

Dwarf Bermudagrass Responses to Flurprimidol and Paclobutrazol

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Abstract. Plant growth regulators are applied to inhibit uneven shoot growth of putting green turf but research is limited on responses of dwarf-type bermudagrass cultivars to growth inhibition. Experiments were conducted at the Clemson University Greenhouse Complex with ‘Champion’ and ‘TifEagle’ bermudagrass grown in polyvinylchloride containers with 40 cm depths and 177 cm² areas built to United States Golf Association specification. Flurprimidol was applied at 0.14, 0.28, and 0.48 kg·ha⁻¹ a.i. and paclobutrazol at 0.14 kg·ha⁻¹ a.i. on separate containers. Flurprimidol at 0.28 and 0.42 kg·ha⁻¹ caused 17% and 31% reduction in turf color 5 weeks after treatment (WAT), respectively. ‘Champion’ exhibited unacceptable turf injury (>30%) 2 WAT from paclobutrazol and all flurprimidol rates. ‘TifEagle’ had unacceptable turf injury from flurprimidol at 0.42 kg·ha⁻¹ 2 WAT, 0.28 kg·ha⁻¹ 3 WAT, and 0.14 kg·ha⁻¹ 4 WAT that did not recover. Moderate injury (16% to 30%) was observed from paclobutrazol on ‘TifEagle’ but ratings were acceptable. After 6 weeks, flurprimidol at 0.14, 0.28, and 0.42 kg·ha⁻¹ reduced bermudagrass green shoot density (GSD) per square centimeter by 20%, 40%, and 40%, respectively, while paclobutrazol reduced GSD 12%. ‘TifEagle’ total clipping yield was reduced 60%, 76%, and 86% from flurprimidol at 0.14, 0.28, and 0.42 kg·ha⁻¹, respectively, and 37% from paclobutrazol. ‘Champion’ total clipping yield was reduced 82%, 90%, and 90% from flurprimidol at 0.14, 0.28, and 0.42 kg·ha⁻¹, respectively, and 58% from paclobutrazol. After 6 weeks, flurprimidol reduced ‘Champion’ total root mass by 44% over all three rates. ‘Champion’ treated with paclobutrazol had similar total root mass to the untreated. ‘TifEagle’ treated with all PGRs had similar rooting to the untreated. Overall, flurprimidol will likely not be suitable for dwarf bermudagrass maintenance at these rates; however paclobutrazol may have potential at ≤0.14 kg·ha⁻¹. Chemical names used: Flurprimidol {α-(1-methylethyl)-α-[4-(trifluoro-methoxy) phenyl] 5-pyrimidine-methanol}; Paclobutrazol, (+/-)-(R*,R*)-β-[4-chlorophenyl] methyl]-α-(1,1-dimethyl)-1H-1,2,4-triazole-1-ethanol.

Plant growth regulators (PGRs) have become important tools for turf managers to inhibit uneven shoot growth and promote uniform golf course putting green surfaces. PGRs modify turfgrass growth by inhibiting either cell division or cell elongation. Phytotoxicity and reduced root growth have prevented widespread use of cell division inhibitors; therefore, gibberellic acid (GA) inhibitors are more frequently used because of less likelihood for leaf burn and turfgrass injury (Murphy et al., 2005).

Two popular GA inhibitors, paclobutrazol and flurprimidol, inhibit the conversion of *ent*-kaurene to *ent*-kaurenoic acid by blocking the enzyme *ent*-kaurene oxidase (Sponsel, 1995; Buchanan et al., 2000). *Ent*-kaurene oxidase is a membrane-bound cytochrome P450 monooxygenase enzyme with a heme prosthetic group responsible for the oxidation of *ent*-kaurene, *ent*-kaurenol, and *ent*-kaurenol forming GA₁₂-aldehyde (Sirvastava, 2002). Paclobutrazol, a

triazole compound, inhibits P-450 monooxygenase enzymes involved in brassinosteroid and GA syntheses. Flurprimidol contains a pyrimidine group and has similar activity as a GA and sterol synthesis inhibitor.

