Response of ‘TifEagle’ Bermudagrass to Seven Plant Growth Regulators

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Abstract. Dwarf bermudagrass morphological characteristics following the use of plant growth regulators have not been reported. The objective of this greenhouse study was to determine short-term effects of seven plant growth regulators on clipping yield, chlorophyll concentration, and root mass of ‘TifEagle’ bermudagrass. Growth regulators tested included ethephon, fenarimol, flurprimidol, maleic hydrazide, mefluidide, paclobutrazol, and trinexapac-ethyl. Two applications of each compound were made over a 6-week period. Root mass was reduced 39% by fenarimol and 43% by flurprimidol, while other PGRs had root mass similar to untreated turf. ‘TifEagle’ bermudagrass treated with paclobutrazol, mefluidide, fenarimol, and flurprimidol averaged 45% less root mass than trinexapac-ethyl-treated turf. Trinexapac-ethyl was the only compound to reduce clippings and enhance turf quality without negative rooting effects. Chemical names used: [4-(cyclopropyl- α)-hydroxymethylene]-3,5-dioxo-cyclohexane carboxylic acid ethyl ester] (trinexapac-ethyl); α -(1-methylethyl)- α -[4-(trifluoro-methoxy)phenyl]5-pyrimidine-methanol] (flurprimidol); (+/-)-(R*,R*)- β -[4-(4-chlorophenyl)methyl]- α -(1, 1-dimethyl)-1H-1,2,4-triazole-1-ethanol (paclobutrazol); N-[2,4-dimethyl-5 [[trifluoromethyl]-sulfonyl] amino]phenyl]acetamide (mefluidide); [1,2-dihydro-3,6-pyridazine-dione] (maleic hydrazide); [(2-chloroethyl)phosphonic acid] (ethephon); and (2-(2-chlorophenyl)-2-(4-chlorophenyl)-5-pyrimidinemethanol) (fenarimol).

Hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) is the warm-season turfgrass used most commonly on putting greens in the warm-humid climatic regions (Beard, 2002). Dwarf-type bermudagrass cultivars that tolerate routine mowing heights of 3.2 mm or closer have recently become available (McCarty and Miller, 2002). These new bermudagrass cultivars provide southern golf courses the desirable putting green qualities once exclusive to creeping bentgrass (*Agrostis palustris* Huds.).

Preliminary testing of dwarf bermudagrasses indicated ‘TifEagle’ as a promising cultivar for putting green turf (Hannah and Elsner, 1999). However, the close mowing endurance of ‘TifEagle’ bermudagrass has apparently been at the expense of a vigorous root system (White, 1998). Practices restricting root biomass could possibly be a limitation for successful long-term culture for this cultivar.

Plant growth regulator (PGR) use has become a common practice for intensive turfgrass management. PGRs are compounds which modify the hormonal status of plants and provide smoother putting surfaces by promoting lateral growth instead of undesirable top growth (Hedden and Hoad, 1994; Murphy et al., 2001). A concern exists where shoot inhibition from PGRs may also cause root inhibition. Additionally, negative root

responses from PGRs may limit their use on turfgrasses with potentially restricted root systems, such as those found on golf course putting greens.

Type I compounds, or cell division inhibitors, tested in this study included mefluidide and maleic hydrazide. Maleic hydrazide, introduced in the early 1950s, is readily translocated to the meristematic regions and suppresses plant growth by inhibiting cell division in shoot, buds, and roots (Watschke et al., 1992). Mefluidide was commercially introduced in 1978 as a seedhead and foliar suppressant for use in low maintenance turf areas. Mefluidide, unlike maleic hydrazide, exhibits little translocation to other leaf organs, roots, and lateral growth meristems. Inconsistent results and turf injury have prevented widespread use of their application.

Type II growth regulators inhibit gibberellic acid (GA) biosynthesis necessary for stem elongation (Rademacher, 2000). Compared to Type I cell division inhibitors, less likelihood exists for leaf burn with gibberellin biosynthesis inhibitors (Murphy et al., 2001). Type II compounds investigated in this study included trinexapac-ethyl (TE), paclobutrazol (PB), and flurprimidol (FP).

