Sequential Postemergence Applications for the Control of Khakiweed in Bermudagrass Turf

Andrew J. Hephner, Tyler Cooper, Leslie L. Beck, and Gerald M. Henry¹

Department of Plant and Soil Science, Texas Tech University, Box 42122, Lubbock, TX 79409

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Abstract. Khakiweed (*Alternanthera pungens* Kunth) response to single and sequential herbicide applications was evaluated during the summer of 2009 and 2010 in Texas. No bermudagrass phytotoxicity was observed throughout the length of each trial regardless of herbicide treatment. Carfentrazone at 0.034 kg a.i./ha, metsulfuron + carfentrazone at 0.021 + 0.034 kg a.i./ha, and trifloxysulfuron + carfentrazone at 0.018 + 0.034 kg a.i./ha exhibited 74% to 85% khakiweed control 2 weeks after initial treatment (WAIT) regardless of application regime. Control with carfentrazone (0.017 kg a.i./ha) was only 63% to 65% 2 WAIT regardless of application regime. Metsulfuron and trifloxysulfuron treatments exhibited 54% or less khakiweed control 2 WAIT regardless of rate. Six weeks later (8 WAIT), sequential applications of metsulfuron exhibited 98% control regardless of rate, whereas control with single applications was 79% to 87%. Sequential applications of trifloxysulfuron exhibited 86% to 88% khakiweed control 8 WAIT regardless of rate, whereas single applications exhibited 47% or less control. Carfentrazone treatments exhibited 5% or less control regardless of rate or sequential application 8 WAIT. Tank-mixing metsulfuron or trifloxysulfuron with carfentrazone did not improve control 8 WAIT compared with either sulfonyleurea herbicide applied alone. Although initial khakiweed injury was observed in all treatments, effective long-term control was difficult to achieve. Excellent control (95% to 97%) was exhibited by sequential metsulfuron applications 12 WAIT regardless of rate. Sequential applications of trifloxysulfuron (0.018 or 0.028 kg a.i./ha) and single applications of metsulfuron at 0.042 kg a.i./ha exhibited moderate khakiweed control (75% to 80%) 12 WAIT. All other treatments exhibited 57% or less khakiweed control 12 WAIT. Efficacy of sequential metsulfuron applications is a strong incentive for its adoption over trifloxysulfuron applications for the control of khakiweed in bermudagrass turf.

Khakiweed (*Alternanthera pungens* Kunth) is a perennial broadleaf weed that readily invades turfgrass throughout the arid and semi-arid regions of the United States (McCarty et al., 2008). The presence of this weed significantly reduces the aesthetic value and playability of desired turfgrass species. Morphological characteristics and the ability to adapt to a wide range of environments have led to the increase in khakiweed prevalence in managed turf. Long-term reductions in turfgrass density often result from the aggressive spread of dense, prostrate khakiweed mats throughout the summer (Shoedice and Renz, 2006; Umeda and Towers, 2004). A deep taproot and a thick waxy cuticle help khakiweed avoid acute drought stress (Parsons and

Cuthbertson, 2001) and may contribute to salinity tolerance. Furthermore, turfgrass managers often observe khakiweed in areas of heavy traffic and wear (e.g., cart paths, athletic fields) where desired turfgrass species are thin and less vigorous (Umeda and Towers, 2004).

Limited options exist for selective khakiweed control in managed turfgrass. Trifloxysulfuron is the only herbicide labeled for the postemergence control of khakiweed in turf (Anonymous, 2009). However, turfgrass managers also use metsulfuron for selective control of khakiweed on athletic fields and golf courses (personal observation). Trifloxysulfuron and metsulfuron both belong to the sulfonyleurea herbicide family. Good crop selectivity, very low acute and chronic animal toxicity, and broad-spectrum weed control at very low use rates (as low as 2 to 75 g·ha⁻¹) make these chemistries very beneficial from a use and environmental risk standpoint (Beyer et al., 1988).

Sulfonyleurea herbicides inhibit the enzyme acetolactate synthase, thereby blocking the biosynthesis of the branched-chain amino acids valine, leucine, and isoleucine (Brown, 1990; Senseman and Armbrust, 2007). Inhibition leads to the termination of plant cell division and growth. Cessation of plant growth in

conjunction with long-term reductions in new leaves and reproductive organs may be attributed to the accumulation of acetolactate synthase substrate (e.g., a-ke-tobutyrate) in leaf tissue (Brown, 1990; LaRossa and Van Dyk, 1987).

