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Seasonal Application Timings Affect Dallisgrass (*Paspalum dilatatum*) Control in Tall Fescue

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Field research was conducted in 2010 and 2011 to investigate the efficacy of herbicides for dallisgrass control when applied at various growing (GDD) or cooling degree day (CDD) –based application timings. Herbicide treatments included fluazifop-p-butyl (fluazifop; 105 g ai ha^{-1}), mesotrione (280 g ai ha^{-1}), tembotrione (92 g ai ha^{-1}), topramezone (37 g ai ha^{-1}), and tank mixtures of fluazifop plus mesotrione, tembotrione, or topramezone. Herbicide treatments were applied at either 75, 175, 375, 775 GDD, or 5 CDD. Treated plots were subjected to three tall fescue interseeding regimes: no seeding, seeding in spring, or seeding in fall (0, 353, and 353 kg pure live seed ha^{-1}, respectively). In 2010, dallisgrass control from fluazifop applied at 75, 375, and 775 GDD was poor ($< 50\%$) by 52 wk after treatment (WAT); in 2011, control from fluazifop application at these timings was higher (62 to 72%). When applied at 175 GDD or 5 CDD in 2010 and 2011, dallisgrass control from fluazifop ranged from 79 to 93% at 52 WAT. The addition of mesotrione, tembotrione, or topramezone to fluazifop did not affect dallisgrass control at any application timing, and control provided by these herbicides alone was low ($< 65\%$). Interseeding tall fescue in the fall improved dallisgrass control from herbicides applied at 75 GDD in 2010 and 175, 375, and 775 GDD at 52 WAT in both years. Results suggest that timing of fluazifop applications at 175 GDD and 5 CDD enhances dallisgrass control.

Nomenclature: Fluazifop-p-butyl; mesotrione; tembotrione; topramezone; dallisgrass, *Paspalum dilatatum* Poir.; tall fescue, *Lolium arundinaceum* (Schreb.) S.J. Darbyshire.

Key words: 4-hydroxyphenylpyruvate dioxygenase, ACCase, aryloxyphenoxypropionate, cooling degree day, growing degree day, HPPD, interseeding, pyrazolone, triketone, turfgrass.

En 2010 y 2011, se realizó un estudio de campo para investigar la eficacia de herbicidas para el control de *Paspalum dilatatum*, cuando estos se aplicaron en diferentes momentos basándose en grados día de crecimiento (GDD) o enfriamiento (CDD). Los tratamientos de herbicidas incluyeron fluazifop-p-butyl (fluazifop; 105 g ai ha^{-1}), mesotrione (280 g ai ha^{-1}), tembotrione (92 g ai ha^{-1}), topramezone (37 g ai ha^{-1}), y mezclas en tanque de fluazifop más mesotrione, tembotrione, o topramezone. Los tratamientos de herbicidas fueron aplicados ya fuera a 75, 175, 375, 775 GDD, o 5 CDD. Las parcelas tratadas fueron sometidas a regímenes de entre-siembra con *Lolium arundinaceum*: sin siembra, siembra en la primavera, o siembra en el otoño (0, 353, y 353 kg de semilla pura viva ha^{-1}, respectivamente). En 2010, el control de *P. dilatatum* con fluazifop aplicado a 75, 375 y 775 GDD fue pobre (<50%) a 52 semanas después del tratamiento (WAT). En 2011, el control con la aplicación de fluazifop en estos mismos momentos fue mayor (62 a 72%). Cuando se aplicó a 175 GDD o 5 CDD en 2010 y 2011, el control con fluazifop de *P. dilatatum* varió entre 79 y 93% a 52 WAT. La adición de mesotrione, tembotrione, o topramezone al fluazifop no afectó el control de *P. dilatatum* en ninguno de los momentos de aplicación, y el control brindado por estos herbicidas aplicados solos fue bajo (<65%). La entre-siembra de *L. arundinaceum* en el otoño mejoró el control de *P. dilatatum* para herbicidas aplicados a 75 GDD en 2010 y 175, 375, y 775 GDD a 52 WAT, en ambos años. Los resultados sugieren que realizar aplicaciones de fluazifop a 175 GDD y 5 CDD mejora el control de *P dilatatum*.

Dallisgrass is a problematic warm-season perennial weed in the mid-Atlantic and southeastern regions of the United States (Beard 2002). Compared to tall fescue, dallisgrass has a lighter green color, coarser texture, and faster growth rate during warmer months, reducing the aesthetic and functional quality of the turfgrass sward (Elmore and Cudney 2001). Tolerance to close mowing, traffic, and high soil moisture enhance dallisgrass persistence in turfgrass stands (Henry et al. 2008, 2009; Rubio et al. 1995; Striker et al. 2006).