Type II growth regulators can be subdivided by the stage of GA biosynthesis they inhibit. Distinct plant responses result from GA inhibition at a particular stage. For example, triazoles interfere with the conversion of *ent*-kaurene to *ent*-kaurenoic acid by blocking the enzyme *ent*-kaurene oxidase early in GA biosynthesis (Hedden and Hoad, 1994). Cyclohexadiones, like TE, disrupt the later stages in the GA biosynthesis pathway, inhibiting 3 β -hydroxylase from converting G₂₀ to GA₁ (Rademacher, 2000).

Applications of TE on ‘Tifway’ bermudagrass have been found to provide consistent growth suppression, avoidance of post inhibition growth enhancement, and improvements in turf quality (Fagerness and Yelverton, 2000). While measuring the effects of TE and PB on creeping bentgrass rooting, Fagerness and Yelverton (2001) noted monthly root growth was not affected from PGR label rates over a two year period. Only PB applied at twice the labeled rate of 0.56 kg a.i./ha inhibited root growth, suggesting normal PGR use may not exacerbate seasonal effects on bentgrass root growth.

Fenarimol, normally a fungicide, works as a dimethylization or sterol inhibitor (DMI or SI) in the membranes of susceptible fungi. In plants, fenarimol inhibits gibberellic acid and one or more cytochrome oxidase enzymes important in the biosynthesis of sterols (Rademacher, 2000). DMI fungicides are commonly used for controlling turfgrass diseases caused by both leaf and root pathogens. With potential growth regulating properties, fenarimol is commonly used in turf as a preemergence herbicide for *Poa annua* L.

Ethephon does not directly inhibit gibberellic acid or cytokinin synthesis as other compounds in this study. When mixed with water, ethephon converts to ethylene gas which signals damage, stress, or physical plant injury (Taiz and Zeiger, 2002). Applications of ethephon on bermudagrass turf have been shown to cause necrosis of the terminal leaves and unusual necrotic-chlorotic striping of developing leaves (Shatters et al., 1998).

PGR use concerns for dwarf bermudagrass cultivars include turfgrass discoloration, negative rooting responses, and post inhibition growth enhancement. However, dwarf bermudagrass rooting response to PGRs has not been reported. Furthermore, research is limited as to the physiological responses of dwarf bermudagrass to growth regulating compounds.

The objective of this greenhouse study was to analyze the short term effects of repeated use of seven plant growth regulators on visual quality, root biomass, clipping yield, and chlorophyll concentration of ‘TifEagle’ bermudagrass.

Materials and Methods

Three studies were conducted at the Clemson University Greenhouse Research Complex, Clemson, S.C., from November 2002 to February 2003 (Studies 1 and 2) and from April to

Table 1. Plant growth regulators, formulations, and rates applied to ‘TifEagle’ bermudagrass in three greenhouse experiments.

Plant growth regulator	Formulation	Application rate (kg a.i./ha/3 weeks)
Ethephon	2L	4.90
Fenarimol	1AS	3.05
Flurprimidol	50WP	0.42
Maleic hydrazide	1.5L	0.84
Mefluidide	2S	0.14
Paclobutrazol	2SC	0.42
Trinexapac-ethyl	1EC	0.05

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May 2003 (Study 3). Greenhouse day/night temperatures ranged from 26 /19 °C. Plugs were collected from a 'TifEagle' bermudagrass green located in the Turf Service Center, Clemson. Soil was washed and plugs placed in 15-cm-diameter pots with a depth of 12 cm. The soil medium was an 85 sand : 15 peatmoss (by volume) mix with about 4% coarse sand (0.5 to 1.0 mm), 32% 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). Starting fertilizers mixed into the soil were a 9N-18P₂O₅-17K₂O with 6.3% ammoniacal N, 0.5% urea N, 1.1% methylenediurea and dimethylenetriurea, and 1.1% water insoluble N and a 16-4-8 urea nitrogen based fertilizer complete with micro-nutrients, each at 24 kg·ha⁻¹ N. Bermudagrass was allowed to initiate active growth before initial PGR treatments.