Trifloxysulfuron and metsulfuron are both labeled for the postemergence control of broad-leaf weeds in warm-season turf (Anonymous, 2009, 2011). Minimal to no bermudagrass phytotoxicity was observed after applications of metsulfuron and trifloxysulfuron for weed control (Butler et al., 2005; Davis et al., 1997; Johnson, 1987; McElroy et al., 2005). Busey (2009) reported 77% control of dollarweed (*Hydrocotyle umbellata* L.) 10 WAIT in St. Augustinegrass [*Stenotaphrum secundatum* S. (Walt.) Kuntze] with applications of metsulfuron at 0.021 kg a.i./ha. Metsulfuron at 0.017, 0.034, and 0.05 kg a.i./ha exhibited 95% to 100% control of broom snakeweed [*Gutierrezia sarothrae* (Pursh) Britt. & Rusby] present in pasture land 7 WAIT (McDaniel and Duncan, 1987). Singh and Singh (2004) observed 80% to 88% control of redroot pigweed (*Amaranthus retroflexus* L.), Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], hairy beggarticks (*Bidens pilosa* L.), tall morning glory [*Ipomoea purpurea* (L.) Roth], and ivyleaf morningglory [*Ipomoea hederacea* Jacq.] in the greenhouse with applications of trifloxysulfuron at 0.063 kg a.i./ha. Trifloxysulfuron at 0.005 kg a.i./ha exhibited 73% control of sicklepod [*Senna obtusifolia* (L.) H.S. Irwin Barneby] 3 WAIT in the greenhouse (Koger et al., 2005).

Postemergence control of khakiweed with herbicides has received limited investigation. Trifloxysulfuron at 0.017, 0.029, and 0.053 kg a.i./ha exhibited 95%, 94%, and 98% control, respectively, 40 d after treatment (DAT) (Kopec et al., 2004a). Single applications of metsulfuron at 0.021 and 0.042 kg a.i./ha exhibited 99% khakiweed control 40 DAT (Kopec et al., 2004a). Penoxsulam at 0.1 kg a.i./ha exhibited 69% khakiweed control 40 d after initial treatment (DAIT) (Kopec et al., 2004b). Umeda (2008) observed 86% khakiweed control 36 DAIT with applications of carfentrazone + 2,4-D + mecoprop + dicamba at 0.45 kg a.i./ha. Tank-mixing carfentrazone + 2,4-D + mecoprop + dicamba at 0.45 kg a.i./ha with fluroxypyr at 0.056 kg a.i./ha provided 85% khakiweed control 40 DAIT (Umeda and Towers, 2004). Applications of 2,4-D + mecoprop + dicamba at 0.14 kg a.i. only controlled khakiweed 1% 27 DAIT (Kopec et al., 2004a). Thus, carfentrazone may have potential for khakiweed control and warrants further investigation in bermudagrass.

The presence of a deep taproot enables khakiweed to regenerate from abundant carbohydrate reserves after defoliation (Umeda, 2008). Minimal research has examined sequential applications for the long-term control of khakiweed. Umeda (2008) reported 94% khakiweed control 36 d after sequential treatment of carfentrazone + 2,4-D + mecoprop + dicamba at 0.45 kg a.i./ha tank-mixed with isoxaben at 0.84 kg a.i./ha. Sequential applications may be necessary to reduce the photosynthetic capability of khakiweed and

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¹To whom reprint requests should be addressed; e-mail gerald.henry@ttu.edu.

associated carbohydrate production to obtain long-term control of perennial plant portions. Therefore, the objective of our research was to examine single vs. sequential applications of various herbicides for long-term control of khakiweed in bermudagrass turf.

Materials and Methods

Field experiments were initiated in June 2009 and 2010 at Meadowbrook Golf Course in Lubbock, TX (lat. 33°35'55" N, long. -101°49'52" W). Research was performed on established khakiweed infestations present in a common bermudagrass [*Cynodon dactylon* (L.) Pers.] rough that was maintained at a height of 5.0 cm. Plots measured 1.5 × 1.5 m and were arranged in a randomized complete block design with four replications. Initial khakiweed cover (40% to 90%) was assessed for each plot before herbicide application through grid counts. All experimental areas were mowed once weekly. There was no rain or irrigation applied for a 24-h period after herbicide applications.

Fourteen herbicide treatments and a non-treated control were included in both years of the study (Table 1). Herbicide treatments were initiated on 9 June 2009 and 10 June 2010. Herbicides included trifloxysulfuron (Monument; Syngenta Crop Protection, LLC, Greensboro, NC), carfentrazone (Quicksilver; FMC Corporation, Philadelphia, PA), and metsulfuron (Blade; PBI Gordon Corporation, Kansas City, MO) (Table 1). Treatments were applied using a CO₂-pressurized backpack sprayer equipped with XR8004VS Teejet nozzle tips (Teejet, flat-fan extended-range spray tips; Spraying Systems Co., Wheaton, IL) calibrated to deliver 375 L·ha⁻¹ at 221 kPa.