Options for selective dallisgrass control in tall fescue are limited. Monosodium methanearsonate (MSMA) is labeled for use in tall fescue, although turfgrass injury is likely (Anonymous 2009; Johnson 1997). EPA restrictions currently prohibit use of MSMA on athletic field and residential turf areas (U.S. EPA 2009). The 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor mesotrione is labeled for use in tall fescue and has activity against field paspalum (*Paspalum leave* Michx.), but dallisgrass control has not been reported (Reicher et al. 2012). Topramezone and tembotrione are HPPD inhibitors that have greater efficacy than mesotrione against various grassy weeds in row-crop production (Bollman et al. 2008). However, data evaluating the use of these HPPD inhibitors for dallisgrass control in turf are limited. The acetyl-CoA carboxylase (ACCase) inhibitor fluazifop-p-butyl (hereafter referred to as fluazifop) has efficacy against dallisgrass in pastures at rates ≥ 140 g ha^{-1}, but provided almost no control 1 yr after treatment (Evers et al. 2002).

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Growing degree day (GDD) accumulation is commonly used to quantify the influence of air temperature on plant development throughout a growing season (McMaster and Wilhelm 1997). In turfgrass, GDD accumulation can predict annual bluegrass (*Poa annua* L.) and Kentucky bluegrass (*P. pratensis* L.) seed-head emergence, smooth crabgrass [*Digitaria ischaemum* (Schreb.) ex Muhl.] emergence, Kentucky bluegrass root formation and viable creeping bentgrass (*Agrostis stolonifera* L.) root length (Danneberger and Vargas 1984; Fidanza et al. 1996; Koski et al. 1988; Schlossberg et al. 2002). Accurately determining the occurrence of these phenological events allows annual bluegrass seed-head suppressants, PRE crabgrass control products, and growth regulators to be applied with the use of GDD-based application timings to maximize efficacy, rather than using a calendar date. (Branham and Danneberger 1989; Fidanza et al. 1996; Kreuser and Soldat 2011). In studies evaluating optimum GDD-based 2,4-D application timing for dandelion (*Taraxacum officinale* F.H. Wigg.), Schleicher et al. (1995) and Schleicher and Throssell (1996) determined that the efficacy of ester and amine formulations of 2,4-D + 2,4-DP against dandelion improved when applied after 130 to 145 GDD_{10C}, which they attributed to improved 2,4-D phloem translocation. Brosnan et al. (2010b), investigating dallisgrass control involving GDD-based application timings, reported $> 90\%$ control of dallisgrass 76 d after initial treatment (DAIT) from single and sequential applications of fluazifop (105 g ha^{-1}) made in early spring (< 160 $GDD_{10\ C}$) but $< 40\%$ control from applications in early summer (> 500 $GDD_{10\ C}$). Brosnan et al. (2011) investigated mixtures of fluazifop + triclopyr for bermudagrass [*Cynodon dactylon* (L.) Pers.] suppression, and determined that applications in early spring (200 GDD_{10C}) and late summer (1,775 and 2,250 $GDD_{10\ C}$) were more effective than late-spring and midsummer applications. Given the seasonal variability in dallisgrass control with fluazifop, a more complete investigation to determine the optimum GDD-based application timing is warranted.

The influence of interseeding desirable turfgrass on dallisgrass control has not been investigated. Cultural practices promoting healthy turfgrass help eliminate voids in the canopy (Turgeon 2005). Eliminating these voids with desirable turfgrass species reduces niches for weed sustenance (Watschke and Engel 1994). Effects of interseeding on weed control in turfgrass are varied. Overseeding with perennial grasses controlled Canada thistle [*Cirsium arvense* (L.) Scop] and downy brome (*Bromus tectorum* L.) in pastures (Whitson and Koch 1998; Wilson and Kachman 1999). Experiments conducted on football pitches and golf course fairways found overseeding + verticutting either increased or had no effect on weed populations (Larsen et al. 2004; Larsen and Fischer 2005). Elford et al. (2008) found perennial ryegrass overseeding did not affect weed populations on municipal athletic fields being used for play. However, in studies wherein a herbicidal or fungal agent was used for weed control, overseeding provided additional weed control. Perennial ryegrass overseeding in combination with sulfentrazone resulted in less annual bluegrass infestation than sulfentrazone alone (Kopec and Gilbert 1999). In another study, the combination of overseeding and a fungal control agent reduced dandelion and white clover (*Trifolium repens* L.) populations more than overseeding or the fungal control agent applied alone (Abu-Dieyeh and Watson 2007). Control of bermudagrass with topramezone + triclopyr was enhanced with tall fescue interseeding (Brosnan and Breeden 2013). These studies suggest the combination of overseeding and herbicides may provide greater dallisgrass control than overseeding or herbicides applied alone.

The objective of this research was to evaluate dallisgrass control provided by fluazifop, mesotrione, tembotrione, or topramezone applied alone or tank mixed at various seasonal application timings in combination with fall or spring tall fescue interseeding.

