuron controlled khakiweed greater than metsulfuron alone 7 and 14 DAT as well. Few differences in ground ivy and khakiweed control were detected 56 DAT because metsulfuron applied alone at 21 g ai ha^{-1} controlled both weeds > 77%, similar to each mixture. These data indicate that when applied in mixtures, sulfentrazone and carfentrazone accelerate ground ivy and khakiweed control with metsulfuron but do not affect long-term efficacy.
Nomenclature: Carfentrazone; metsulfuron; sulfentrazone; ground ivy, *Glechoma hederacea* L.; khakiweed; *Alternanthera pungens* Kunth.
Key words: Efficacy, golf course, postemergence herbicides, tank mixtures, turf, turfgrass.

Glechoma hederacea y *Alternanthera pungens* son malezas problemáticas de hoja ancha en céspedes de época cálida. En 2008 y 2010 se realizaron estudios de campo en Tennessee (TN) y Texas (TX) para evaluar la eficacia de mezclas en tanque de sulfentrazone más metsulfuron y carfentrazone más metsulfuron, comparadas con solo metsulfuron, para el control de *G. hederacea* y *A. pungens.* En TN, sulfentrazone más metsulfuron y carfentrazone más metsulfuron proporcionaron un control acelerado de *G. hederacea* en comparación con metsulfuron solo. A lo largo de un período de dos años, el control de *G. hederacea* con metsulfuron a 10, 21 y 42 g ia ha^{-1} varió de 0 a 5% 7 días después del tratamiento (DAT) y de 12 a 60% 14 DAT. El control de *G. hederacea* con mezclas de sulfentrazone más metsulfuron varió de 40 a 72% 7 DAT y de 87 a 100% 14 DAT. Similarmente, carfentrazone más metsulfuron controlaron la *G. hederacea* de 5 a 32% 7 DAT y de 23 a 93% 14 DAT. En TX, carfentrazone más metsulfuron y sulfentrazone más metsulfuron controlaron *A. pungens* mejor que metsulfuron por sí solo, también a los 7 y 14 DAT. Pocas diferencias en el control de *G. hederacea* y *A. pungens* fueron detectas a los 56 DAT, mientras metsulfuron aplicado sólo a 21 g ia ha^{-1} controló ambas malezas >77%, similar al control con cada mezcla. Estos datos indican que cuando se aplican en mezclas con metsulfuron, sulfentrazone y carfentrazone aceleran el control de *G. hederacea* y *A. pungens* pero no afectan su eficacia a largo plazo.

Ground ivy is a perennial weed that spreads aggressively from stolons that root at the nodes. Infestations of ground ivy are problematic in warm- and cool-season turfgrasses throughout the central and eastern United States (Reicher and Weisenberger 2007). In a survey of lawn care operators, nearly 50% of respondents reported poor to fair control of ground ivy, and 86% reported that sequential applications were required to achieve control (Kohler et al. 2004).

Khakiweed, also referred to as "chaffweed," is a perennial species that has been termed the fastest growing turfgrass weed problem in the southwestern United States (Kopec et al. 2004). A herbaceous perennial, khakiweed also spreads from stolons that root at the nodes, allowing it to form dense mats ranging from 0.15 to 0.61 m diam (Sholedice and Renz 2006). Its prostrate growth habit allows tolerance to frequent mowing at heights of < 2 cm. In most environments, khakiweed outcompetes bermudagrass [*Cynodon dactylon* (L.) Pers.] for space, water, and nutrients (Kopec et al. 2004). Data describing efficacy of herbicides for khakiweed control are limited; however, Umeda (2008) reported > 90% khakiweed control 54 d after initial treatment with sequential applications of carfentrazone plus 2,4-D plus mecoprop (MCPP) plus dicamba or triclopyr plus fluroxypyr applied in combination with isoxaben.

Metsulfuron is a sulfonylurea herbicide that inhibits the acetolactate synthase enzyme (ALS; EC 2.2.1.6) in susceptible species (Senseman 2007). ALS inhibition prevents the formation of branched chain amino acids valine, leucine, and isoleucine. Labeled for control of numerous broadleaf weeds in warm-season turf, metsulfuron is commonly applied throughout the transition zone and southern United States (Anonymous 2008).

Mixtures of protoporphyrinogen oxidase (PPO; EC 1.3.3.4) and ALS-inhibiting herbicides have been shown to improve broadleaf weed control in soybean [*Glycine max* (L.) Merr.]

