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Data describing seasonal variations in bermudagrass suppression in response to applications of fluazifop (Fusilade II) plus triclopyr (Turflon Ester) could help superintendents managing zoysiagrass fairways design more effective bermudagrass control programs. The objective of this research conducted at the University of Tennessee was to determine points in the growing season in which bermudagrass was most susceptible to applications of fluazifop and triclopyr.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 450 projects at a cost of $31 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Application Timing Affects the Efficacy of Herbicides Used for Control of Bermudagrass in Zoysiagrass Fairways

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SUMMARY

Zoysiagrasses (*Zoysia* spp.) are commonly used on golf course fairways throughout the United States transition zone. Bermudagrass (*Cynodon dactylon*) is a troublesome weed of zoysiagrass golf course fairways. Field research was conducted at the University of Tennessee during 2009 and 2010 evaluating the seasonal variability of bermudagrass to applications of fluazifop (Fusilade II) plus triclopyr (Turflon Ester). Results include:

- Bermudagrass was most susceptible to applications of fluazifop and triclopyr when transitioning out of winter dormancy in spring or transitioning into winter dormancy in fall.
- Cooling accumulation may be a signal to turf managers that plants are beginning to transition into winter dormancy before visual signs of this transition are apparent and thus are more susceptible to herbicide treatment. Applications made when average daily air temperature fell below 72 F provided the greatest suppression each year.
- Increasing the rate of fluazifop above 0.10 kg ai ha^{-1} did not improve efficacy for treatments applied to bermudagrass at optimal timings. When applied at sub-optimal summer timings, increased rates of fluazifop resulted in greater bermudagrass suppression.
- Except for a single summer timing in 2010, zoysiagrass injury from fluazifop plus triclopyr at labeled rates never exceeded 5%.

Zoysiagrasses (*Zoysia* spp.) are commonly used on golf course fairways throughout the transition zone of the U.S. Lyman et al. (8) reported that 81% of all zoysiagrasses planted on golf courses were found in the transition zone, with 18% found in the southeastern United States. Use of zoysiagrass has increased in that several cultivars offer high turf quality, low nitrogen fertility requirements, and improved drought, shade, and cold tolerance compared to other warm-season species (14).

One of the most troublesome weeds to control in zoysiagrass is bermudagrass (*Cynodon dactylon* (L.) Pers.), as physiological similarities between these species often render them susceptible to similar herbicide chemistries (6). Several researchers have illustrated that mixtures of fluazifop (e.g., Fusilade II) and triclopyr (e.g., Turflon Ester) applied sequentially during mid-summer can provide bermudagrass suppression for up to 4 weeks without inducing significant zoysiagrass injury (7, 11). However, numerous applications are required over several years rendering control of this species a struggle for superintendents.

Seasonal variability in postemergence herbicide efficacy for control of C_4 grasses has been reported (2, 10). Data describing seasonal variations in bermudagrass suppression with applications of fluazifop plus triclopyr could help superintendents managing zoysiagrass fairways design more effective bermudagrass control programs.

Zoysiagrasses (*Zoysia* spp.) are commonly used on golf course fairways throughout the transition zone of the U.S.

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Four herbicide treatments were evaluated: (1) fluazifop at 0.10 kg ha^{-1} plus triclopyr at 1.12 kg ae (acid equivalent) ha^{-1}; (2) fluazifop at 0.21 kg ha^{-1} plus triclopyr at 1.12 kg ae ha-1; (3) fluazifop at 0.32 kg ha^{-1} plus triclopyr at 1.12 kg ae ha^{-1}; and (4) untreated control.

However, limited data have been published on this topic. The objective of this research was to determine points in the growing season in which bermudagrass was most susceptible to applications of fluazifop and triclopyr.

Materials and Methods

Research was conducted from 2009 to 2011 on a mature stand of ‘Zenith’ zoysiagrass (*Zoysia japonica* Steud.) at the East Tennessee Research and Education Center (Knoxville, TN). Turf was established on silt loam soil with a pH of 6.2 and 2.1% organic matter content. The stand was mowed at 1.6 cm with a reel-mower and irrigation was applied on an as-needed basis to prevent wilt. A 0.5-m^2 section of ‘Riviera’ bermudagrass sod was installed in the center of each 1-m^2 plot two years prior to initiating this research.