Materials and Methods

Field Site. Experiments were initiated in 2010 and 2011 on a field site containing both 'Coyote II' and 'Kentucky 31′ tall fescue at the East Tennessee Research and Education Center (Knoxville, TN; 35.95°N) naturally infested with dallisgrass. The soil was a Sequatchie loam (fine–loamy, siliceous, semiactive, thermic humic Hapludult) with a 6.2 soil pH and 2.1% in organic-matter content. Experiments were conducted in an area of full sunlight with a natural dallisgrass infestation, mowed twice weekly at 7.5 cm, and irrigated as needed to prevent wilt.

Treatment Application. Seven treatments were evaluated in 2010 and 2011: (1) fluazifop (Fusilade II, 2 EC; Syngenta Professional Products, Greensboro, NC) (105 g ai ha^{-1}); (2) mesotrione (Tenacity 4 SC; Syngenta Professional Products, Greensboro, NC) (280 g ai ha^{-1}); (3) topramezone (Impact 2.8 SC; Amvac Chemical, Los Angeles, CA) (37 g ai ha^{-1}); (4) tembotrione (Laudis 3.5 SC; Bayer CropScience, Research Triangle Park, NC) (92 g ai ha^{-1}); (5) fluazifop + mesotrione; (6) fluazifop + topramezone; (7) fluazifop + tembotrione. A nontreated control was included for comparison. A nonionic surfactant (Activator 90; Loveland Products Inc., Loveland, CO) was included with all treatments at 0.25% v/v. Treatments were mixed with water and applied with the use of a CO_2-powered sprayer containing four flat-fan nozzles (TeeJet 8002; Spraying Systems Co., Roswell, GA) calibrated to deliver 280 L ha^{-1}.

Treatments were applied singly at 5 GDD or cooling degree day (CDD) –based application timings: 75, 175, 375, 775 GDD, or 5 CDD. Growing and cooling degree day accumulation was calculated with the use of Equations 1 and 2, respectively.

$$GDD = [(T_{max} - T_{min})/2] - T_{base}, \tag{1}$$

$$CDD = T_{base} - [(T_{max} - T_{min})/2]. \tag{2}$$

In these equations, T_{max} represents the daily maximum air temperature, T_{min} represents the daily minimum air temperature, and T_{base} in Equation 1 is the lowest temperature at which the biological process of interest (e.g., plant growth) does not advance (McMaster and Wilhem 1997). Similar to Brosnan et al. (2010b, 2011), T_{base} used for GDD equations

Table 1. Calendar dates corresponding to herbicide treatment application at target growing and cooling degree day accumulations in 2010 and 2011.[a]

Application timing	Calendar date	
	2010	2011
75 GDD[b]	April 7	March 22
175 GDD	April 22	April 14
375 GDD	May 18	May 12
775 GDD	June 15	June 13
5 CDD	September 8	September 9

[a] Abbreviations: GDD, growing degree day; CDD, cooling degree day.

[b] Yearly accumulated GDD and CDD values were calculated on a Celsius scale with the use of the equations GDD = $[(T_{\max} + T_{\min})/2]\ 2 - T_{\text{base}}$ and CDD = $T_{\text{base}} - [(T_{\max} - T_{\min})/2]$, where $T_{\max}$ was the daily maximum air temperature, $T_{\min}$ was the daily minimum air temperature, and T_{base} was 10 and 21 C in GDD and CDD equations, respectively. GDD and CDD accumulation began on January 1 and July 1, respectively.

was 10 C. Similar to that described by Allen (1976), CDD accumulation was a function of when average daily temperatures fell below a certain threshold, T_{base} (21 C) in Equation 2. This value was selected as daily increases in dallisgrass shoot weight at 21 C can be nearly 50% of those in optimal temperatures (Mitchell 1956). Brosnan et al. (2011) suggested using a cooling accumulation model to schedule fall applications might be preferred to using GDD accumulation. Similar to CDD accumulation, thresholds of chilling hours have been used to determine when trees will break bud upon warming temperatures (Richardson et al. 1974). Described by Allen (1976) as a potential method to predict insect diapause or the chilling requirement for plants, CDDs may be indicative of dallisgrass undergoing cold acclimation; dallisgrass may be more susceptible to herbicide applications during cold accumulation. Additionally, average daily air temperatures below 21 C indicate a seasonal shift in Knoxville, TN based on a 30-yr climatological average (National Oceanographic and Atmospheric Administration [NOAA] 2010). The use of CDD accumulation to estimate plant growth or schedule fall herbicide applications has not been examined. GDD accumulation was monitored from January 1 to July 1, and CDD accumulation was monitored from July 1 to December 31 during each year of this experiment. Air temperature was measured by a weather station (HOBO U30, Onset Computer Corp., Bourne, MA) located approximately 180 m from the field site. Calendar dates for each herbicide application in this study are listed in Table 1.