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production (Dirks et al. 2000; Krausz et al. 1998). Sulfentrazone is a PPO-inhibiting herbicide that causes rapid desiccation of foliar plant tissue when applied to established weeds and controls certain weed species germinating in the soil profile (Ohmes et al. 2000; Senseman 2007). Mixtures of sulfentrazone with cloransulam have been shown to increase common waterhemp (*Amaranthus rudis* Sauer) and yellow nutsedge (*Cyperus esculentus* L.) control compared with cloransulam alone (Dirks et al. 2000; Krausz et al. 1998). Similarly, Krausz et al. (1998) reported increased ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq] control with mixtures of sulfentrazone plus imazaquin compared to imazaquin alone. Although the researchers reported no differences in giant foxtail (*Setaria faberi* Herrm.) control with sulfentrazone plus imazaquin mixtures, addition of sulfentrazone to cloransulam increased giant foxtail and common cocklebur (*Xanthium strumarium* L.) control compared with cloransulam alone (Krausz et al. 1998). Dirks et al. (2000) also observed increased giant foxtail and common waterhemp control with cloransulam plus sulfentrazone mixtures but reported no increases in common cocklebur control with these treatments. Another PPO-inhibiting herbicide, carfentrazone, has been shown to increase white clover (*Trifolium repens* L.) control when applied in mixtures with the hydroxyphenylpyruvatedioxygenase (HPPD) inhibitor mesotrione (Willis et al. 2007). Similarly, the addition of carfentrazone has been reported to enhance fall applications of 2,4-D plus MCPP plus dicamba for ground ivy control (Reicher and Weisenberger 2007).

When applied in mixtures, sulfentrazone and carfentrazone may improve ground ivy and khakiweed control with metsulfuron. However, data describing the effects of sulfentrazone and carfentrazone on the weed control efficacy of metsulfuron are limited. Thus, the objective of this research was to evaluate the efficacy of sulfentrazone plus metsulfuron and carfentrazone plus metsulfuron mixtures for control of ground ivy and khakiweed.

Materials and Methods

Ground Ivy Research Site. Two studies were conducted from 2008 to 2010 on mature stands of common bermudagrass (cultivar unknown) at Egwani Farms Golf Course (Rockford, TN) infested with ground ivy. The soil was a Hamblen (fine-loamy, siliceous, semiactive, thermic fluvaquenticeutrudept) silt loam, with pH 6.4 and 2.8% organic matter content. Turf was mowed at a height of 5 cm with a rotary mower, and clippings were returned to the surface after mowing. Rainfall was the only water source because no irrigation was available. All treatments were applied with a CO_2-powered boom sprayer equipped with 8002 flat-fan nozzles (Teejet, P.O. Box 7900, Wheaton, IL) calibrated to deliver 281 L ha^{-1} of spray volume. For study 1, treatments were applied to 5- by 3-m plots on July 27, 2009, with the entire trial replicated at an adjacent location on Egwani Farms Golf Course on May 26, 2010. For study 2, treatments were applied to 5- by 3-m plots on August 28, 2008, and the trial was repeated with applications made on July 27, 2009.

Study 1. Sulfentrazone Plus Metsulfuron Mixtures for Ground Ivy Control. The experimental design was a randomized complete block with three replications. Treatments included metsulfuron (Manor Selective Herbicide, NuFarm Americas Inc., Burr Ridge, IL) at 10, 21, and 42 g ai ha^{-1}, as well as a preformulated mixture of sulfentrazone plus metsulfuron (Blindside, FMC Corporation, Philadelphia, PA) at 166 plus 17, 264 plus 26, 273 plus 27, 294 plus 29, 391 plus 39, 400 plus 40, and 421 plus 42 g ai ha^{-1}. The sulfentrazone to metsulfuron ratio in this preformulated mixture was 10 : 1 (Anonymous 2010). Sulfentrazone was not evaluated as a standalone herbicide treatment because the previous research had found it to be ineffective in controlling ground ivy (Brosnan and Breeden 2008a). Application rates in this study were selected to span the range of rates labeled for broadleaf weed control with metsulfuron (Anonymous 2008). An untreated check was also included for comparison.