Data collected included bermudagrass phytotoxicity and khakiweed control based on digital image analysis and grid counts, respectively. Digital photographs were taken 1, 2, 4,

6, 7, and 8 WAIT with a Nikon (Coolpix P5000; Nikon Inc. USA, Melville, NY) 10.0-megapixel camera mounted on a light box equipped with four incandescent light bulbs each with a light output of 172 μmol·m⁻²·s⁻¹. Digital images were analyzed using WinCam 2007 software (Regent Instruments Inc., Quebec, Canada) to determine the percentage of bermudagrass leaf firing (chlorotic tissue) per plot. Percent bermudagrass leaf firing data were converted to percent bermudagrass phytotoxicity by comparing values for each plot with the untreated control within each experimental replication. Grid counts were taken 1, 2, 4, 6, 8, and 12 WAIT using a 0.3-m² grid (25 intersecting points) tossed into each plot [e.g., 15 plants equal 60% cover (15/25 × 100)]. Khakiweed cover from grid counts was converted to percent khakiweed control by comparing khakiweed cover for each plot with the cover recorded at initial herbicide application. Percent bermudagrass phytotoxicity and percent khakiweed control were arcsine square root transformed before analysis. Transformation did not improve variance homogeneity; therefore, non-transformed data were used in analysis and presentation. There were no significant year-by-treatment interactions, so data were combined and subjected to analysis of variance using error partitioning appropriate to a randomized complete block design analysis in the general linear models procedure provided by SAS (SAS, Statistical Analysis Systems, 2002–2008, Release 9.2; Statistical Analysis Systems Institute, Cary, NC). Means were separated using Fisher's protected least significant difference at the 0.05 significance level.

Results and Discussion

No bermudagrass phytotoxicity was observed throughout the length of each trial regardless of herbicide treatment (data not

shown). Johnson (1987) observed similar results on bermudagrass in response to metsulfuron at 0.03, 0.07, and 0.13 kg a.i./ha, whereas McElroy et al. (2005) reported bermudagrass seedling tolerance (13% or less phytotoxicity) to trifloxysulfuron applications at 0.03 kg a.i./ha.

Herbicide treatment main effects were observed for khakiweed control (Table 1). Carfentrazone at 0.034 kg a.i./ha, metsulfuron + carfentrazone at 0.021 + 0.034 kg a.i./ha, and trifloxysulfuron + carfentrazone at 0.018 + 0.034 kg a.i./ha exhibited 74% to 85% khakiweed control 2 WAIT regardless of application regime. Umeda (2008) observed similar results (72% khakiweed control 10 DAT) with applications of carfentrazone + 2,4-D + mecoprop + dicamba at 0.45 kg a.i./ha. Weeds treated with carfentrazone often exhibit necrosis and die within a few days (Senseman and Armbrust, 2007). Carfentrazone alone (0.017 kg a.i./ha) in our research exhibited 63% to 65% control 2 WAIT regardless of application regime. However, metsulfuron and trifloxysulfuron treatments exhibited 54% or less khakiweed control 2 WAIT regardless of rate. Injury symptoms after application of metsulfuron and trifloxysulfuron have been reported to take greater than 1 to 2 weeks to appear (Senseman and Armbrust, 2007).

Six weeks later (8 WAIT), sequential applications of metsulfuron exhibited 98% control regardless of rate, whereas control with single applications of metsulfuron was only 79% to 87%. Kopec et al. (2004a) reported a similar response in khakiweed control (99%) 40 DAT with single applications of metsulfuron at 0.021 and 0.042 kg a.i./ha. Sequential applications of trifloxysulfuron exhibited 86% to 88% khakiweed control 8 WAIT regardless of rate, whereas single applications exhibited 47% or less control. These findings differ from those of Kopec et al. (2004a) who observed 94% to 99% khakiweed control 40 DAT with applications of trifloxysulfuron at 0.017, 0.029, and 0.053 kg a.i./ha. Carfentrazone treatments exhibited 5% or less khakiweed control regardless of rate or sequential application 8 WAIT. Tank-mixtures of metsulfuron or trifloxysulfuron with carfentrazone did not improve control 8 WAIT compared with either sulfonylurea herbicide applied alone. Rapid burn-down of khakiweed foliage in response to carfentrazone may reduce sulfonylurea translocation, therefore decreasing long-term control. Hutchinson et al. (2006) theorized a similar mechanism for metribuzin safening the phytotoxic effects of sulfentrazone applied post-emergence to potatoes. Metribuzin may cause rapid cell disintegration, which in turn inhibits sulfentrazone translocation, resulting in less total sulfentrazone injury (Hutchinson et al., 2006).

