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Relative Tolerance of Perennial Ryegrass (*Lolium perenne*) and Tall Fescue (*Festuca arundinacea*) to Flucarbazone

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Flucarbazone controls certain grassy weeds in wheat and may have potential for controlling perennial ryegrass in tall fescue turf. The objective of these experiments was to investigate perennial ryegrass and tall fescue tolerance to flucarbazone at two application timings. In field experiments, flucarbazone applications in May were more injurious to both species than in February and March. Single applications of flucarbazone from 30 to 60 g ai ha^{-1} in May injured both species 35 to 50% and sequential treatments increased injury approximately twofold. Two applications of flucarbazone at 60 g ha^{-1} in May injured both grasses $> 90\%$, similar to sequential applications of trifloxysulfuron at 29 g ai ha^{-1}. In growth chamber experiments, injury from flucarbazone on both grasses increased as temperature increased from 10 to 30 C. Flucarbazone reduced total shoot biomass of both grasses at all temperatures after 4 wk. Overall, perennial ryegrass and tall fescue are tolerant to flucarbazone at moderate temperatures (10 to 20 C). However, injury increased substantially under warmer conditions (30 C), suggesting flucarbazone could control perennial ryegrass and tall fescue during late spring and early summer.

Nomenclature: Perennial ryegrass, Lolium perenne L.; tall fescue, Festuca arundinacea Schreb.
Key words: Efficacy, turf, turfgrass, weed control, wheat.

Flucarbazone controla varias malezas gramíneas en trigo y puede tener potencial para el control de *Lolium perenne* en el césped *Festuca arundinacea*. El objetivo de estos experimentos fue investigar la tolerancia a flucarbazone de *L. perenne* y *F. arundinacea* en dos momentos de aplicación. En experimentos de campo, las aplicaciones de flucarbazone en Mayo fueron más dañinas en ambas especies que las aplicaciones en Febrero y Marzo. Las aplicaciones de flucarbazone de 30 y 60 g ai ha^{-1} en Mayo dañaron ambas especies 35 y 50% y los tratamientos secuenciales incrementaron el daño aproximadamente al doble. Dos aplicaciones de flucarbazone a 60 g ha^{-1} en Mayo dañaron ambos zacates, similarmente a las aplicaciones secuenciales de trifloxysulfuron a 29 g ai ha^{-1}. En cámaras de crecimiento, el daño causado por flucarbazone en ambos zacates aumentó cuando la temperatura incrementó de 10 a 30 C. Flucarbazone redujo la biomasa aérea en ambos zacates en todas las temperaturas después de 4 semanas. En general, *L. perenne* y *F. arundinacea* fueron tolerantes a flucarbazone a temperaturas moderadas (10 a 20 C). Sin embargo, el daño incrementó sustancialmente bajo condiciones más calientes (30 C), lo que sugiere que flucarbazone podría controlar *L. perenne* y *F. arundinacea* tarde en la primavera y temprano en el verano.

Perennial ryegrass and tall fescue are popular cool-season turfgrasses used on lawns, golf courses, athletic fields, and other landscaped areas (Beard 1973). Tall fescue is a major lawn species in the U.S. transition zone and newer varieties have improved heat, drought, and disease tolerance (Bokmeyer et al. 2009; Sellmann et al. 2006). Perennial ryegrass has a fine leaf texture and dark green color, and is most commonly used for overseeding dormant bermudagrass [*Cynodon dactylon* (L.) Pers.] in the U.S. transition zone (Beard 1973). These turfgrasses are usually established from seed and escaped plants may become perennial weeds in stands of other turfgrass species.

Sulfonylurea herbicides such as flazasulfuron, rimsulfuron, and trifloxysulfuron effectively control perennial ryegrass in warm-season turfgrasses (Hutto et al. 2008; Toler et al. 2007). Controlling perennial ryegrass may be important after overseeding, especially in tall fescue that may border these areas. For example, golf courses in the transition zone often have tall fescue roughs adjacent to bermudagrass and the ability to control escaped perennial ryegrass in tall fescue is limited with herbicide chemistries currently available (Lycan and Hart 2006).