Four herbicide treatments were evaluated: (1) fluazifop at 0.10 kg ha^{-1} plus triclopyr at 1.12 kg ae (acid equivalent) ha^{-1}; (2) fluazifop at 0.21 kg ha^{-1} plus triclopyr at 1.12 kg ae ha-1; (3) fluazifop at 0.32 kg ha^{-1} plus triclopyr at 1.12 kg ae ha^{-1}; and (4) untreated control. The maximum-labeled use rate of fluazifop is 0.10 kg ha^{-1} (1). Rates above this threshold were evaluated to determine if higher rates of fluazifop would increase bermudagrass suppression and zoysiagrass injury. All herbicide treatments were mixed with a non-ionic surfactant at 0.25% v/v and applied with a CO_2-powered boom sprayer equipped with four 8002 flat-fan nozzles calibrated to deliver 281 L ha^{-1} of spray volume.

Growing degree-day (GDD_{10C}) accumulation was used to identify six application timings: 200, 450, 825, 1,275, 1,775, and 2,250 GDD_{10C}. Calendar dates for these timings are listed in Table 1. Zoysiagrass reached 100% green-up when treatments were initiated, while bermudagrass green-up measured approximately 85%.

Yearly accumulated GDD_{10C} were calculated on a Celsius (C) scale using the equation:

$$GDD_{10C} = [(T_{max} - T_{min})/2] - T_{base}$$

Growing degree day[a]	2009 Calendar date	2009 Air temperature[b] at application	2009 Soil temperature[c] at application	2010 Calendar date	2010 Air temperature at application	2010 Soil temperature at application
$GDD_{10\,C}$[d]		------C-------	-------C-------		-------C--------	-------C-------
200	April 22	13	9	April 28	13	18
450	May 20	17	14	May 24	28	27
825	June 18	28	27	June 17	32	32
1275	July 20	28	28	July 13	31	28
1775	Aug. 24	27	27	Aug. 11	37	32
2250	Oct. 5	24	21	Sept. 9	24	26

[a] Yearly accumulated GDD_{10C} values were calculated on a Celsius scale using the equation: $GDD_{10C} = [(T_{max}-T_{min})/2] - Tbase$, where T_{max} represented the daily maximum air temperature, T_{min} represented the daily minimum air temperature, and T_{base} represented the minimum temperature required for the growth of a particular plant species.

[b] Air temperature was measured using a hand-held weather meter immediately following herbicide application.

[c] Soil temperature measured at 2.5-cm depth using a hand-held digital soil thermometer immediately following herbicide application.

[d] Abbreviations: GDD_{10C}, growing degree-day.

Table 1. Calendar dates of GDD_{10C} based applications of fluazifop plus triclopyr for bermudagrass (*Cynodon dactylon* L. Pers.) suppression in 2009 and 2010 in Knoxville, TN.

where T_{max} represented the daily maximum air temperature, T_{min} represented the daily minimum air temperature, and T_{base} represented the minimum temperature required for the growth of a particular plant species (13). A value of 10 C was used for T_{base} in this study (2). Air temperature (2.0 m above ground level) data were collected beginning January 1 from the National Weather Service Station located at McGhee Tyson Airport (KTYS), approximately 11 km from the research site. Daily maximum and minimum temperature data (T_{max} and T_{min}) were valid for a given date from midnight to midnight local time.

Bermudagrass suppression and zoysiagrass injury were visually evaluated on a 0 (no suppression or turf injury) to 100% (complete suppression/kill of all turf) scale relative to the untreated control weekly until suppression subsided. Relative chlorophyll index (RCI) data were collected using a CM-1000 chlorophyll meter similar to the methods of Teuton et al. (16) to support visual assessments of bermudagrass suppression and zoysiagrass injury (data not presented).

The experimental design was a 4 by 6 factorial randomized complete block with three replications. Data were subjected to ANOVA with main effects and all possible interactions tested using the appropriate expected mean square values described by McIntosh (12). Significant year-by-treatment interactions were detected, thus, data from each year were analyzed and are presented individually with Fisher's protected least significant difference (LSD) values used to separate treatment means at the 0.05 level.

Results and Discussion

Few differences in bermudagrass suppression were detected between treatments 1 to 2 weeks after treatment (WAT). By 2 WAT, bermudagrass suppression ranged from 69 to 89% in 2009 and 61 to 96% in 2010 (Table 2). Other researchers have reported similar levels of bermudagrass suppression with mixtures of AOPP

GDD_{10C}[b]	2009								
	1 WAT[a]	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT	8 WAT	9 WAT
200	52	73	97	98	91	68	39	11	4
450	36	69	72	54	31	8	2	0	0
825	31	71	71	59	7	16	0	0	0
1275	57	89	93	89	63	4	3	4	9
1775	69	81	90	97	95	91	91	87	91
2250	50	81	92	91	91	--	--	--	--
$LSD_{0.05}$	13	NS	10	12	11	12	13	11	13

Bermudagrass Suppression (%)

GDD_{10C}[b]	2010								
	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT	8 WAT	9 WAT
200	89	99	96	98	96	86	23	0	0
450	91	97	96	86	74	3	0	0	0
825	89	95	61	84	82	57	0	0	0
1275	93	91	94	83	57	0	0	0	0
1775	66	89	93	92	78	76	0	0	0
2250	68	89	92	95	95	--	--	--	--
$LSD_{0.05}$	8	3	8	8	12	12	11	NS	NS

[a] Abbreviations: WAT, weeks after treatment; GDD_{10C}, growing degree day; NS, non-significant.