Study 2.Carfentrazone Plus Metsulfuron Mixtures for Ground Ivy Control. The experimental design was a randomized complete block with three replications. Treatments included the factorial combination of metsulfuron (10, 21, and 42 g ha^{-1}) and carfentrazone (Quicksilver T&O, FMC Corporation, Philadelphia, PA) at 17 and 33 g ai ha^{-1}. Carfentrazone was not evaluated as a standalone herbicide treatment because previous research had found it to be ineffective in controlling ground ivy (Brosnan and Breeden 2008b). Application rates in this study were selected to span the range of rates labeled for broadleaf weed control with metsulfuron (Anonymous 2008). An untreated check was also included for comparison.

Khakiweed Research Sites. Research was conducted in 2010 on mature stands of common bermudagrass (cultivar unknown) at Meadowbrook Golf Course and Lake Ridge Golf Course (Lubbock, TX) infested with khakiweed. Soil at each location was a Brownfield (Loamy, mixed, superactive, thermic Arenic Aridic Paleustalfs) sandy clay loam, with pH 8.0 at Meadowbrook Golf Course and pH 8.2 at Lake Ridge Golf Course. Turf at each location was mowed to a height of 4 cm with a rotary mower, and clippings were returned to the surface after mowing. Turf at each location received approximately 5 cm of irrigation per week from an automatic irrigation system.

Study 3. Carfentrazone and Sulfentrazone Mixtures with Metsulfuron for Khakiweed Control. The experimental design was a randomized complete block with four replications. Treatments included metsulfuron (10, 21, and 42 g ha^{-1}) and a preformulated mixture of carfentrazone plus metsulfuron (F9007, FMC Corporation, Philadelphia, PA) at 15 plus 12, 22 plus 17, 25 plus 19, 31 plus 24, 34 plus 26, and 43 plus 33 g ha^{-1}. The carfentrazone to metsulfuron ratio in this pre-formulated mixture was 4 : 3 (F. R. Walls, personal communication). Application rates in this study were selected to span the range of rates labeled for broadleaf weed control with metsulfuron (Anonymous 2008). Carfentrazone was not evaluated as a standalone herbicide treatment because previous research had found it to be ineffective in controlling khakiweed (Hephner et al. 2011). The preformulated mixture of sulfentrazone plus metsulfuron used in study 1 was also evaluated in this research at 294 plus 29 g ha^{-1} and 421 plus 42 g ha^{-1}. An untreated check was also included for comparison. All treatments were applied with a CO_2-powered boom sprayer equipped with 8004 flat-fan nozzles (Teejet, P.O. Box 7900, Wheaton, IL) calibrated to deliver 374 L ha^{-1} of spray volume. Treatments were applied to 1.5- by 1.5-m plots on August 18, 2010, at Meadowbrook Golf Course. The trial was repeated at

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Table 1. Ground ivy control with metsulfuron and metsulfuron plus sulfentrazone in Rockford, TN, in 2009 and 2010.

		Ground ivy control							
		2009				2010			
Herbicide	Rate	7 DAT[a]	14 DAT	28 DAT	56 DAT	7 DAT	14 DAT	28 DAT	56 DAT
	g ai ha^{-1}	%							
Metsulfuron	10	0	27	67	82	7	43	87	92
	21	2	40	82	88	10	87	99	97
	42	3	58	89	92	13	67	100	100
Sulfentrazone + metsulfuron[b]	166 + 17	65	88	95	90	50	92	100	98
	264 + 26	62	87	89	95	47	92	100	98
	273 + 27	72	96	98	100	47	90	97	95
	294 + 29	63	93	96	98	47	93	100	97
	391 + 39	60	92	99	100	53	100	100	100
	400 + 40	68	96	100	100	43	90	100	100
	421 + 42	57	90	100	98	40	73	97	98
$LSD_{0.05}$		13	13	12	7	23	26	6	7

[a] Abbreviations: DAT, days after treatment.

[b] A preformulated mixture of sulfentrazone plus metsulfuron at a 10 : 1 ratio (Anonymous 2010).

Lake Ridge Golf Course with applications made on August 25, 2010.

Statistical Analysis. Weed control and bermudagrass injury were assessed visually in each study because researchers have reported that quantitative methods (e.g., digital image analysis, fluorometry, etc.) offer few advantages over visual assessments for quantifying herbicide responses in turf (Elmore et al. 2011; Lewis et al. 2010; Yelverton et al. 2009). Ground ivy and khakiweed control were rated visually on a scale of 0% (no weed control) to 100% (complete kill of all weeds) relative to the untreated control at 7, 14, 28, and 56 DAT. In studies 1 and 3, bermudagrass injury was evaluated on a scale of 0% (no injury) to 100% (complete kill of all turf) relative to an untreated control on the same dates as well.