Flucarbazone-sodium (delineated flucarbazone) is an acetolactate synthase (ALS) inhibitor that controls grassy and broadleaf weeds including wild oat (*Avena fatua* L.), foxtails (*Setaria* spp.), mustards (*Brassica* spp.), and other species in wheat (*Triticum aestivum* L.) (Ellis et al. 2010; Lockhart and Howatt 2004; Rauch et al. 2010). Flucarbazone also controls Italian ryegrass (*Lolium multiflorum* L.) and may be used for controlling populations of Italian ryegrass resistant to diclofop or other POST-applied herbicides (Ellis et al. 2010; Tucker et al. 2006). Flucarbazone registration in turf is currently limited to a 24-C label for controlling grassy weeds in Kentucky bluegrass (*Poa pratensis* L.) seed production (Anonymous 2005) but may have potential for use in other turfgrass species. For example, tall fescue has shown acceptable tolerance levels to flucarbazone with early spring applications but injury from applications required to control perennial weeds have received limited investigation (T. R. Murphy, personal communication). Potential tall fescue tolerance and efficacy for controlling ryegrasses (*Lolium* spp.) with flucarbazone has promising implications and warrants further

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investigation for future uses. The objective of this research was to investigate the relative tolerance of perennial ryegrass and tall fescue to flucarbazone at two application timings.

Materials and Methods

Field Experiments. Experiments were conducted from February to June 2011 in Griffin, GA, and Knoxville, TN. Soil in Georgia was a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) with 2% organic matter and a pH of 6.0. Soil in Tennessee was Sequatchie loam soil (fine-loamy, siliceous, semiactive, thermic humic Hapludult), measuring 6.2 in soil pH and 2.1% in organic matter content.

Fields at the two locations were treated with a broadcast application of glyphosate (Roundup Pro, Monsanto Company, St. Louis, MO 63167) at 2.2 kg ai ha^{-1} on September 20 and 21, 2010, in Tennessee and Georgia, respectively. Fields were mowed to 3.8 cm with a rotary mower, debris was removed, and seedbeds received two passes with a vertical mower set to a depth of approximately 1.3 cm. 'Manhattan IV' perennial ryegrass (Pure Seed Testing, Inc., Hubbard, OR 97032) and 'Titan' tall fescue (Seed Research of Oregon, Inc., Corvallis, OR 97339) were seeded separately and over half of all plots in a strip-block at 390 kg ha^{-1} with a drop spreader on September 28 and 29, 2010, in Tennessee and Georgia, respectively. The sites were irrigated as needed to promote establishment and a 10-10-10 granular fertilizer was applied at 48 kg N ha^{-1} approximately 4 wk after seeding (WAS) at both locations. After establishment, fields were mowed at 6.4-cm height with a rotary mower and clippings were returned. Grasses were irrigated as needed to prevent wilt.

Plot sizes were 1 by 3 m and 1.5 by 3 m in Georgia and Tennessee, respectively. Treatments were applied perpendicular to the tall fescue and perennial ryegrass strips in each plot. The factorial combination of four herbicides, two application numbers, and two seasonal timings was evaluated. An untreated control was included for comparison. Treatments included flucarbazone (flucarbazone-sodium 70DF, Arysta Lifesciences, 15401 Weston Parkway, Suite 150, Cary, NC 27513) at 15, 30, or 60 g ai ha^{-1} and trifloxysulfuron (Monument 75WG, Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC, 27419-8300) at 29 g ai ha^{-1}. All herbicides included a nonionic surfactant (Chem Nut 80-20, Chem Nut Inc., P.O. Box 3706, Albany, GA 31706) at 0.25% v/v. Treatments were applied once or twice on a 3-wk interval. In Georgia, treatments at the first application timing were applied on February 21 and March 14, 2011. In Tennessee, treatments at the first application timing were applied on February 22 and March 16, 2011. Treatments for the second application timing were applied on May 10 and May 31, 2011, in Georgia and May 9 and May 31, 2011, in Tennessee. Air temperatures were 22 to 23 C and 10 to 12 C at the first application timing in Georgia and Tennessee, respectively, and 31 to 33 C and 26 to 31 C for the second application timing, respectively. Treatments in Georgia were applied at 375 L ha^{-1} with a CO_2-pressured backpack sprayer with a single 9504E flat-fan nozzle (TeeJet, Spraying Systems Co., Roswell, GA 30075). Treatments in Tennesseewere applied at 280 L ha^{-1} with a CO_2-pressured backpack sprayer equipped with four 8002 flat-fan nozzles (TeeJet, Spraying Systems Co.) spaced 25 cm apart.