[b] Yearly accumulated GDD_{10C} values were calculated on a Celsius scale using the equation: $GDD_{10C} = [(T_{max} - T_{min})/2] - T_{base}$, where T_{max} represented the daily maximum air temperature, T_{min} represented the daily minimum air temperature, and T_{base} represented the minimum temperature required for the growth of a particular plant species.

Table 2. Effect of growing degree-day (GDD_{10C}) timing on bermudagrass (*Cynodon dactylon* L. Pers.) suppression with fluazifop plus triclopyr in Knoxville, TN in 2009 and 2010.

(aryloxyphenoxypropionate) herbicides and triclopyr (4, 7, 11)

After 2 WAT, bermudagrass suppression varied due to application timing. Applications at 200 GDD_{10C} in April suppressed bermudagrass at least 90% at 5 WAT each year (Table 2). Treatment at 2,250 GDD_{10C} also yielded at least 90% bermudagrass suppression by 5 WAT. Comparatively, late spring and mid-summer applications (450 GDD_{10C}, 825 GDD_{10C}, and 1,275 GDD_{10C}) only suppressed bermudagrass 7 to 63% at 5 WAT in 2009 and 57 to 82% at 5 WAT in 2010 (Table 2).

Growing conditions at these late spring and mid-summer timings may have allowed bermudagrass to more quickly recover from herbicide injury than following spring and fall treatments. Average daily high air temperature measured approximately 7 C higher during the 5 weeks after treatments were applied at 450, 825, and 1,275 GDD_{10C} compared to those applied at 200 and 2,250 GDD_{10C}. Additionally, daily high air temperatures following these mid-summer applications were in the range for optimal bermudagrass shoot growth (9).

Increased bermudagrass suppression with

spring and fall applications may also be related to herbicide absorption and translocation. As bermudagrass emerges from winter dormancy, young leaves are produced at apical meristems. Fluazifop is more readily absorbed in younger leaves with a thinner cuticle and accumulates primarily in apical meristems (3, 15).

Enhanced efficacy of late-season applications may be due to fluazifop translocation being concomitant with phloem translocation of carbohydrates to rhizomes and stolons as bermudagrass transitions into winter dormancy (5). In both years, late-season applications were most successful when average daily air temperatures measured less than 22 C on several dates prior to treatment, regardless of GDD_{10C} accumulation. In 2009, treatments on August 24 at 1,775 GDD_{10C} provided more than 86% bermudagrass suppression from 3 to 9 WAT. Prior to application, the average daily air temperature measured less than 22 C on four dates after the summer solstice.

In 2010, the average daily air temperature

			Bermudagrass Suppression (%)			
			2009		2010	
Timing	Herbicide	Rate	4 WAT[a]	5 WAT	5 WAT	6 WAT
GDD_{10C}[b]		kg ha^{-1}				
200	fluazifop + triclopyr	0.10 + 1.12	94	82	94	82
		0.21 + 1.12	100	92	97	85
		0.32 + 1.12	100	100	97	92
450	fluazifop + triclopyr	0.10 + 1.12	30	13	47	0
		0.21 + 1.12	43	23	82	0
		0.32 + 1.12	90	55	93	10
825	fluazifop + triclopyr	0.10 + 1.12	23	7	75	23
		0.21 + 1.12	65	10	83	75
		0.32 + 1.12	90	3	87	73
1275	fluazifop + triclopyr	0.10 + 1.12	78	17	23	0
		0.21 + 1.12	93	82	68	0
		0.32 + 1.12	95	92	78	0
1775	fluazifop + triclopyr	0.10 + 1.12	95	95	73	55
		0.21 + 1.12	98	95	80	83
		0.32 + 1.12	98	95	82	90
2250	fluazifop + triclopyr	0.10 + 1.12	90	90	95	97
		0.21 + 1.12	93	92	96	98
		0.32 + 1.12	93	92	96	98
	$LSD_{0.05}$		21	20	22	21

[a] Abbreviations: GDD_{10C}, growing degree-day; WAT, weeks after treatment.