A randomized complete block design with four replications of eight pots per block (seven PGRs and one control) was used due to reduced natural light during winter months. Supplemental lighting added 50 µmol·m⁻²·s⁻¹ for 3 h·d⁻¹ in November, 4 h·d⁻¹ in December and January, 3 h·d⁻¹ in February, 2 h·d⁻¹ in March, and 1 h·d⁻¹ in April. PGRs tested included ethephon, fenarimol, flurprimidol, maleic hydrazide, mefluidide, paclobutrazol, and trinexapac-ethyl. Due to the lack of labeled rates for growth regulators on dwarf bermudagrass, labeled rates for traditional bermudagrass cultivars, bentgrass greens, and low rates for higher mowed hybrid bermudagrass were applied (Table 1). Two applications were made at 3-week intervals to evaluate root and shoot growth responses after 6 weeks.

Pots were irrigated and mowed daily at an approximate 4 mm mowing height. Ammonium nitrate N was applied weekly at 12 kg·ha⁻¹. PGR applications were made with a greenhouse spray chamber (model SB6-094; Devries Manufacturing, Hollandale, Minn.) with a 6-HP (Craftsman model 919.165110) pump delivering 560 L·ha⁻¹.

Roots were harvested 6 weeks after initial treatment (WAIT) from the entire pot in all three studies. For Studies 2 and 3, clipping yield was harvested weekly. Clippings and root samples were oven-dried at 100 °C for 48 h, then weighed. Visual quality ratings were made on a 1 to 9 scale with 9 being dark green turf and 1 completely dormant or dead turf. Quality ratings below 7 were considered unacceptable. Chlorophyll concentrations (mg·g⁻¹ of fresh clipping weight) were determined 3 and 6 weeks after initial treatments with a spectrophotometer (Genesys 20 Thermo Spectronic model 4001/4; Waltham, Mass.) (Moran and Porath, 1980). Leaf tissue was sampled before the second PGR applications, 3 WAIT, and again at 6 WAIT. Data analyses were made using the analysis of variance with SAS general linear model procedure (SAS Institute, Cary, N.C.).

Results

Clipping reduction, chlorophyll concentration, and visual quality responses varied on 'TifEagle' bermudagrass receiving the seven

compounds. Study × PGR interaction was not significant for root mass or total clipping yield, therefore studies were combined. Root mass was reduced 39% and 43% for fenarimol and flurprimidol treated turf, respectively, compared to the control (Fig. 1). Bermudagrass receiving other PGRs had root mass similar to the untreated. However, 'TifEagle' bermudagrass treated with mefluidide, paclobutrazol, fenarimol, and flurprimidol averaged 45% less root mass than trinexapac-ethyl treated turf (Fig. 1).

Trends in turf visual quality in all three studies were consistently equivalent or greater than the control when treated with trinexapac-ethyl (Table 2). Trinexapac-ethyl reduced clipping yield 56% (Fig. 2). Turf treated with trinexapac-ethyl had 80% higher chlorophyll concentration compared to the control 3 WAIT in Study 1 (Table 3). After 6 weeks, chlorophyll concentrations were similar to the untreated in all three studies for trinexapac-ethyl treated turf (Table 3).

Paclobutrazol applications initially improved turf quality; however, repeat applications caused unacceptable quality (Table 2). Paclobutrazol reduced clippings 86% compared to the control (Fig. 2). Paclobutrazol treatments resulted in 113% higher chlorophyll A and 150% higher chlorophyll B 3 WAIT in Study 1 (Table 3). By week 6 in all studies, total chlorophyll concentrations for paclobutrazol treated turf were similar to the control.