Experimental Design, Measurements, and Data Analysis. Experimental design was a randomized complete block with four replications in Georgia and three replications in Tennessee. Perennial ryegrass and tall fescue injury was visually evaluated 3 and 6 wk after initial treatment (WAIT) on a percentage scale where 0% equaled no injury and 100% equaled completely dead turfgrass.

Data were subjected to analysis of variance in SAS (SAS Institute, 100 SAS Campus Drive Cary, NC 27513-2414) with main effects and all possible interactions tested using the appropriate expected mean square values as described by McIntosh (1983). Data were pooled over locations because location-by-treatment interactions were not detected in perennial ryegrass or tall fescue injury data. Means were separated with Fisher's Protected LSD test at the 0.05 probability level.

Growth Chamber Experiments. Two experiments were conducted at the University of Georgia Envirotron from November 2010 to February 2011. Titan tall fescue and Manhattan IV perennial ryegrass sod was collected from the aforementioned stands at the University of Georgia. Sod was placed in pots (100 cm^2 area by 10 cm depth) filled with a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults). Pots were placed in a growth chamber set at 20 C air

Table 1. Manhattan IV perennial ryegrass and Titan tall fescue injury following flucarbazone treatments in two combined field experiments conducted in 2011 in Griffin, GA, and Knoxville, TN.

				Injury (WAIT)[c]			
				Perennial ryegrass		Tall fescue	
Timing[a]	Appli-cations	Treatment[b]	Rate	3	6	3	6
			g ai ha^{-1}	%			
February + March	1	Flucarbazone	15	2	0	2	1
			30	2	0	2	0
			60	2	0	4	1
		Trifloxysulfuron	29	14	30	13	42
	2	Flucarbazone	15		0		6
			30		1		9
			60		9		20
		Trifloxysulfuron	29		48		54
			$LSD_{0.05}$	3	3	3	5
May	1	Flucarbazone	15	17	19	8	14
			30	23	46	15	35
			60	25	50	20	47
		Trifloxysulfuron	29	36	96	34	96
	2	Flucarbazone	15		69		77
			30		79		86
			60		94		93
		Trifloxysulfuron	29		100		100
			$LSD_{0.05}$	5	13	5	11

[a] Treatments were applied on February 21 and March 14, 2011, in Griffin, GA, and February 22 and March 16, 2011, in Knoxville, TN. Treatments for the second timing were applied on May 10 and May 31, 2011, in Griffin, GA, and May 9 and May 22, 2011, in Knoxville, TN.

[b] Products applied were flucarbazone-sodium 70DF (Arysta Lifesciences) and Monument 75WG (trifloxysulfuron-sodium; Syngenta Crop Protection, Inc.). All herbicide treatments were applied with a nonionic surfactant at 0.25% v/v

[c] Abbreviation: WAIT = weeks after initial treatment.

temperature, 95% relative humidity, and a 12-h photoperiod of 400 μmol m^{-2} s^{-1}.

Once grasses resumed active growth, each pot was watered to prevent plant wilt and mowed weekly at a 5-cm height with sheers. Grasses were then placed in one of three growth chambers set to provide air temperatures of 10, 20, or 30 C with 95% relative humidity, and a 12-h photoperiod of 400 μmol m^{-2} s^{-1} . Grasses were allowed to acclimate to these conditions for 1 wk before being treated with flucarbazone (flucarbazone-sodium 70DF, Arysta Lifesciences) at 0, 15, 30, 60, 90, or 120 g ai ha^{-1}. Treatments included a nonionic surfactant (Chem Nut 80-20) at 0.25% v/v and were applied at 375 L ha^{-1} with a CO_2-pressured backpack sprayer with a single 9504E flat-fan nozzle (TeeJet, Spraying Systems Co.).

Perennial ryegrass and tall fescue injury were visually evaluated 2 and 4 wk after treatment (WAT) on a percentage scale where 0% equaled no injury and 100% equaled completely dead turfgrass. Total shoot biomass was harvested from all pots 4 WAT. Shoot biomass was weighed after oven drying at 55 C for approximately 72 h. Results were converted to percentage of the untreated control at each temperature using Equation 1 where Q_x represented the shoot biomass of treated turf and Q_0 equaled the shoot biomass of nontreated turf.

$$\text{Percent Reduction} = [(Q_0 - Q_x)/(Q_0)] \times 100$$

Experimental design was a completely randomized split plot with temperature serving as the whole plot treatment and herbicide rate serving as the subplot treatment. Four pots were placed in each growth chamber as subsamples and were considered replicates in the analysis. To reduce variability within each growth chamber, pot positions were randomized every 10 d.