All plots were subjected to three interseeding regimes: no interseeding, spring interseeding at 353 kg pure live seed (PLS) ha^{-1}, or fall interseeding at 353 kg PLS ha^{-1}. Spring seeding treatments were applied 2 wk after 175 GDD herbicide treatments were applied (May 6 and April 28 in 2010 and 2011, respectively), and fall seeding treatments were applied 2 wk after the 5 CDD herbicide treatments were applied (September 22 and 23 in 2010 and 2011, respectively) each year. 'Coyote II' tall fescue was used in 2010, and 'Falcon IV' tall fescue was used in 2011. Although using different tall fescue genotypes was not ideal, 'Falcon IV' and 'Coyote II' performed similarly in trials conducted by the National Turfgrass Evaluation Program in categories of percent establishment, weed infestation, turf quality, spring, summer, and fall density, brown patch (causal agent: *Rhizoctonia solani* Kühn) and *Pythium* blight (*Pythium* spp.) incidence; 'Falcon IV' had slightly superior transition zone quality and seedling vigor than 'Coyote II' (National Turfgrass Evaluation Program [NTEP] 2005). Interseeding treatments were applied with the use of a slit-seeder (Ryan Mataway overseeder/dethatcher, Schiller Grounds Care Inc., Johnson Creek, WI). Irrigation frequency was increased as necessary to ensure adequate soil moisture in the upper 0.5 cm of the soil for 2 wk after interseeding. A complete (24-6-12) fertilizer (Complete Fertilizer, Harrell's Inc., Lakeland, FL) at 49 kg N ha^{-1} was broadcast over the entire experimental area immediately after interseeding. Except in conjunction with seeding, fertilizer was not applied to the site at any time after experiment initiation. Fertilizer was broadcast to the entire site at both spring and fall seeding; therefore all plots received fertilizer.

Treatment Evaluation and Statistical Analysis. Treatments were arranged in a split–split plot design with three replications. Application timing served as the whole plot treatment, herbicide served as the subplot treatment, and seeding served as the sub-sub plot treatment. Whole plots measured 12.2 by 5.5 m; subplots measured 1.5 by 5.5 m; sub-sub plots measured 1.5 by 1.8 m. In order to characterize dallisgrass morphology at each application timing, 20 dallisgrass plants were randomly selected from each whole plot immediately before applying herbicide treatments. The diameter (distance across the base between the innermost ring of leaves) and number of leaves in each clump were assessed nondestructively (Table 2).

Dallisgrass control in each whole and subplot was visually evaluated 2, 4, 8, and 18 wk after herbicide treatment (WAT) on a 0 (no bleaching or necrosis) to 100% (complete death) scale relative to the nontreated control. At 52 WAT, dallisgrass control was visually evaluated in all sub-sub plots with the aforementioned percent scale. Additionally, dallisgrass control was assessed quantitatively with the use of a 100 by 100–cm grid containing 81 squares (10 cm by 10 cm). The presence or absence of dallisgrass was noted in each square. Grid counts were supported visual assessments of dallisgrass control 52 WAT. Tall fescue injury was visually evaluated in both whole and sub plots at 1, 2, and 4 WAT with the use of a 0 (no bleaching or necrosis) to 100% (complete death) scale. Dallisgrass cover varied seasonally, but ranged from approximately 20 to 60% in nontreated control plots in the summer months.

All data were subjected to ANOVA in SAS (Statistical Analysis Software, Inc., Cary, NC) ($\alpha \leq 0.05$) with the use of the appropriate expected mean-square values as described by Carmer et al. (1989). Model assumptions were tested through residual analysis (Shapiro–Wilk statistic) in SAS, and no transformations were needed. Two contrasts were conducted with visual weed control data. In the first contrast, dallisgrass control provided by all fluazifop-containing treatments was averaged and compared to the average control provided by all treatments not containing fluazifop (HPPD inhibitors applied alone) to determine if these two groups of treatments were different ($\alpha \leq 0.05$). In the second contrast, dallisgrass control provided by fluazifop + mesotrione, tembotrione and

Table 2. Dallisgrass diameter (measured across the base of the innermost ring of leaves) and number of leaves per plant present when herbicide treatments were applied 2010 and 2011.[a]

	Dallisgrass diameter		Dallisgrass leaves	
Application timing	2010	2011	2010	2011
	cm		No. plant^{-1}	
75 GDD[b]	2.5	2.7	36	15
175 GDD	1.7	3.1	7	17
375 GDD	2.2	3.3	11	22
775 GDD	2.1	3.7	20	41
5 CDD	2.2	3.4	44	17
LSD	NS	NS	NS	6

[a] Abbreviations: GDD, growing degree day; CDD, cooling degree day; LSD, Fisher's least significant difference; NS, nonsignificant as determined by Fisher's Protected LSD test ($\alpha \leq 0.05$).

[b] Yearly accumulated GDD and CDD values were calculated on a Celsius scale with the use of the equations GDD $= [(T_{\mathrm{max}} + T_{\mathrm{min}})/2]\ 2 - T_{\mathrm{base}}$ and CDD $= T_{\mathrm{base}} - [(T_{\mathrm{max}} - T_{\mathrm{min}})/2]$, where T_{max} was the daily maximum air temperature, T_{min} was the daily minimum air temperature, and T_{base} was 10 and 21 C in GDD and CDD equations, respectively. GDD and CDD accumulation began on January 1 and July 1, respectively.

topramezone was averaged and compared to control provided by fluazifop alone.