Existing concerns with PGR applications include turfgrass discoloration and root growth inhibition. Flurprimidol and paclobutrazol are effective PGRs for common and hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) maintained at golf course fairway mowing heights (Johnson, 1992); however, turf injury has been observed with single and repeated applications on these grasses (Johnson, 1989, 1990, 1992, 1994). Dwarf-type bermudagrasses are hybrid cultivars introduced for golf course putting greens that may be more sensitive to these PGRs due to finer leaf textures and lower growth habits. Research is currently lacking to verify this.

Dwarf-type bermudagrass cultivars tolerate long term mowing heights of 3.2 mm or closer (McCarty and Miller, 2002). Routine closer mowing heights of dwarf cultivars, such as ‘Champion’ and ‘TifEagle’, may reduce root vigor, depth, and mass compared to traditional bermudagrass cultivars (White, 1998). Dwarf-type bermudagrasses have also shown sensitivity to PGR and herbicide applications (McCullough, 2004; McCullough et

al., 2004), raising concerns over PGR induced root growth restrictions.

Registered rates of paclobutrazol on creeping bentgrass, 0.28 and 0.42 kg·ha⁻¹, have shown unacceptable turf injury (>30%) on ‘TifEagle’ (McCullough et al., 2005). Similar results were observed on ‘TifEagle’ with repeated applications of flurprimidol at 0.42 kg·ha⁻¹ (McCullough et al., 2004). Applications of paclobutrazol at 0.14 kg·ha⁻¹ per 6 weeks have shown to produce similar turf quality to untreated ‘TifEagle’ but root mass was reduced after 12 weeks. Root mass reductions of 43% were also observed in these experiments with repeated applications of flurprimidol at 0.42 kg·ha⁻¹ per 3 weeks on ‘TifEagle’.

Although adjusted PGR rates may provide acceptable dwarf bermudagrass shoot quality, inhibited root growth may prove their application unacceptable for routine maintenance. Single applications of these compounds at appropriate rates may be more suitable for dwarf bermudagrass if turf quality and root growth are unaffected. Although paclobutrazol rates have been tested on dwarf bermudagrass, research is limited on various flurprimidol rates. The objective of this greenhouse experiment was to investigate growth responses of ‘Champion’ and ‘TifEagle’ treated with flurprimidol at 0.14, 0.28, and 0.42 kg·ha⁻¹ and paclobutrazol at 0.14 kg·ha⁻¹.

Materials and Methods

Two studies were conducted over 6 weeks from September to October 2003 (Study 1) and November to December 2003 (Study 2) at the Clemson University Greenhouse Complex, Clemson, S.C. Greenhouse day/night temperatures were set at about 26/20 °C. Due to reduced natural lighting during winter months, supplemental lighting was added for about 3 h·d⁻¹ at 50 μmol·m⁻²·s⁻¹ and the experimental design was a randomized complete block with three replications. Plugs were collected from ‘TifEagle’ and ‘Champion’ greens located in the Turf Service Center, Clemson, established in July 2002 and 2003, respectively. Bermudagrass plugs were washed free of soil and roots were cut about 2.5 cm from the thatch layer, and then transplanted to polyvinyl chloride containers. Containers were built approximately to United States Golf Association specifications (USGA Green Section Staff, 1993) to help mimic field conditions. An 85:15 (v/v) sand and peat moss rootzone mix was the soil medium consisting of 6% coarse sand (0.5 to 1.0 mm), 30% medium sand (0.25 to 0.5 mm), 48% fine sand (0.1 to 0.25 mm), and 16% very fine sand (<0.1 mm). Containers had 40 cm depths with 177 cm² surface areas and had drainage holes cut at about 6 mm diameter at the bottom. Starting fertilizer, 9N–18P₂O₅–17K₂O (Scott’s, Marysville, Ohio) was mixed into the soil at 48 kg·ha⁻¹ N.

Bermudagrass was irrigated and mowed with grass sheers (Black and Decker, Towson, Md.) at 4 mm 5 d·week⁻¹ and had a 3-week establishment period to resume active growth before initial PGR treatments. Nitrogen as ammonium nitrate solution was applied at 12

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Table 1. Turf color for 'Champion' and 'TifEagle' bermudagrass treated with paclobutrazol and flurprimidol in two combined greenhouse studies. Different letters indicate a significant difference at the 0.05 probability level by column.