Flurprimidol performed similarly to paclobutrazol as visual quality declined to unacceptable levels after the second application (Table 2). Flurprimidol applications reduced clippings 88% (Fig. 2). Chlorophyll concentrations were enhanced 113% 3 WAIT in Study 1

(Table 3). Compared to the untreated 6 WAIT, turf treated with flurprimidol in Study 2 had 41% reduced chlorophyll A concentrations and in Study 3 33% and 20% reduced chlorophyll A and B concentrations, respectively (Table 3).

'TifEagle' bermudagrass treated with mefluidide had similar visual quality to the untreated throughout the three studies (Table 2). Mefluidide reduced total clippings harvested by 25% (Fig. 2). Chlorophyll concentrations in mefluidide treated turf were similar to the control (Table 3).

Visual ratings for turf treated with fenarimol were unacceptable after the second treatment (Table 2). Fenarimol reduced total clipping yield 34% from the control (Fig. 2). Chlorophyll concentrations were similar to the control for fenarimol treated turf (Table 3).

Bermudagrass treated with maleic hydrazide had turf quality similar to the control, with the exception of 6 WAIT in Study 1 (Table 2). Maleic hydrazide reduced clippings 46% compared to the untreated (Fig. 2). Chlorophyll B concentration was increased 105% from the control 3 WAIT in Study 1 (Table 3). Chlorophyll concentrations for maleic hydrazide treated turf were similar to the control 6 WAIT (Table 3).

Ethephon treatments had unacceptable quality beginning 1 WAIT (Table 2). Quality ratings were consistently unacceptable for ethephon treated turf and declined until the end of Studies 2 and 3 (Table 2). Ethephon treated turf had clipping yield reduced 41% from the control (Fig. 2). Chlorophyll concentrations of ethephon treated turf were similar to the untreated during Study 1 and Study 2 (Table 3). By week 6 of Study 3, chlorophyll A concentrations were reduced 14% compared to the control for ethephon treated turf.

Fig. 1. Dry root mass (g·m⁻²) averaged across three studies for 'TifEagle' bermudagrass treated with seven growth regulators. Different letters indicate a significant difference at *P* = 0.10 according to Fishers protected LSD test. MF = mefluidide; FN = fenarimol; EP = ethephon; MH = maleic hydrazide; TE = trinexapac-ethyl; PB = paclobutrazol; FP = flurprimidol.

Discussion

Root mass was found to be reduced as a result of repeated fenarimol and flurprimidol applications compared to the control and turf treated with trinexapac-ethyl and maleic hydrazide. Trinexapac-ethyl was found to be the most promising PGR for single and repeated applications on 'TifEagle' bermudagrass. Inhibiting bermudagrass shoot growth with trinexapac-ethyl has shown to be a valuable tool for reducing mowing requirements and enhancing bermudagrass quality (Johnson, 1997; Waltz, 1997; Fagerness and Yelverton, 2000). Incorporating trinexapac-ethyl in putting green maintenance has also been effective for improving ball roll distances and enhancing turf quality without affecting creeping

bentgrass root systems (Fagerness et al., 2000; Fagerness and Yelverton, 2001). In this study, trinexapac-ethyl was the only compound to enhance quality, inhibit shoot growth, and have no deleterious effect on 'TifEagle' bermudagrass root growth. These responses are likely due to the unique mode of action of TE, inhibiting GA production late in the biosynthesis pathway (Rademacher, 2000).

The early GA inhibitors paclobutrazol and flurprimidol are effective PGRs for common and hybrid bermudagrass 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). These findings were similar for 'TifEagle' bermudagrass, as single applications of pa-

clobutrazol and flurprimidol at 0.42 kg-ha⁻¹ were excessive and repeat applications may be extremely injurious at 3-week intervals. Flurprimidol was applied at the labeled rate for 'Tifgreen' (328) bermudagrass and should be reevaluated for proper rates and application intervals on dwarf bermudagrass cultivars.