Although initial khakiweed injury was observed with all treatments, effective long-term control was difficult to achieve. Excellent control (95% to 97%) was exhibited by sequential metsulfuron applications 12 WAIT regardless of rate. Sequential applications of trifloxysulfuron (0.018 or 0.028 kg a.i./ha) and single applications of metsulfuron at 0.042 kg

Table 1. Control of khakiweed (*Alternanthera pungens* Kunth) in bermudagrass 2, 8, and 12 WAIT at Meadowbrook Golf Course (Lubbock, TX) in 2009 and 2010.^z

Treatment ^y	Rate (kg a.i./ha)	2 WAIT	8 WAIT (% control)	12 WAIT
Trifloxy ^a	0.018	32	30	22
Trifloxy	0.028	50	47	28
Trifloxy fb ^w Trifloxy 5 WAIT	0.018 + 0.018	37	86	75
Trifloxy fb Trifloxy 5 WAIT	0.028 + 0.028	53	88	80
Carfen ^v	0.017	65	0	0
Carfen	0.034	82	0	0
Carfen fb Carfen 5 WAIT	0.017 + 0.017	63	0	0
Carfen fb Carfen 5 WAIT	0.034 + 0.034	85	5	0
Met ^u	0.021	42	79	57
Met	0.042	54	87	79
Met fb Met 5 WAIT	0.021 + 0.021	41	98	95
Met fb Met 5 WAIT	0.042 + 0.042	53	98	97
Met + Carfen	0.021 + 0.034	78	60	42
Trifloxy + Carfen	0.018 + 0.034	74	26	9
Nontreated	—	0	0	0
Least significant difference (<i>P</i> = 0.05)	—	6	6	5

^zControl estimates are based on grid counts. Data were pooled over experiments conducted in 2009 and 2010. WAIT = weeks after initial treatment.

^ySingle or sequential applications were made with each application within a treatment receiving the same herbicide rate.

^atrifloxy = trifloxysulfuron.

^wfb = followed by.

^vcarfen = carfentrazone.

^umet = metsulfuron.

a.i./ha exhibited moderate khakiweed control (75% to 80%) 12 WAIT. All other treatments exhibited 57% or less khakiweed control 12 WAIT. Previous research has only examined khakiweed control over shorter time periods (49 DAT or less) (Kopeck et al., 2004a, 2004b; Umeda, 2008; Umeda and Towers, 2004).

Khakiweed produces a deep taproot used to store carbohydrates for emergence and growth in subsequent years. Effective khakiweed control is likely limited by absorption and translocation of applied herbicides. Leys and Slife (1988) reported 58% of applied ^{14}C -metsulfuron was readily absorbed by wild garlic (*Allium vineale* L.) 144 h after application and 16% of that absorbed material translocated out of the treated leaf. Troxler et al. (2003) observed 53% or less of applied ^{14}C -trifloxysulfuron was absorbed by yellow nutsedge (*Cyperus esculentus* L.) and purple nutsedge (*C. rotundus* L.) 96 h after treatment. Approximately 30% of the absorbed ^{14}C -trifloxysulfuron translocated out of both *Cyperus* spp.-treated leaves with 4% moving into tubers and roots. McElroy et al. (2004) observed similar results in green kyllinga (*Kyllinga brevifolia* Rottb.) and false-green kyllinga (*Kyllinga gracillima* Miq.). Both spp. absorbed 47% of the applied ^{14}C -trifloxysulfuron 96 h after application. Approximately 2% and 4% of the absorbed ^{14}C -trifloxysulfuron translocated to the roots and rhizomes, respectively. Substantial amounts of translocation exhibited by metsulfuron and trifloxysulfuron in other weed species may explain the amount of khakiweed control observed in this research.

Long-term (12 WAIT) khakiweed control efficacy with sequential metsulfuron applications is a strong incentive for its adoption over trifloxysulfuron for selective khakiweed control in bermudagrass turf. Although sequential trifloxysulfuron applications may provide moderate (80%) khakiweed control, remaining plants exhibit carbohydrate production and storage necessary for the emergence of new plants the next year. Enhanced khakiweed control 2 WAIT with carfentrazone warrants further research. Applications of trifloxysulfuron or metsulfuron after

carfentrazone treatment may offer improved control of this perennial weed.

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