Arcsine–square-root transformations were performed to stabilize variance before subjecting data to ANOVA, with main effects and all possible interactions tested using the appropriate expected mean square values described by McIntosh (1983). Interpretations were not different from nontransformed data; therefore, nontransformed means are presented here for clarity. Fisher's LSD values were calculated when the *F* ratio was significant at the 0.05 level.

Results and Discussion

Study 1. Sulfentrazone Plus Metsulfuron Mixtures for Ground Ivy Control. Significant year-by-treatment interactions were detected; thus, data from each year were analyzed and are presented separately. Mixtures of sulfentrazone plus metsulfuron increased the rate of injury symptom development compared with metsulfuron alone (Table 1). Ground ivy control in 2009 ranged from 0 to 3% 7 DAT and 27 to 58% 14 DAT, with all rates of metsulfuron applied alone. Comparatively, ground ivy control with all mixtures of sulfentrazone plus metsulfuron ranged from 57 to 72% and 87 to 96% 7 and 14 DAT, respectively (Table 1). In 2010, similar relationships were detected between treatments 7 DAT. However, only one sulfentrazone plus metsulfuron mixture (391 plus 39 g ha^{-1}, respectively) controlled ground ivy greater than metsulfuron at 21 or 42 g ha^{-1} 14 DAT. Ground ivy control 14 DAT in 2010 ranged from 67 to 100% with all treatments (Table 1). Metsulfuron alone provided good to excellent control (82 to 100%) each year at 56 DAT. Few significant differences were detected between treatments at 56 DAT as ground ivy control ranged from 82 to 100% in 2009 and 92 to 100% in 2010 (Table 1). Bermudagrass injury with mixtures of sulfentrazone plus metsulfuron ranged from 0 to 7% by 7 DAT in 2009 but dissipated to 0% by 14 DAT (data not shown). Injury measured 0% on all other dates in 2009 and 2010.

Study 2. Carfentrazone Plus Metsulfuron Mixtures for Ground Ivy Control. Significant year-by-treatment interactions were detected; thus, data from each year were analyzed and are presented separately. Certain mixtures of carfentrazone plus metsulfuron increased ground ivy control 7, 14, and 28 DAT compared with metsulfuron alone in 2008 and 2009 (Table 2). In 2008, ground ivy control with metsulfuron ranged from 12 to 15% compared with 23 to 35% for carfentrazone plus metsulfuron mixtures 14 DAT (Table 2). While ground ivy control with all herbicides increased in 2009, similar relationships were detected between treatments. In 2009, ground ivy control with metsulfuron ranged from 40 to 60% compared with 57 to 93% for carfentrazone plus metsulfuron 14 DAT (Table 2). Few significant differences in ground ivy control were detected between metsulfuron and carfentrazone plus metsulfuron mixtures either year at 56 DAT. Overall ground ivy control with metsulfuron alone ranged from 60 to 98% depending on year and application rate (Table 2). Reicher and Weisenberger (2007) also reported that improved short-term efficacy with mixtures of carfentrazone plus 2,4-D plus MCPP plus dicamba did not improve long-term ground ivy control.

At the conclusion of the study in 2008, ground ivy control ranged from 60 to 93% compared with 93 to 100% in 2009 (Table 2). Increased ground ivy control in 2009 could be related to differences in soil moisture. The research site received 10 cm of rainfall during the 30 d before treatment in 2009. Additionally, 14 cm of rain fell during the first 30 d after application, including 9 cm during the first 7 d after application. In 2008, the research site received only 5 cm of rainfall during the 30 d before

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Table 2. Ground ivy control with metsulfuron and carfentrazone plus metsulfuron in Rockford, TN, in 2008 and 2009.