Results and Discussion

Dallisgrass Control. Treatment-by-year interactions were detected; therefore, data collected from treatments applied in 2010 and 2011 will be presented separately. Significant application-timing–by–herbicide interactions were detected on every evaluation date in 2010. In 2011, significant application-timing–by–herbicide interactions were detected on several dates. Therefore, application-timing–by–herbicide interactions are presented. Dallisgrass diameter or number of leaves did not explain variations in dallisgrass control in 2010 or 2011 (Table 2).

Initial Dallisgrass Control (2 to 8 WAT). Fluazifop applied at 175, 375, and 775 GDD controlled dallisgrass 47 to 68% in both years 2 WAT (Table 3). When applied at 75 GDD, fluazifop-containing treatments provided $\leq$ 5% dallisgrass control 2 WAT in 2010 and 2011. Reduced dallisgrass control at 75 GDD was likely related to air temperature at application, as daily low air temperatures averaged 5 C in the 7 d following the 75-GDD application each year. By 4 WAT, fluazifop controlled dallisgrass 60 to 97% at all application timings. Dallisgrass control provided by fluazifop application at 775 GDD was lower than that provided by application at 175 GDD or 5 CDD in 2010 at 4 WAT. In 2011, fluazifop provided only 53% control at 4 WAT when applied at 75 GDD and 85 to 92% control for all other application timings. When evaluated 8 WAT, fluazifop applications at 175 GDD and 5 CDD provided greater control than those at 75 and 775 GDD in 2010. In 2011, fluazifop applied at 5 CDD controlled dallisgrass 98% at 8 WAT, more than treatments applied at 75, 375, and 775 GDD. Dallisgrass control from fluazifop applied at 175 GDD was similar to the 60 to 90% control by 76 d after treatment reported by Brosnan et al. (2010b) with fluazifop application at < 160 GDD$_{10\ \mathrm{C}}$.

Contrasts indicate that fluazifop-containing treatments applied at 175 GDD and 5 CDD provided more control than treatments that did not contain fluazifop on all but one evaluation date 2 to 8 WAT. Contrasts also indicate tank mixtures of fluazifop with mesotrione, tembotrione, or topramezone controlled dallisgrass similarly to fluazifop alone except at 2 WAT in 2010 when fluazifop alone provided more control than fluazifop tank mixtures. Mesotrione, tembotrione, and topramezone applied alone never controlled dallisgrass more than fluazifop-containing treatments 2 to 8 WAT. Regardless of application timing, mesotrione, tembotrione, and topramezone provided < 65% control 8 WAT in both years with mesotrione providing least amount of control (< 20%). Application of tembotrione and topramezone at 175 or 375 GDD was generally more efficacious than application at other timings (data not presented).

Long-term dallisgrass control (18 to 52 WAT). By 18 WAT, fluazifop controlled dallisgrass > 98% in both years when applied at 5 CDD; more than applications at 75, 375, or 775 GDD. Fluazifop application at 175 GDD controlled dallisgrass 83% at 18 WAT in 2010; more than application at 75, 375, or 775 GDD. In 2011, fluazifop application at 175 GDD provided 60% control 18 WAT, similar to applications at 75 or 375 GDD. Compared to 2010 (83%), reduced efficacy of fluazifop applied at 175 GDD in 2011 (60%) cannot be explained by differences in air temperatures at or within 14 d before or after herbicide treatment. GDD accumulations throughout the spring and summer after the herbicide applications are also unable to explain the difference in control. Precipitation following herbicide application at 175 GDD in 2011 was 58 mm compared to 21 mm in 2010. This may have reduced root uptake of the herbicide, though previous research indicates soil activity is negligible when fluazifop is applied postemergence (Buhler and Burnside 1984).

By 52 WAT, dallisgrass control was highest from fluazifop applications made at 175 GDD and 5 CDD (79 and 88%, respectively), whereas control from applications 75, 375, and 775 GDD was poor (< 50%) in 2010. In 2011, fluazifop provided similar control (62 to 93%) at all application timings 52 WAT. Grid count data supported visual assessments of dallisgrass control 52 WAT in 2010 and 2011 ($r = -0.77$ and -0.67, respectively, $P < 0.05$). For example, in 2010, plots treated with fluazifop at 175 GDD

Table 3. Dallisgrass control 2, 4, 8, 18, and 52 wk after herbicide treatment (WAT) in 2010 and 2011. Control was rated on a 0 (no control) to 100 (complete kill) percent scale. Fluazifop-*p*-butyl (fluazifop), mesotrione, tembotrione, and topramezone were applied at 105, 280, 92, and 37 g ha^{-1}, respectively. Herbicide treatments were applied singly at five application timings (75, 175, 375, and 775 growing degree days and 5 cooling degree days). Two contrasts were conducted to determine if control provided by fluazifop-containing treatments was greater ($\alpha \leq 0.05$) than nonfluazifop containing treatments and if control from fluazifop applied alone was different from tank mixtures of fluazifop plus a 4-hydroxyphenylpyruvate dioxygenase inhibitor (mesotrione, tembotrione, or topramezone).[a]