After confirming homogeneity of variance, data were subjected to a combined analysis of variance in SAS (SAS Institute) to test for effects of study repetition and the split plot treatment structure. Repetition-by-treatment interactions were not detected; thus, results were pooled over experiments. Nonlinear regression analyses were used to determine rates of flucarbazone causing 20% injury (I_{20}) and 50% reduction in shoot biomass (SR_{50}) for each species. These values were chosen because 20% injury would be considered unacceptable in fine turf management and 50% reductions from the untreated control indicate significant shoot growth inhibition.

Results and Discussion

Field Experiments. Seasonal application timing significantly influenced perennial ryegrass and tall fescue tolerance to flucarbazone (Table 1). Injury from single flucarbazone applications in February caused minimal injury (< 5%) to both grasses by 3 and 6 WAIT. Sequential flucarbazone applications in March caused < 10% injury at all rates on perennial ryegrass. Sequential flucarbazone applications at 15 and 30 g ha^{-1} on tall fescue responded similarly. However, tall fescue was injured 20% from two applications of flucarbazone at 60 g ha^{-1}. Single and sequential applications of trifloxysulfuron in February and March caused 30 to 48% perennial ryegrass injury and 42 to 54% tall fescue injury by 6 WAIT.

May applications of flucarbazone were more injurious than the earlier application timing. Single applications of flucarbazone at 15 g ha^{-1} in May injured perennial ryegrass and tall fescue < 20% but all other flucarbazone treatments caused ≥ 35% injury on both species at 3 WAIT (Table 1). Sequential applications of the lowest rate of flucarbazone evaluated (15 g ha^{-1}) injured perennial ryegrass and tall fescue 69 and 77%, respectively, by 6 WAIT in May. Flucarbazone at 30 and 60 g ha^{-1} injured perennial ryegrass 46 to 50% when applied singly and 79 to 94% when applied sequentially. Tall fescue responded similarly. A single application of trifloxysulfuron in May injured both species 96%, which was similar to sequential applications of flucarbazone at 60 g ha^{-1}. All other flucarbazone treatments were less injurious than trifloxysulfuron on both perennial ryegrass and tall fescue.

Efficacy of flucarbazone appears to be significantly influenced by seasonal application timing and temperature as previously reported with ALS-inhibiting herbicides in turfgrass (Hart and McCullough 2007; Hutto et al. 2008; Lycan and Hart 2006; McCullough and Hart 2006, 2008). Air temperatures on the day of initial treatments in February were approximately 10 C cooler than treatment dates in May, suggesting flucarbazone efficacy increases at higher temperatures in late spring. In overseeded bermudagrass, Hutto et al. (2008) noted perennial ryegrass control from six sulfonylurea herbicides was greater when soil temperatures reached 26 C compared to 17 or 21 C. In the current study, soil temperatures ranged from 10 to 16 C when February treatments were applied. Although most sulfonylurea herbicides generally provide quick (approximately 2- to 3-wk) control of perennial ryegrass in spring, flucarbazone could offer end-users a transition aid to gradually reduce overseeded perennial ryegrass populations. Similar slow injury has been reported with pronamide, diclofop, and other herbicides to minimize discoloration of perennial ryegrass and promote gradual bermudagrass release in spring (Johnson 1976, 1990, 1994).

Tall fescue injury with spring applications of flucarbazone at 30 or 60 g ha^{-1} may be unacceptable (> 20%) if considered a desirable species. However, results are similar to previous reports of ALS inhibitors used for tall fescue control, suggesting flucarbazone could be used to control this species. In Kentucky bluegrass, sequential applications of chlorsulfuron have shown to provide excellent (≥ 90%) tall fescue control (Dernoeden 1986; Larocque and Christians 1985; Maloy and Christians 1986; McCullough and Hart 2008). Similarly, tall fescue has shown poor tolerance to sulfosulfuron and sequential spring applications may control populations in tolerant turfgrasses (Lycan and Hart 2004; McCullough and Hart 2008). Treatments of flucarbazone in cool temperatures (10 to 15 C) appear safe in tall fescue and perennial ryegrass but further research is needed to evaluate efficacy for weed control under these conditions.