Plant growth regulator	Rate (kg·ha ⁻¹ a.i.)	Week after treatment					
		Turf color ^z (1–9 scale)					
		1	2	3	4	5	6
Untreated	---	7.0 b	7.0 a	7.0 bc	7.0 bc	7.0 a	7.0 ab
Flurprimidol	0.14	7.2 ab	7.2 a	7.5 a	7.4 ab	7.1 a	7.2 a
Flurprimidol	0.28	7.2 ab	7.2 a	6.9 c	6.9 c	5.8 b	6.8 b
Flurprimidol	0.42	7.3 a	7.0 a	7.2 abc	6.3 d	4.8 c	5.9 c
Paclobutrazol	0.14	7.3 a	7.1 a	7.4 ab	7.5 a	7.0 a	7.2 a

^zTurf color was rated 1 to 9, where 1 = dead or dormant turf and 9 = dark green, dense turf.

Table 2. Turf injury for 'Champion' and 'TifEagle' bermudagrass treated flurprimidol and paclobutrazol in two combined greenhouse experiments. Different letters indicate a significant difference at the 0.05 probability level for a cultivar by column.

Plant growth regulator	Rate (kg·ha ⁻¹ a.i.)	Week after treatment					
		Turf injury ^z (%)					
		1	2	3	4	5	6
Champion bermudagrass							
Untreated	---	0 c	0 b	0 d	0 d	0 d	0 d
Flurprimidol	0.14	13 bc	50 a	43 b	60 b	43 b	42 b
Flurprimidol	0.28	30 a	50 a	55 ab	68 ab	71 a	73 a
Flurprimidol	0.42	25 ab	58 a	63 a	80 a	76 a	80 a
Paclobutrazol	0.14	23 ab	45 a	28 c	30 c	22 c	17 c
TifEagle bermudagrass							
Untreated	---	0 b	0 c	0 b	0 d	0 c	0 d
Flurprimidol	0.14	7 ab	7 bc	17 a	32 bc	13 c	27 c
Flurprimidol	0.28	7 ab	17 b	37 a	47 ab	50 ab	57 b
Flurprimidol	0.42	13 a	40 a	44 a	62 a	65 a	72 a
Paclobutrazol	0.14	3 b	3 bc	7 b	17 cd	23 bc	3 d

Table 3. Green shoot density after 6 weeks for 'Champion' and 'TifEagle' bermudagrass treated with flurprimidol and paclobutrazol in two combined greenhouse experiments. Different letters indicate a significant difference at the 0.05 probability level.

Plant growth regulator	Rate (kg·ha ⁻¹ a.i.)	Cultivar	Green shoots/cm ²
Untreated	---		25 a
Flurprimidol	0.14		20 b
Flurprimidol	0.28		15 c
Flurprimidol	0.42		15 c
Paclobutrazol	0.14		22 b
		Champion	19 b
		TifEagle	21 a

kg·ha⁻¹·week⁻¹. Flurprimidol (50WP) was applied at 0, 0.14, 0.28, and 0.42 kg·ha⁻¹ and paclobutrazol (2SC) at 0.14 kg·ha⁻¹ in a greenhouse spray chamber (model SB6-094; Devries Manufacturing (Hollandale, Minn.) delivering 720 L·ha⁻¹. Flurprimidol rates were chosen based on registered rates for 'Tifgreen' (Sepro Corp., 2002) and previous research on 'TifEagle'.

Turf color was rated visually on a 1 to 9 scale with 9 being dark green turf and 1 completely dormant turf. Ratings were based on leaf color and below 7 were considered unacceptable. Turf injury was evaluated weekly on a percent scale basis, where 0 = no injury, 1% to 15% = minor discoloration, 16% to 30% = moderate injury, >30% = unacceptable injury, and 100% = completely dead turf. Injury ratings were based on loss of stand density and turf uniformity relative to untreated turf. Green shoot density counts per square centimeter were made after 6 weeks in three random samples per experimental

unit with a sampling grid (cm² cell size). Samples were pooled per experimental unit for data analyses. Clippings and roots were harvested and oven-dried at 80 °C for 48 h, and weighed. Roots were sampled in 10-cm increments after 6 weeks from the entire container. Root length was measured from where roots were no longer present in the soil profile to the top of the container. A 6-week period was chosen to detect rooting effects and as a threshold extent from potential turf injury. Data were subjected to an analysis of variance with SAS General Linear Model procedure. Mean separations were based on Fishers LSD test at *P* = 0.05. Study by treatment interaction was not detected and thus studies were combined.

