Dallisgrass (*Paspalum dilatatum*) Control with Thiencarbazone-methyl, Foramsulfuron, and Halosulfuron- methyl in Bermudagrass Turf

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Abstract. Dallisgrass control in response to various timings and frequencies of single and combination herbicide treatments was evaluated from 2010 to 2012 in Lubbock, TX. Treatments included thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl (TFH) at 15 + 31 + 47 or 22 + 45 + 70 g a.i./ha, foramsulfuron at 106 g a.i./ha, and foramsulfuron + thiencarbazone-methyl + iodosulfuron-methyl-sodium + dicamba (foramsulfuron + TID) at 106 + (22 + 5 + 147) g a.i./ha. Applications of TFH provided ≤65% dallisgrass control by 10 weeks after initial treatment (WAIT) across two rates (15 + 31 + 47 or 22 + 45 + 70 g a.i./ha) and three application timings [September, October, or September followed by (fb) a sequential October application]. At 37 WAIT, sequential applications of TFH at 15 + 31 + 47 g a.i./ha resulted in 92% dallisgrass control. Similarly, application of TFH at 22 + 45 + 70 g a.i./ha provided 94% and 97% dallisgrass control when applied in September or September fb October, respectively. However, single October applications of TFH only provided ≤55% dallisgrass control 37 WAIT. Sequential combinations of foramsulfuron + TID at 106 + (22 + 5 + 147) g a.i./ha provided 93% dallisgrass control 37 WAIT, equivalent to single applications of TFH at 15 + 31 + 47 g a.i./ha and sequential treatments at 15 + 31 + 47 or 22 + 45 + 70 g a.i./ha. However, initial control (10 WAIT) with foramsulfuron + TID was moderate (63%). Sequential foramsulfuron applications (106 g a.i./ha) resulted in inadequate dallisgrass control (35% and 48%) 10 and 37 WAIT, respectively. Results from this study suggest that long-term dallisgrass control may be achieved when TFH is applied in September or September fb October. Applications initiated in October resulted in inadequate control, regardless of rate, which may be linked to reduced herbicidal absorption and translocation due to the onset of dallisgrass dormancy in late fall. Chemical names used: methyl 4-[(4,5-dihydro-3-methoxy-4-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl)carbonylsulfamoyl]-5-methylthiophene-3-carboxylate (thiencarbazone-methyl); 2-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoyl]-4-formamido-*N,N*-dimethylbenzamide (foramsulfuron); methyl 3-chloro-5-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoyl]-1-methylpyrazole-4-carboxylate (halosulfuron-methyl); sodium (5-iodo-2-methoxycarbonylphenyl)sulfonyl-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)carbamoyl]azanide (iodosulfuron-methyl-sodium); and 3,6-dichloro-2-methoxybenzoic acid (dicamba).

Dallisgrass (*Paspalum dilatatum* Poir.) is a problematic rhizomatous perennial grass weed of managed turfgrass stands throughout the southern United States. Dallisgrass is often considered a desirable grass species in pastures and roadsides; however, its wide adaptability to different environmental conditions has likely contributed to it becoming a weed in turfgrass settings. The presence of dallisgrass reduces turfgrass aesthetics and functionality of recreational, commercial, and residential turfgrass stands (Elmore et al., 2013; Henry et al., 2007a). Tolerance of dallisgrass to low mowing heights (1.3 cm) has been reported, suggesting that it can be problematic in both golf course fairways and

roughs (Henry et al., 2007a). Furthermore, dallisgrass growth is often encouraged in areas with high volumetric water content and its survival has been observed in regions prone to flooding (Henry et al., 2009; Loreti and Oesterheld, 1996; Rubio et al., 1995; Rubio and Lavado, 1999).

Chemical control options are currently limited for dallisgrass. One of the most common control programs is the use of sequential monosodium methanearsonate (MSMA) applications; however, this may present phytotoxicity concerns to warm-season turfgrasses (Henry et al., 2007b; Henry et al., 2008). Summer applications of MSMA have been reported to cause reductions in turf quality in both 'Tifway' hybrid bermudagrass (*Cynodon dactylon* × *Cynodon transvaalensis* Burt-Davy) and common bermudagrass [*C. dactylon* (L.) Pers.] (McCarty et al., 1991). Additionally, commercial

availability and continued use of MSMA has been uncertain following the 2009 decision by the Environmental Protection Agency, which eliminated the use of MSMA on home lawns and athletic fields, while restricting use on sod farms, golf courses, and highway rights of way and prohibiting use in all turfgrass environments after 31 Dec. 2013 (United States Environmental Protection Agency (EPA), 2009). The 2009 EPA decision on MSMA prohibition was recently delayed, pending a registration review that began in 2013 and is scheduled for completion in 2019 (United States Environmental Protection Agency, 2015).