		Ground ivy control							
		2008				2009			
Herbicide	Rate	7 DAT[a]	14 DAT	28 DAT	56 DAT	7 DAT	14 DAT	28 DAT	56 DAT
	g ai ha^{-1}	%							
Metsulfuron	10	0	12	40	60	3	60	93	97
	21	0	13	50	78	2	40	87	95
	42	2	15	67	78	5	53	93	98
Carfentrazone + metsulfuron	17 + 10	5	23	73	80	7	77	97	97
	17 + 21	7	23	82	85	10	65	93	97
	17 + 42	7	25	87	93	8	93	100	100
	33 + 10	12	32	70	77	23	78	94	93
	33 + 21	13	35	85	84	32	87	99	100
	33 + 42	10	30	82	83	13	57	100	100
$LSD_{0.05}$		6	19	15	19	12	23	11	7

[a] Abbreviations: DAT, days after treatment.

treatment, and only 11 cm of rain fell during the entire 56-d evaluation period thereafter. Similar to the findings of Kells et al. (1984), dry conditions in 2008 might have affected absorption and translocation of herbicides applied to ground ivy tissue negatively. Kohler et al. (2004) also reported variability in ground ivy control because of differences in environmental conditions after application.

Study 3. Carfentrazone Plus Metsulfuron Mixtures for Khakiweed Control. No significant location-by-treatment interactions were detected; thus, data from each location were combined. Similar to the responses observed for ground ivy, mixtures of both carfentrazone plus metsulfuron and sulfentrazone plus metsulfuron controlled khakiweed greater than metsulfuron alone 7 and 14 DAT (Table 3). Khakiweed control with metsulfuron ranged from 19 to 24% 7 DAT and 44 to 59% 14 DAT. Umeda (2008) reported similar levels of khakiweed control with single applications of other ALS-inhibiting herbicides, including imazaquin, sulfosulfuron (CAS 141776-32-1, *N*-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-2-(ethylsulfonyl)imidazo[1,2-*a*]pyridine-3-sulfonamide), and trifloxysulfuron (CAS 199119-58-9, *N*-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-3-(2,2,2-trifluoroethoxy)-2-pyridinesulfonamide) applied alone. Comparatively, when treated with carfentrazone plus metsulfuron in the current study, khakiweed control ranged from 52 to 67% 7 DAT and 73 to 80% 14 DAT. Mixtures of sulfentrazone plus metsulfuron responded similarly (Table 3). No differences in khakiweed control were detected between any mixture treatment and metsulfuron alone at ≥ 21 g ha^{-1} at 56 DAT; all treatments controlled khakiweed 84 to 95%. Umeda (2008) reported a similar level of khakiweed control with single and sequential applications of carfentrazone plus 2,4-D plus MCPP plus dicamba. In the current study, carfentrazone plus metsulfuron mixtures at ≥ 31 plus 24 g ha^{-1} resulted in greater khakiweed control than applications at lower rates (Table 3). No bermudagrass injury was observed on any evaluation date (data not shown).

Table 3. Khakiweed (*Alternanthera pungens* Kunth.) control with combinations of carfentrazone, sulfentrazone, and metsulfuron in Lubbock, TX, in 2010.

		Khakiweed control			
Herbicide	Rate	7 DAT[a]	14 DAT	28 DAT	56 DAT
	g ai ha-1	%			
Metsulfuron	10	19	44	66	72
	21	12	53	87	89
	42	24	59	85	86
Carfentrazone + metsulfuron[b]	15 + 12	52	80	85	85
	22 + 17	55	76	81	84
	25 + 19	55	73	80	84
	31 + 24	67	78	95	95
	34 + 26	63	77	96	95
	43 + 33	66	79	94	95
Sulfentrazone + metsulfuron[c]	294 + 29	61	80	90	94
	421 + 42	65	83	92	92
$LSD_{0.05}$		7	8	10	10

[a] Abbreviations: DAT, days after treatment.

[b] A preformulated mixture of carfentrazone plus metsulfuron at a 4 : 3 ratio (F. R. Walls, personal communication).

[c] A preformulated mixture of sulfentrazone plus metsulfuron at a 10 : 1 ratio (Anonymous 2010).

Data in the current studies illustrate that sulfentrazone and carfentrazone accelerate broadleaf weed control with metsulfuron when applied in mixtures. However, these mixtures did not affect long-term weed control 56 DAT. Other researchers have reported similar findings with both sulfentrazone and carfentrazone (Dirks et al. 2000; Krausz et al. 1998; Reicher and Weisenberger 2007; Willis et al. 2007). Considering that bermudagrass requires a threshold number of days without species competition for optimal health (Askew 2010), herbicides increasing the speed of ground ivy and khakiweed control that do not affect long-term efficacy are beneficial to turf managers, in that they allow bermudagrass more time without competition from other species.

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