Growth Chamber Experiments. Air temperature affected perennial ryegrass and tall fescue responses to flucarbazone in growth chamber experiments. At 2 WAT, flucarbazone

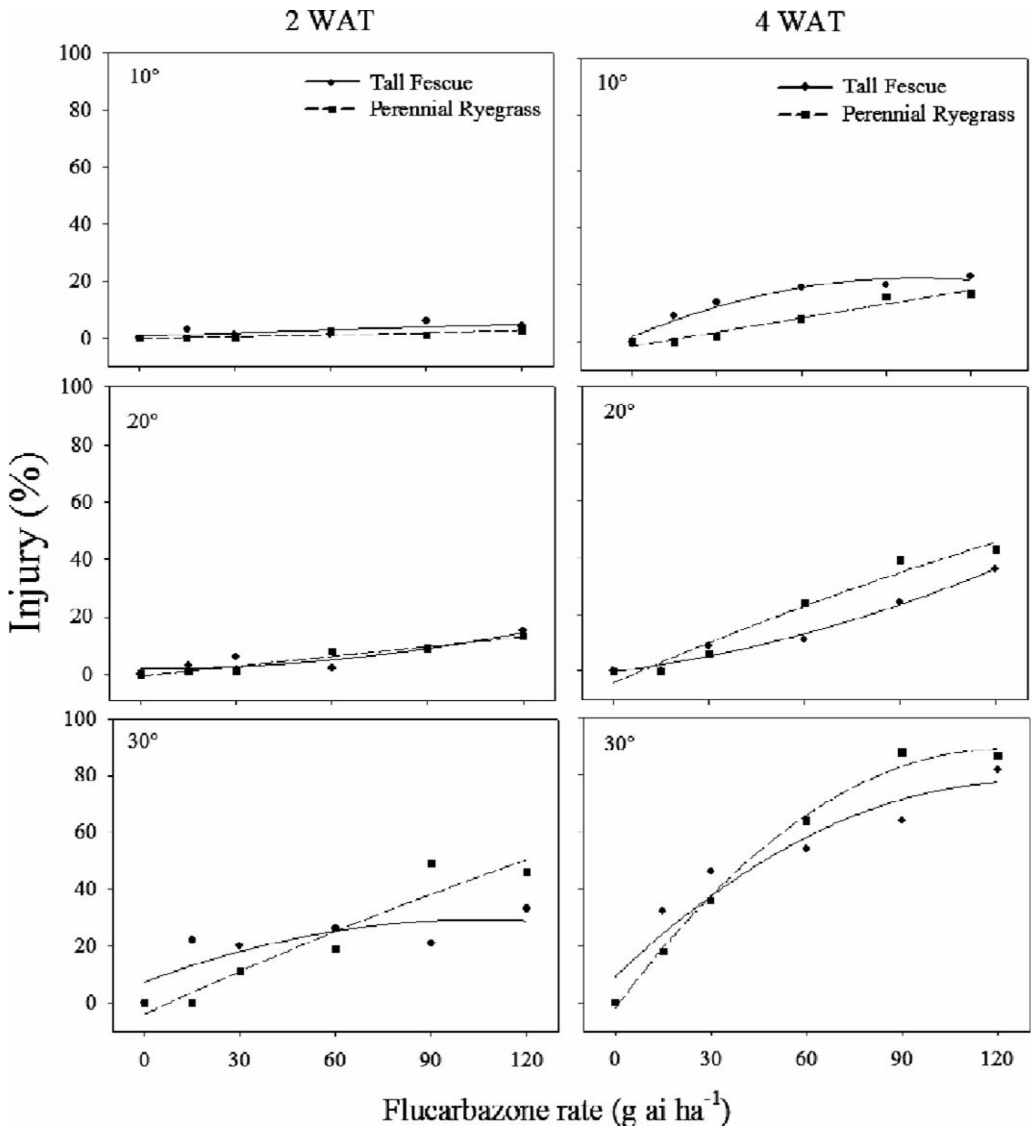

Figure 1. Manhattan IV perennial ryegrass and Titan tall fescue injury following flucarbazone applications in two combined growth chamber experiments conducted in 2010 and 2011 in Griffin, GA. Abbreviation: WAT = weeks after treatment.

injured both species $<$ 20% at 10 and 20 C. Comparatively, injury measured up to 50% on perennial ryegrass and 35% on tall fescue maintained at 30 C (Figure 1; Table 2). By 4 WAT, injury on both grasses from flucarbazone was generally exacerbated by increases in air temperature. Flucarbazone rates resulting in 20% perennial ryegrass injury (I_{20} values) were estimated at $>$ 120, 55, and 14 g ha^{-1} for the 10, 20, and 30 C air temperatures, respectively. Similarly, I_{20} values for tall fescue were 70, 81, and 11 g ha^{-1} for the 10, 20, and 30 C air temperatures, respectively (Table 2).