Results

Turf color. Cultivar by PGR interaction was not detected for turf color; therefore treatment effects were pooled across cultivar and studies. Turf color was enhanced 4% 1 WAT by flurprimidol at 0.42 kg·ha⁻¹ and paclobutrazol (Table 1). However, flurprimidol at 0.28 and 0.42 kg·ha⁻¹ caused a 17% and 31% reduction in turf color by 5 WAT, respectively. Other PGR treatments produced similar turf color to the untreated.

Turf injury. Cultivar × PGR interaction was detected for turf injury; therefore, results are presented by cultivar (Table 2). 'Champion' exhibited unacceptable turf injury 2 WAT from paclobutrazol and all flurprimidol rates. 'Champion' injury recovered to acceptable levels from paclobutrazol by 5 WAT. 'TifEagle' had unacceptable turf injury from flurprimidol at 0.42 kg·ha⁻¹ 2 WAT, 0.28 kg·ha⁻¹ 3 WAT, and 0.14 kg·ha⁻¹ 4 WAT. Moderate

injury was observed from paclobutrazol on 'TifEagle' but ratings were acceptable. Bermudagrass injury from flurprimidol applications did not recover by 6 WAT.

Cultivar × PGR interaction was not detected for green shoot density after 6 weeks; therefore, results were pooled over cultivar and PGR (Table 3). After 6 weeks, flurprimidol at 0.14, 0.28, and 0.42 kg·ha⁻¹ reduced bermudagrass green shoot density by 20%, 40%, and 40%, respectively. Turf treated with paclobutrazol had 12% reduced green shoot density than non-PGR treated turf. Averaged across PGR treatments, 'TifEagle' green shoot density was 11% greater than 'Champion'.

Clipping yield. Cultivar × PGR interaction was detected for weekly clipping yield; therefore results are presented by cultivars. PGR treatments reduced clipping yield about 70% for both bermudagrass cultivars 1 WAT (Table 4). 'TifEagle' treated with paclobutrazol had clipping yield inhibited from 1 to 4 WAT but clipping yield was similar to untreated turf 5 WAT. 'Champion' clippings were suppressed by paclobutrazol 74% 3 WAT with 45% reductions by 6 WAT. Total clipping yield was reduced 60%, 76%, and 86% from flurprimidol at 0.14, 0.28, and 0.42 kg·ha⁻¹, respectively, and 37% from paclobutrazol on 'TifEagle'. Total clipping yield was reduced 82%, 90%, and 90% from flurprimidol at 0.14, 0.28, and 0.42 kg·ha⁻¹, respectively, and 58% from paclobutrazol on 'Champion'.

Root mass and length. Cultivar × PGR interaction was detected for root mass and length and thus cultivars are presented separately. Comparing untreated turf, 'TifEagle' averaged 66% less total root mass and 33% less root length than 'Champion' (Table 5). Flurprimidol reduced 'Champion' total root mass 44% over all three rates. Flurprimidol at 0.28 and 0.42 kg·ha⁻¹ reduced 'Champion' root mass 43% at the 0 to 10 cm soil depth and 61% at the 10 to 20 cm soil depth compared to the untreated. 'Champion' treated with paclobutrazol had reduced root mass at the 20 to 30 cm soil depth but total root mass was similar to the untreated. 'TifEagle' treated with PGRs had similar rooting to the untreated.

Discussion

Plant growth regulators are commonly applied to golf course putting greens to reduce uneven shoot growth and enhance turf quality. Ideally, PGRs should inhibit turfgrass shoot growth without turf injury or deleterious effects on root growth. These principles have even greater importance for PGR selection on fine textured dwarf bermudagrasses with potentially reduced root growth from closer mowing heights.

'Champion' and 'TifEagle' displayed unacceptable turf injury from flurprimidol with little to no recovery after 6 weeks. Paclobutrazol injured 'Champion' more severely than 'TifEagle'. Plugs collected for the 'TifEagle' were established in the field 1 year before 'Champion' and observed injury on 'Champion', relative to 'TifEagle', may have resulted

Table 4. Dry clipping yield for 'Champion' and 'TifEagle' bermudagrass treated with flurprimidol and paclobutrazol in two combined greenhouse experiments. Different letters indicate a significant difference at the 0.05 probability level for a cultivar by column.