Limitations on the efficacy of other herbicides for dallisgrass control have also been reported. Henry et al. (2007b) observed <60% dallisgrass control 1 month after initial treatment (MAIT) in response to sequential foramsulfuron applications made in summer; control was <5% 1 year after initial treatment. Bingham et al. (1993) also reported insufficient control of dallisgrass in tall fescue (*Festuca arundinacea* Schreb.) roadsides with fenoxaprop and imazethapyr. Herbicide application timing has also been determined to be a limiting factor for effective dallisgrass control, and previous research has illustrated the ineffectiveness of certain herbicides when applied after early spring. Brosnan et al. (2010) reported that single fluzifop applications made after the accumulation of 500 growing degree days provided 46% and 0% dallisgrass control 28 and 76 d after treatment, respectively, and sequential applications resulted in similar trends. The same research indicated that tank mixtures of fluzifop with mesotrione provided no better control than single or sequential fluzifop applications alone. In addition to a lack of efficacy for dallisgrass control when applied after early spring, it has also been well documented that fluzifop may cause phytotoxicity to bermudagrass turf (Bryson and Wills, 1985; Johnson, 1992; McElroy and Breeden, 2006;). Nonselectivity of glyphosate limits its use to spot spray applications that may cause nontarget damage to hybrid bermudagrass (Henry et al., 2008). The lack of noninjurious and effective herbicides for dallisgrass control warrants further investigation into chemical control options for use in warm-season turfgrasses.

A combination product containing the acetolactate synthase inhibitors TFH became commercially available in 2012 for the control of annual and perennial grass weeds, sedges, and broadleaf weeds in bermudagrass and zoysiagrass (*Zoysia* spp.) turf (Anonymous, 2016). Previous research examined the efficacy of this combination chemistry for the control of nutsedge (*Cyperus* sp.) in bermudagrass (Henry et al., 2013). May and June applications of TFH resulted in 89% to 93% yellow nutsedge (*Cyperus esculentus* L.) control 12 WAIT (Henry et al., 2013). Yellow nutsedge, like dallisgrass, is a difficult-to-control perennial weed with abundant vegetative tissue for carbohydrate storage (Wills, 1987). Perennial grass rhizomes act

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as sink tissue for carbohydrate reserves before the onset of dormancy; therefore, coinciding herbicide treatments with basipetal carbohydrate movement may maximize long-term perennial weed control (Davis et al., 1978; Smith et al., 1993). Research investigating this approach to dallisgrass control is lacking and highly warranted. Thus, the objectives of this research were to evaluate the efficacy of fall applications of TFH compared with other herbicides on dallisgrass control in bermudagrass turf, and to determine the effect of rate, application timing, and number of applications on efficacy of these herbicide treatments.

Materials and Methods

Field experiments were conducted during the fall of 2010 at Meadowbrook Golf Course (lat. 33°35' 55" N, long. 101°49' 52" W) and in 2011 at Texas Tech University (lat. 33°35' 4" N, long. 101°53' 3" W) in Lubbock, TX. Research at Meadowbrook Golf Course was performed on a common bermudagrass rough maintained at a height of 5.1 cm. Research at Texas Tech University was conducted on a 'Tifway' hybrid bermudagrass maintained at a height of 3.8 cm. Both sites contained mature dallisgrass infestations that had been present for multiple years. The Meadowbrook Golf Course and Texas Tech University site soils were both brownfield sandy clay loams (loamy, mixed, super active, thermic Arenic Aridic Paleustalfs), with a pH of 7.9 and organic matter content of 1.1% and a pH of 8.1 and organic matter content of 1.4%, respectively. Plots measured 1.5 × 1.5 m and were arranged in a randomized complete block design with four replications at each location. Percent cover of dallisgrass was assessed before initial herbicide applications for each site. Initial dallisgrass cover ranged from 50% to 95% and was used to estimate control. Both sites were irrigated daily with an automated system, with the exception of the first 24 h following herbicide applications.