Flucarbazone reduced total shoot biomass of both species but reductions as affected by increased temperature were comparable to visual estimates of injury. (Figure 2). Approximately 50 g ha^{-1} of flucarbazone was required to cause a 50% reduction in shoot biomass (SR_{50} value) of each species maintained at 20 C (Table 2). When maintained at 30 C, SR_{50} values were reduced 20% compared to 20 C suggesting potentially slower recovery of shoot growth at this temperature at 4 WAT. Because growth chamber experiments were terminated after 4 wk, the duration of perennial ryegrass and tall fescue shoot growth inhibition and recovery could not be evaluated. These data suggest that flucarbazone may inhibit shoot growth of these species regardless of air temperature. Perennial ryegrass and tall fescue may exhibit reduced growth without significant injury at cooler temperatures, suggesting flucarbazone could have potential as a growth regulator at cool temperature.

Results of growth chamber experiments suggest efficacy of flucarbazone significantly increases with elevated air temperature, explaining differences noted in the field with application timing. In field experiments, applications of flucarbazone in February were made when air and soil temperatures were approximately 10 C cooler than those made in May. The influence of temperature on flucarbazone

Table 2. Predicted flucarbazone rates required to cause 20% injury (I_{20}) and 50% reductions in shoot biomass (SR_{50}) on Manhattan IV perennial ryegrass and Titan tall fescue following applications from 15 to 120 g ha^{-1} in two combined growth chamber experiments conducted in 2010 and 2011 in Griffin, GA.

	I_{20} (2 WAT)[a]			I_{20} (4 WAT)			SR_{50} (4 WAT)[b]		
	10 C	20 C	30 C	10 C	20 C	30 C	10 C	20 C	30 C
					g ha−1				
Perennial ryegrass	> 120	> 120	43	> 120	55	14	74	52	42
Tall fescue	> 120	> 120	36	70	81	11	47	50	32
Equations									
Perennial ryegrass	$r^2 = 0.17y = -0.03 + 0.006x + 0.0001x^2$	$r^2 = 0.26y = -0.39 + 0.10x + 0.0001x^2$	$r^2 = 0.35y = -3.83 + 0.52x - 0.0006x^2$	$r^2 = 0.67y = -1.52 + 0.16x + 0.0001x^2$	$r^2 = 0.30y = -4.03 + 0.49x - 0.001x^2$	$r^2 = 0.68y = -1.84 + 1.50x - 0.006x^2$	$r^2 = 0.42y = 7.83 + 0.92x - 0.0048x^2$	$r^2 = 0.60y = 0.62 + 1.20x - 0.005x^2$	$r^2 = 0.49y = 14.87 + 1.25x - 0.01x^2$
Tall fescue	$r^2 = 0.06y = 0.56 + 0.07x - 0.0004x^2$	$r^2 = 0.22y = 1.93 - 0.01x + 0.001x^2$	$r^2 = 0.11y = 7.33 + 0.42x - 0.002x^2$	$r^2 = 0.53y = 1.77 + 0.42x - 0.0021x^2$	$r^2 = 0.60y = -0.17 + 0.14x + 0.0013x^2$	$r^2 = 0.42y = 9.14 + 1.07x - 0.0042x^2$	$r^2 = 0.51y = 12.63 + 1.09x - 0.0065x^2$	$r^2 = 0.58y = 6.45 + 1.23x - 0.007x^2$	$r^2 = 0.63y = 14.01 + 1.40x - 0.0084x^2$

[a] Abbreviations: WAT = weeks after treatment.

[b] Dry shoot mass of the untreated tall fescue was 0.39, 0.64, and 0.70 g dm^{-2} at 10, 20, and 30 C, respectively, and 0.48, 0.64, and 0.65 g dm^{-2} for untreated perennial ryegrass, respectively.