Plant growth regulator	Rate (kg·ha ⁻¹ a.i.)	Clipping yield (g·m ⁻²)						
		Week after treatment						
		1	2	3	4	5	6	Total
Champion bermudagrass								
Untreated	---	2.4 a	1.6 a	1.9 a	1.5 a	2.3 a	2.2 a	11.9 a
Flurprimidol	0.14	0.9 b	0.4 bc	0.3 b	0.1 b	0.2 c	0.3 c	2.2 bc
Flurprimidol	0.28	0.5 b	0.3 c	0.2 b	0.2 b	0.0 c	0.0 c	1.2 c
Flurprimidol	0.42	0.5 b	0.4 bc	0.2 b	0.1 b	0.0 c	0.0 c	1.2 c
Paclobutrazol	0.14	1.0 b	1.0 ab	0.5 b	0.4 b	0.9 b	1.2 b	5.0 b
TifEagle bermudagrass								
Untreated	---	3.2 a	2.3 a	2.3 a	2.1 a	2.7 a	1.9 a	14.5 a
Flurprimidol	0.14	0.9 c	0.6 c	0.9 c	0.4 c	1.5 b	1.6 a	5.9 c
Flurprimidol	0.28	0.9 c	0.6 c	0.5 d	0.5 c	0.5 c	0.5 b	3.5 cd
Flurprimidol	0.42	0.6 c	0.5 c	0.3 d	0.2 c	0.2 c	0.2 b	2.0 d
Paclobutrazol	0.14	1.4 b	1.0 b	1.2 b	1.2 b	2.4 a	2.0 a	9.2 b

Table 5. Root length and dry root mass after six weeks for 'Champion' and 'TifEagle' bermudagrass treated with flurprimidol and paclobutrazol in two combined greenhouse studies.

Plant growth regulator	Rate (kg·ha ⁻¹ a.i.)	Champion					TifEagle				
		Root length (cm)	Root mass (g·m ⁻²)				Root length (cm)	Root mass (g·m ⁻²)			
			0–10 cm	10–20 cm	20–30 cm	Total		0–10 cm	10–20 cm	20–30 cm	Total
Untreated	---	26.7 aA ²	14.3 abA	2.8 aA	0.5 aA	17.6 aA	18.0 aB	5.5 aB	0.4 aB	0.0 aB	5.9 aB
Flurprimidol	0.14	19.9 bA	10.1 bcA	0.7 cA	0.0 bA	10.8 bA	18.2 aA	4.1 aB	0.4 aA	0.0 aA	4.5 aB
Flurprimidol	0.28	19.9 bA	8.2 cA	1.0 bcA	0.1 bA	9.3 bA	16.3 aA	5.1 aB	0.3 aB	0.0 aA	5.4 aB
Flurprimidol	0.42	20.3 bA	8.1 cA	1.2 bcA	0.2 abA	9.5 bA	15.2 aB	4.6 aB	0.4 aA	0.0 aA	5.0 aB
Paclobutrazol	0.14	23.3 abA	15.5 aA	2.1 abA	0.2 bA	17.8 aA	18.2 aA	4.8 aB	0.8 aB	0.0 aA	5.6 aB

²Lower case letters are mean separations among columns, capital letters are mean separations between cultivars by row and parameter.

from differences in PGR absorbency potential. Nevertheless, both cultivars exhibited injury following PGR applications.

'Champion' bermudagrass showed severe root mass and root length reductions from flurprimidol applications while 'TifEagle' was unaffected. Differences observed between cultivars resulted from greater root growth of 'Champion' relative to 'TifEagle'. White (1998) noted 'TifEagle' had 57% less root mass than 'Champion' 4 months after sprigging the cultivars. Thus, the more actively growing roots of 'Champion' may have been more vulnerable to flurprimidol induced restrictions compared to 'TifEagle'.

Paclobutrazol injured both grasses; however, recovery occurred to acceptable levels with generally no root growth restrictions. Of the two PGRs, paclobutrazol may have potential for applications at lower rates, such as 0.05 to 0.10 kg·ha⁻¹, on dwarf bermudagrasses. Future research is needed on these PGRs, but flurprimidol will likely not be suitable for dwarf bermudagrass maintenance at traditional putting green application rates.

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