		Dallisgrass control									
		2 WAT		4 WAT		8 WAT		18 WAT		52 WAT	
Herbicide treatment[b]	Application Timing	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
		%									
Fluazifop 105 g ha^{-1}	75 GDD[c]	0	5	72	53	55	67	28	55	40	72
	175 GDD	68	47	90	92	92	77	83	60	79	83
	375 GDD	67	62	75	85	65	67	25	55	49	66
	775 GDD	62	57	60	90	38	60	20	17	33	62
	5 CDD	78	0	97	92	96	98	99	98	88	93
	$LSD_{0.05}$	23	9	27	27	35	28	35	38	28	NS
Contrast fluazifop vs. no fluazifop	75 GDD	NS[d]	NS	***	***	***	***	**	***	**	*
	175 GDD	***	***	***	***	***	***	NS	***	***	**
	375 GDD	***	***	***	***	*	**	NS	NS	NS	***
	775 GDD	***	***	*	***	NS	**	NS	NS	NS	**
	5 CDD	*	NS	***	**	***	***	***	***	***	***
Contrast fluazifop vs. fluazifop + HPPD-inhibitor	75 GDD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	175 GDD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	375 GDD	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
	775 GDD	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
	5 CDD	*	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] Abbreviations: WAT, weeks after treatment; LSD, Fisher's least significant difference.

[b] All herbicide treatments applied with a nonionic surfactant at a 0.25% v/v ratio.

[c] Yearly accumulated GDD and CDD values were calculated on a Celsius scale with the use of the equations $GDD = [(T_{max} + T_{min})/2]\ 2 - T_{base}$ and $CDD = T_{base} - [(T_{max} - T_{min})/2]$, where T_{max} was the daily maximum air temperature, T_{min} was the daily minimum air temperature, and T_{base} was 10 and 21 C in GDD and CDD equations, respectively. GDD and CDD accumulation began on January 1 and July 1, respectively.

[d] NS, nonsignificant; *, **, ***, significant when $\alpha \leq 0.05$, 0.01, and 0.001, respectively.

and 5 CDD had 14 and 4 grid sections containing dallisgrass, respectively, compared to 39 and 42 for their respective untreated plots (data not presented).

Contrasts indicate that tank mixtures of fluazifop with mesotrione, tembotrione, or topramezone were not different from fluazifop alone at 18 or 52 WAT in either year, except for applications at 375 GDD in 2010 and at 775 GDD in 2011; at these timings fluazifop alone controlled dallisgrass greater than fluazifop-containing tank mixtures. Except at 18 WAT for treatments applied at 175 GDD in 2010 when control was similar, contrasts indicate that fluazifop-containing treatments provided more control than mesotrione, tembotrione, or topramezone applied alone at 75 and 175 GDD as well as 5 CDD. When applied at 375 and 775 GDD (when overall dallisgrass control was lower), control provided by fluazifop-containing treatments was not different from treatments not containing fluazifop. Mesotrione provided 20% dallisgrass control at 175 and 375 GDD 18 WAT in 2010, but no control at all other application timings in both years (data not presented). Except at 175 GDD in 2010 and 775 GDD in 2011, tembotrione provided ≤ 20% control 18 WAT. Topramezone provided consistently more dallisgrass control than mesotrione or tembotrione but never exceeded 65% 18 WAT regardless of application timing (data not presented).

Tall Fescue Injury. Similar to responses in dallisgrass control data, significant application-by-herbicide interactions were detected in tall fescue injury data collected in 2010 and 2011.

Contrasts indicate tall fescue injury from fluazifop-containing treatments exceeded nonfluazifop treatments on all but one evaluation date for treatments applied at 375 and 775 GDD in both years (Table 4). Tall fescue injury at 2 WAT was greatest 375 and 775 GDD following fluazifop application in 2010 and 175, 375, and 775 GDD timings in 2011 (13 to 25% injury). At 4 WAT injury from fluazifop application 775 GDD was highest (38%) in 2010; in 2011 application at 75, 175, 375, and 775 caused similar injury (10 to 17%). Injury 2 WAT from fluazifop applied at 175 GDD was 3% in 2010 but 18% in 2011. Reasons for this increased tall fescue injury are unclear, as daily maximum air temperatures were similar during the 2 wk following the 175- GDD application each year. Injury from fluazifop applied at 75 GDD never exceeded 3% in 2010, but was 17% by 4 WAT in 2011. No injury was observed with any herbicide treatment applied at 5 CDD in either year.