Nine herbicide treatments and a nontreated control were included in both experiments and are listed in Table 1. Initial herbicide treatments were made on 27 Sept. 2010 and 23 Sept. 2011 at Meadowbrook Golf Course and Texas Tech University, respectively. Herbicides applied included TFH (Tribute Total; Bayer Environmental Science, Research Triangle Park, NC) at 15 + 31 + 47 or 22 + 45 + 70 g a.i./ha, foramsulfuron (Revolver 0.19 SC; Bayer Environmental Science, Research Triangle Park, NC) at 106 g a.i./ha, and TID (Celsius WG; Bayer Environmental Science,) at 22 + 5 + 147 g a.i./ha. All TFH treatments included methylated seed oil (Dyne-Amic; Helena Chemical Company, Collierville, TN) and ammonium sulfate (Sigma-Aldrich, St. Louis, MO) at 0.5% v/v and 2% w/v, respectively. October and sequential treatments were applied on 21 Oct. 2010 and 2011 at Meadowbrook Golf Course and Texas Tech University, respectively. Treatments were applied using a CO₂ pressurized

backpack sprayer equipped with XR8004VS Teejet (Teejet flat-fan extended range spray tips; Spraying Systems Co., Wheaton, IL) nozzle tips calibrated to deliver 374 L·ha⁻¹ at 221 kPa.

Percent bermudagrass phytotoxicity and percent dallisgrass control were estimated visually. Bermudagrass phytotoxicity was rated at 2 and 4 WAIT, on a scale of 0% (no visible phytotoxic symptoms) to 100% (complete turfgrass necrosis). Dallisgrass control was rated at 10 and 37 WAIT on a scale of 0% (no dallisgrass control) to 100% (complete dallisgrass removal). No significant location interactions were detected, thus data were combined. Data were analyzed using analysis of variance (ANOVA) and means were separated using Fisher's protected least significant difference test ($\alpha = 0.05$) provided by SAS (Release 9.2; Statistical Analysis Systems Institute, Cary, NC). All TFH treatments were subsequently analyzed by a separate ANOVA and orthogonal contrasts were performed to analyze the relationship of application timing, rate, and application number on dallisgrass control with this herbicide (Table 2).

Results and Discussion

Bermudagrass toxicity. No bermudagrass phytotoxicity was detected in response to any treatment at any rating date (data not shown). Similarly, Henry et al. (2013) reported <3% bermudagrass phytotoxicity within 7 d of early summer applications of TFH at 22 + 45 + 70 g a.i./ha as well as TID at 30 + 7 + 197 g a.i./ha. Cross et al. (2011) noted 0% bermudagrass injury from fall foramsulfuron + TID applications. Busey (2004) noted only 3% to 7% bermudagrass phytotoxicity within 5 weeks of foramsulfuron applications at 29 to 44 g a.i./ha. Results of this research align with previous reports that these herbicides are likely safe to use on bermudagrass both early and late in the growing season.

Dallisgrass control. Dallisgrass control 10 WAIT was ≤35% with all single applications of TFH (Table 1). Control from sequential applications of foramsulfuron at 106 g a.i./ha was 35%. Similarly, Henry et al. (2007b) reported 19% to 40% dallisgrass control 3 MAIT in response to sequential foramsulfuron treatments applied in early June. In contrast, Breeden and McElroy

Table 1. Dallisgrass control in bermudagrass following herbicide applications in field experiments, 2010–12, Lubbock, TX.

Timing of initial application ^z	Treatment	Rate (g a.i./ha)	Dallisgrass control (%)	
			10 (WAIT) ^y	37 (WAIT)
September	TFH ^x	15 + 31 + 47	28	82
October	TFH	15 + 31 + 47	29	39
September	TFH fb ^w TFH 4WAIT	15 + 31 + 47	49	92
September	TFH	22 + 45 + 70	35	94
October	TFH	22 + 45 + 70	33	55
September	TFH fb TFH 4WAIT	22 + 45 + 70	65	97
September	Foram ^v fb foram 4WAIT	106	35	48
September	Foram + TID ^u fb foram + TID	106 + 22 + 5 + 147	63	93
	Nontreated		0	0
	Least significant difference (0.05)		7	6

^zSeptember (and initial) treatments were applied on 27 Sept. 2010 and 23 Sept. 2011 at Meadowbrook Golf Course and Texas Tech University, Lubbock, TX, respectively. October (and sequential) treatments were applied on 21 Oct. 2010 and 2011 at Meadowbrook Golf Course and Texas Tech University, Lubbock, TX, respectively.

^yWAIT = week after initial treatment.

^xTFH = thienencarbazone-methyl + foramsulfuron + halosulfuron-methyl. All thienencarbazone-methyl + foramsulfuron + halosulfuron-methyl treatments included methylated seed oil and ammonium sulfate at 0.5% v/v and 2% w/v, respectively.

^wfb = followed by. Treatments containing sequential applications were made at the same rate as the initial application.

^vForam = foramsulfuron.

^uTID = thienencarbazone-methyl + iodosulfuron-methyl-sodium + dicamba.

Table 2. Effect of application timing, application rate, and the addition of a sequential treatment of TFH^z on dallisgrass control in field experiments, 2010–12, Lubbock, TX.