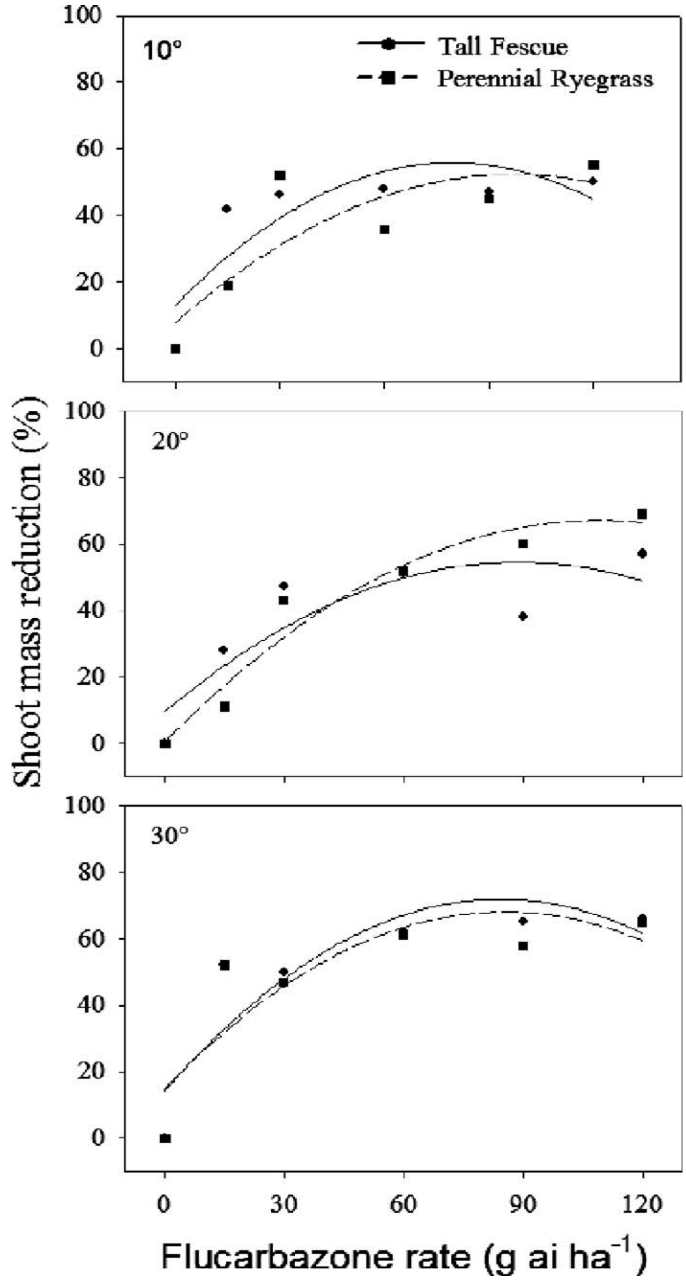

Figure 2. Manhattan IV perennial ryegrass and Titan tall fescue shoot biomass reductions 4 wk after treatments with flucarbazone in two combined growth chamber experiments conducted in 2010 and 2011 in Griffin, GA.

efficacy appears comparable to previous research with other ALS inhibitors used in turfgrass. In growth chamber experiments, efficacy of bispyribac-sodium, primisulfuron, and sulfosulfuron for grassy weed control increased as air temperature increased from 10 to 30 C (Hart and McCullough 2007; McCullough and Hart 2006, 2008). Similarly, these herbicides exhibited greater efficacy when applied in summer than spring in New Jersey (Hart and McCullough 2007; Lycan and Hart 2006). Flucarbazone applications in warm temperatures caused significantly greater injury to both perennial ryegrass and tall fescue than those made in cool temperatures, suggesting this herbicide could be used for controlling either species at approximately 30 C.

Overall, flucarbazone has potential for use in desirable perennial ryegrass and tall fescue at cool temperatures (10 to 20 C) but further research is needed to evaluate efficacy for POST weed control under these conditions. Flucarbazone could have potential as a POST herbicide for controlling weedy perennial ryegrass and tall fescue in other species, such as bermudagrass, but two applications at 30 to 60 g ha^{-1} appear necessary to obtain good (80 to 89%) to excellent (90 to 100%) control. Further research is needed to evaluate flucarbazone applications for selective control of perennial ryegrass or tall fescue in other potentially tolerant species, including bermudagrass and Kentucky bluegrass.

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