Mesotrione, tembotrione, and topramezone caused 5, 18, and 33% tall fescue injury, respectively, 4 WAT when applied at 775 GDD in 2010 (data not presented). In 2011, ≤ 10% injury was observed from mesotrione, tembotrione, and topramezone on all evaluation dates. Significant tall fescue injury was not observed with mesotrione, topramezone, or tembotrione applications at 75, 175, 375, or 5 CDD

Table 4. Visual estimates of tall fescue injury 1, 2, and 4 wk after herbicide treatment (WAT) in 2010 and 2011. Fluazifop-*p*-butyl (fluazifop), mesotrione, tembotrione, and topramezone were applied at 105, 280, 92, and 37 g ha^{-1}, respectively. Herbicide treatments were applied singly at five application timings (75, 175, 375, and 775 growing degree days and 5 cooling degree days). Two contrasts were conducted to determine if injury from fluazifop-containing treatments was greater ($\alpha \leq 0.05$) than nonfluazifop containing treatments and if injury from fluazifop applied alone was different from tank mixtures of fluazifop plus a 4-hydroxyphenylpyruvate dioxygenase inhibitor (mesotrione, tembotrione, or topramezone). [a]

		Tall fescue injury					
		1 WAT		2 WAT		4 WAT	
Herbicide treatment[b]	Application timing	2010	2011	2010	2011	2010	2011
		%					
Fluazifop 105 g ha^{-1}	75 GDD[c]	3	0	0	0	0	17
	175 GDD	2	7	3	18	0	10
	375 GDD	5	6	17	25	8	13
	775 GDD	0	0	13	20	38	12
	5 CDD	0	0	0	0	0	0
	LSD	4	3	6	4	9	9
Contrast fluazifop vs. no fluazifop	75 GDD	**[d]	NS	NS	NS	NS	***
	175 GDD	NS	*	**	***	NS	***
	375 GDD	***	***	***	***	***	***
	775 GDD	**	**	NS	***	*	**
	5 CDD	NS	NS	NS	NS	NS	NS
Contrast fluazifop vs. fluazifop + HPPD-inhibitor	75 GDD	NS	NS	NS	NS	NS	NS
	175 GDD	*	NS	NS	NS	NS	NS
	375 GDD	NS	NS	NS	NS	NS	NS
	775 GDD	NS	NS	NS	NS	NS	NS
	5 CDD	NS	NS	NS	NS	NS	NS

[a] Abbreviations: DAT, days after treatment; LSD, Fisher's least significant difference.

[b] All herbicide treatments applied with a nonionic surfactant at a 0.25% v/v ratio.

[c] Yearly accumulated GDD and CDD values were calculated on a Celsius scale with the use of the equations GDD = $[(T_{\max} + T_{\min})/2]\ 2 - T_{\text{base}}$ and CDD = $T_{\text{base}} - [(T_{\max} - T_{\min})/2]$, where $T_{\max}$ was the daily maximum air temperature, $T_{\min}$ was the daily minimum air temperature, and T_{base} was 10 and 21 C in GDD and CDD equations, respectively. GDD and CDD accumulation began on January 1 and July 1, respectively.

[d] NS, nonsignificant; *, **, ***, significant when $\alpha \leq 0.05$, 0.01, and 0.001, respectively.

applications in either year. With the exception of application at 775 GDD in 2010, tall fescue injury in these experiments was similar to previous reports documenting the safety of mesotrione, tembotrione, and topramezone to cool-season turfgrasses (Brosnan et al. 2010a; Elmore et al. 2012; Willis and Askew 2008; Willis et al. 2006).

Data indicate fluazifop applications at ≥ 375 GDD can cause > 20% tall fescue injury. Mesotrione, tembotrione, and topramezone may cause injury when applied at > 775 GDD.

Effect of Interseeding. Significant application timing by interseeding interactions were detected in dallisgrass control data collected 52 WAT each year. Application timing by herbicide by interseeding applications were not significant and will not be presented.

Fall interseeding improved dallisgrass control following herbicide treatment at 175, 375, and 775 GDD (Figure 1) compared to spring interseeding or no interseeding (data not presented) by > 20% in 2010. Dallisgrass control due to interseeding was greater at the 375 and 775 GDD timings in 2010; however, herbicidal control was lower at these timings. In 2011, fall interseeding improved dallisgrass control for herbicides applied at 75, 175, 375, and 775 GDD by > 25%. Several researchers have reported interseeding or overseeding enhances weed control provided by herbicides or fungal pathogens used to control weeds. (Abu-Dieyeh and Watson 2007; Brosnan and Breeden 2013; Kopec and Gilbert 1999).