Treatment		Dallisgrass control (%)	
		10 (WAIT) ^y	37 (WAIT)
Single application	September	32	88
	October	31	47
	Contrast	NS	***
Rate (g a.i./ha)	15 + 31 + 47	35	71
	22 + 45 + 70	44	82
	Contrast	***	***
No. of applications	Single (September)	32	88
	Sequential (September + October)	57	95
	Contrast	***	*

^zTFH = thienencarbazone-methyl + foramsulfuron + halosulfuron-methyl.

^yWAIT = week after initial treatment.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

(2008) noted that sequential spot applications of foramsulfuron in the fall at a high spray volume resulted in $\geq 98\%$ dallisgrass control 4 weeks after sequential treatment.

Sequential applications of TFH provided 49% and 65% dallisgrass control 10 WAIT when applied at 15 + 31 + 47 and 22 + 45 + 70 g a.i./ha, respectively. The sequential foramsulfuron + TID treatment at 106 + 22 + 5 + 147 g a.i./ha provided 63% dallisgrass control 10 WAIT and was comparable to control observed with sequential applications of TFH. Cross et al. (2011) reported similar dallisgrass control (57%) in response to fall spot treatments of foramsulfuron + TID. Willis et al. (2009) noted that sequential applications of thiencarbazone-methyl at 32 g a.i./ha in combination with foramsulfuron provided 74% dallisgrass control 8 weeks after treatment.

By 37 WAIT, sequential applications of TFH provided 92% and 97% dallisgrass control when applied at 15 + 31 + 47 and 22 + 45 + 70 g a.i./ha, respectively. Control in response to the 22 + 45 + 70 g a.i./ha rate applied sequentially was the highest level of control observed at any rating date from any treatment. The single application of TFH at 22 + 45 + 70 g a.i./ha in September provided a similar level of control (94%). While the single September application of TFH at 15 + 31 + 47 g a.i./ha provided 82% control, single October applications at both rates resulted in poor control (39% to 55%) 37 WAIT. These results may be due to reduced basipetal carbohydrate movement at the time of the October treatment. Weak control (48%) was also observed with sequential foramsulfuron treatments at 106 g a.i./ha. On the contrary, Breeden and McElroy (2008), observed $\geq 83\%$ dallisgrass control 36 weeks after sequential spot applications of foramsulfuron applied in the fall at a spray volume of 200 gallons/acre. The foramsulfuron + TID treatment resulted in 93% dallisgrass control 37 WAIT, which was almost twice as much as the control offered by foramsulfuron alone and was comparable to the aforementioned TFH treatments.

Effect of application timing, rate, and sequential applications on dallisgrass control from TFH applications. At 10 WAIT, no significant difference in dallisgrass control was detected between single treatments of TFH applied in September or October (Table 2). However, the effect of rate was highly significant ($P \leq 0.001$) 10 WAIT, regardless of the fact that both rates provided poor control ($\leq 44\%$). Adding a sequential application in October resulted in control of 57% whereas a single application in September resulted in only 32% control at 10 WAIT. Although highly significant, the addition of a sequential application only resulted in 55% control 10 WAIT.

When pooled across rates, single September applications of TFH resulted in 88% control 37 WAIT, nearly doubling the control observed with single October applications

(47%) ($P \leq 0.001$). When pooled across single application timings, increasing rates of TFH from 15 + 31 + 47 to 22 + 45 + 70 g a.i./ha resulted in improved dallisgrass control from 71% to 82%, respectively, 37 WAIT ($P \leq 0.001$). Pooled across rates, the addition of a sequential application resulted in 95% dallisgrass control 37 WAIT, an increase from the 88% control observed with single September applications ($P \leq 0.05$).

Overall, excellent long-term control ($\geq 92\%$) was observed in response to several treatments the summer following application. Sequential treatments of TFH were necessary to achieve excellent dallisgrass control (92%) when applications were made at the low rate (15 + 31 + 47 g a.i./ha). However, at the high rate (22 + 45 + 70 g a.i./ha), dallisgrass control in response to TFH applied once in September was similar to the control with sequential applications. This is of great practical value to turf managers that may lack the ability to afford sequential applications. Waiting until October to apply TFH at either rate resulted in poor long-term control. Dallisgrass plants may have initiated dormancy in mid-October, which reduced herbicidal absorption and translocation to rhizome tissue. Sequential applications of foramsulfuron + TID resulted in similar long-term control as sequential treatments of TFH and single treatments at the high rate. Effective fall herbicide timings for dallisgrass control may be environmentally dependent; changing both spatially and temporally. Future research with TFH applications for dallisgrass control should incorporate the accumulation of cooling degree days similar to Elmore et al. (2013) to further increase herbicide efficiency and long-term control.

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