[b] Yearly accumulated GDD10C values were calculated on a Celsius scale using the equation: $GDD_{10C} = [(T_{max} - T_{min})/2] - T_{base}$, where T_{max} represented the daily maximum air temperature, T_{min} represented the daily minimum air temperature, and T_{base} represented the minimum temperature required for the growth of a particular plant species.

Table 3. Effect of growing degree-day (GDD_{10C}) by-herbicide treatment interaction on bermudagrass (*Cynodon dactylon* L. Pers.) suppression in Knoxville, TN in 2009 and 2010.

Timing	Zoysiagrass Injury (%)									
	2009					2010				
	1 WAT[a]	2 WAT	3 WAT	4 WAT	5 WAT	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT
GDD_{10C}[b]										
200	15	8	7	4	0	11	9	13	4	2
450	0	5	8	2	0	7	7	13	0	0
825	1	2	0	0	0	1	0	0	0	0
1,275	4	13	4	3	0	0	0	0	0	0
1,775	7	0	0	0	0	0	0	5	0	0
2,250	12	0	0	0	0	24	0	0	0	0
$LSD_{0.05}$	2	2	2	2	NS	4	3	3	1	1

[a] Abbreviations: WAT, weeks after treatment; GDD_{10C}, growing degree days; NS, non-significant.

[b] Yearly accumulated GDD_{10C} were calculated on a C scale using the equation: $GDD_{10C} = [(T_{max} - T_{min})/2] - T_{base}$, where T_{max} represented the daily maximum air temperature, T_{min} represented the daily minimum air temperature, and Tbase represented the minimum temperature required for the growth of a particular plant species.

Table 4. Effect of growing degree-day (GDD_{10C}) timing on zoysiagrass (*Zoysia japonica* Steud.) with of fluazifop plus triclopyr at in Knoxville, TN in 2009 and 2010.

never measured less than 22 C before 1,775 GDD_{10C} treatments were applied on August 11, and bermudagrass suppression measured 0% after 7 WAT (Table 2). Five days in 2010 yielded average daily air temperatures less than 22 C prior to applying 2,250 GDD_{10C} treatments that suppressed bermudagrass more than 90% for 5 WAT (Table 2). Average daily high air temperatures during the 5 weeks after 1,775 and 2,250 GDD_{10C} treatments were applied in 2009 and 2010, respectively, were similar (approximately 26 C). Cooling accumulation may be a signal that plants are beginning to transition into winter dormancy before visual signs of this transition are apparent and thus are more susceptible to herbicide treatment.

Significant GDD_{10C}-by-application rate interactions were detected each year (Table 3). However, no statistically significant differences in bermudagrass suppression were detected between the 0.10, 0.21, and 0.32 kg ha^{-1} rates of fluazifop applied at 200 GDD_{10C} and 2,250 GDD_{10C} each year, suggesting that bermudagrass susceptibility to fluazifop plus triclopyr may be greatest at these application timings. When applied during late spring and mid-summer (450, 825, and 1,275 GDD_{10C}), increasing fluazifop application rate tended to improve bermudagrass suppression 4 to 6 WAT.

Zoysiagrass injury (less than 25%) was observed until 5 WAT each year (Table 4). Herbicide applications at timings in which increased bermudagrass suppression was observed (200 and 2,250 GDD_{10C}) also yielded the highest degree of zoysiagrass injury. However, injury at these timings measured less than 10% by 2 WAT each year. Except for the 450 GDD_{10C} application in 2010, zoysiagrass injury with fluazifop plus triclopyr at labeled rates (0.10 kg ha^{-1} and 1.12 kg ae ha^{-1}, respectively) never exceeded 5%, which supports findings of other researchers (7, 11).

Several GDD_{10C}-by-application rate interactions were detected in zoysiagrass injury data (data not presented). However, 200 GDD_{10C} was the only application timing in which increases in injury were reported with increased fluazifop rate. This response suggests that zoysiagrass may tolerate higher rates of fluazifop for bermudagrass suppression. However, when applied at 200 and 2,250 GDD_{10C}, increasing fluazifop rate did not improve bermudagrass suppression either year.

Conclusion

Data illustrate that bermudagrass susceptibility to applications of fluazifop plus triclopyr varies during the growing season. Spring and fall applications resulted in improved bermudagrass suppression compared to those made during midsummer. Application timings based on heating (i.e., GDD_{10C}) or cooling accumulation may reduce the number of sequential applications required to provide effective bermudagrass control in zoysiagrass turf. Future research should evaluate bermudagrass control programs with other herbicides incorporating this strategy.

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