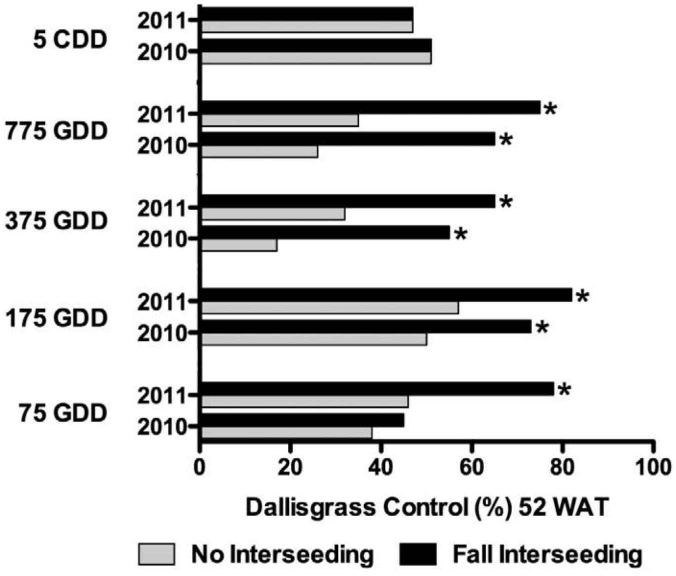

Figure 1. Visual estimates of dallisgrass control 52 wk after herbicide treatment at various growing or cooling degree day–based application timings. The main effects of fall tall fescue interseeding (353 kg pure live seed ha^{-1}) or no interseeding are presented. Means were separated with the use of Fisher's Protected LSD test ($\alpha \leq 0.05$). An asterisk indicates fall interseeding improved dallisgrass control compared to no interseeding.

The influence of interseeding on weed control is more inconsistent when other methods of weed control are not used in conjunction with interseeding (Elford et al. 2008; Larsen et al. 2004; Larsen and Fischer 2005). Survival of tall fescue interseeded in spring was minimal and did not improve control from any herbicide application timing in either year. Fall interseeding did not increase dallisgrass control from herbicides at 5 CDD. This is likely a result of tall fescue stand losses the following summer, as tall fescue establishment in plots treated with herbicide at 5 CDD was similar to that in plots treated with herbicides at other timings. Applications of preventative fungicides with efficacy for brown patch control may have prevented summer losses in tall fescue stand density due to disease pressure; however, tall fescue stand density was not measured in this research. Future research should explore this concept in further detail.

Conclusions

The results indicate that dallisgrass is most susceptible to fluazifop applications at 175 GDD or 5 CDD. Results are similar to those of Brosnan et al. (2010b), who suggested fluazifop applications in early spring (< 160 $\mathrm{GDD}_{10\ \mathrm{C}}$) were more successful than those in late spring (> 500 $\mathrm{GDD}_{10\ \mathrm{C}}$). Additionally, increased tall fescue injury from fluazifop application at 375 and 775 GDD further suggests optimum fluazifop application timings for dallisgrass control are 175 GDD and 5 CDD. Interseeding tall fescue in the fall improved dallisgrass control with when fluazifop was applied at 175, 375, and 775 GDD. Future research should evaluate dallisgrass control programs involving sequential applications of fluazifop (105 g ha^{-1}) at 175 GDD and 5 CDD combined with a fall interseeding to provide end users with improved strategies for dallisgrass control in tall fescue. Dallisgrass control from single applications of fluazifop at other CDD-based application timings (e.g., 25, 125, 200) should also be evaluated.

Additionally, research should investigate the physiological basis for seasonal variability in dallisgrass control with fluazifop. Though no investigations on the effects of temperature on metabolism of ACCase-inhibiting herbicides were conducted in this study, more rapid fluazifop metabolism as temperatures increase in the spring could explain lack of efficacy at 375 and 775 GDD timings. Lack of fluazifop translocation could explain low fluazifop efficacy with 75 GDD applications, as compared to the 175 GDD application timing. Fluazifop translocation in quackgrass [*Elymus repens* (L.) Gould] can be greater as temperature increases (Harker and Dekker 1988). Furthermore, Schleicher and Throssel (1996) reported greater phloem translocation of 2,4-D in dandelion when it was applied at 160 $\mathrm{GDD}_{10\ \mathrm{C}}$ than at 110 $\mathrm{GDD}_{10\ \mathrm{C}}$. An optimum combination of translocation and susceptibility of dallisgrass at emergence from winter dormancy could explain the success of fluazifop application at 175 GDD. Fluazifop is phloem-translocated to apical meristems, where it is most effective (Carr et al., 1986). Leaf tissue production via apical meristems is integral to emergence from dormancy. Fluazifop-induced apical meristem dysfunction may be more detrimental during this emergence from winter dormancy (when few photosynthetically active leaves exist) than at other times of the year. However, excellent fluazifop efficacy at 5 CDD may have been for different reasons. Fluazifop may have interrupted processes involved in cold acclimation prior to winter dormancy. Plants, including seashore paspalum (*Paspalum vaginatum* Swartz.) and other warm-season grasses undergo numerous metabolic changes in the crown during cold acclimation, including increasing the ratio of unsaturated to saturated fatty acids to maintain lipid membrane fluidity (Cyril at el. 2002; Theocharis et al. 2012). The ACCase-inhibitor fluazifop inhibits fatty acid synthesis in susceptible plants (Walker et al. 1988). Application of fluazifop at 5 CDD may have disrupted fatty acid synthesis and subsequent fatty acid desaturation during cold acclimation, which increased dallisgrass control due to increased winter injury.

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