Type I PGRs, mefluidide and maleic hydrazide, generally did not reduce bermudagrass quality at the applied rates. Mefluidide provided quality similar to untreated 'TifEagle' bermudagrass at 0.14 kg-ha⁻¹ per 3 weeks, but with the absence of a surfactant. The addition of a surfactant may reduce the safety of this compound to bermudagrass and future field tests are needed to evaluate effects on quality, rooting, and growth inhibition of dwarf bermudagrass.

Fenarimol is a compound bermudagrass managers traditionally apply for preemergence *Poa annua* control and as a preventative fungicide for spring dead spot. However, abrasive qualities observed in field studies may have deleterious effects on bermudagrass putting greens (Elliot, 1999). Injury to bermudagrass roots from fenarimol applied in the fall may serve as a major entry route for *Ophiostoma* spp. pathogens (Engel and Illnicki, 1969). Further research is needed to address timing and rates of fenarimol applications that will not reduce dwarf-type bermudagrass quality or root growth in herbicide and fungicide programs.

Single and repeat applications of ethephon decreased 'TifEagle' bermudagrass quality. Turf discoloration likely occurred as ethephon accelerated leaf senescence through the release of ethylene and caused chlorophyll breakdown and color fading (Taiz and Zaiger, 2002). 'TifEagle' bermudagrass discoloration from ethephon in this study was similar to previous reports on hybrid bermudagrass (Shatters, et al, 1998). The most applicable approach for ethephon use on bermudagrass putting greens may be to thin out turf before fall overseeding.

Finally, these results should serve as a basis for future field and greenhouse PGR research on dwarf-type bermudagrasses. As these grasses continue to be planted for putting green turf, the applications of PGRs will likely become an important practice for promoting putting surfaces by inhibiting diurnal shoot growth

Table 2. Turf quality^z for TifEagle bermudagrass treated with seven plant growth regulators (PGRs) at 3-week intervals.

PGR	Rate (kg a.i./	Week after initial treatment					
	ha/3 weeks	1	2	3	4	5	6
Study 1							
Control	---	6.0 bc ^y	6.8 ab	6.5 abc	7.0 ab	7.0 ab	7.0 ab
Trinexapac-ethyl	0.05	6.8 ab	7.3 a	7.5 a	7.8 a	8.0a	7.8 a
Paclobutrazol	0.38	7.0 a	7.3 a	7.3 ab	7.3 ab	6.5 b	6.0 bcd
Flurprimidol	0.38	6.8 ab	6.5 ab	5.8 c	5.0 cd	3.8 c	3.3 e
Mefluidide	0.14	6.0 bc	7.0 ab	6.3 bc	7.0 ab	7.3 ab	6.8 abc
Fenarimol	3.05	5.8 c	6.9 ab	5.8 c	6.0 bc	6.5 b	5.5 d
Maleic hydrazide	0.84	6.0bc	7.0 ab	7.3 ab	7.3 ab	6.5 b	5.8 cd
Ethephon	4.90	5.5 c	5.8 b	5.5 c	4.3 d	6.8 b	5.5 d
Study 2							
Control	---	7.0 a	7.0 ab	7.0 b	7.0 ab	7.0 b	7.0 b
Trinexapac-ethyl	0.05	7.0 a	7.5 a	8.0 a	7.5 a	8.0 a	8.0 a
Paclobutrazol	0.38	7.0 a	7.0 ab	6.3 bcd	5.0 c	3.0 de	2.3 e
Flurprimidol	0.38	7.0 a	6.3 bc	5.8 cd	4.8 c	2.5 e	1.5 f
Mefluidide	0.14	6.5 b	6.3 bc	6.8 b	6.8 ab	6.8 b	6.5 b
Fenarimol	3.05	6.8 ab	6.5 bc	6.5 bc	6.5 b	4.8 c	4.8 c
Maleic hydrazide	0.84	7.0 a	7.0 ab	7.0 b	7.0 ab	7.0 b	7.0 b
Ethephon	4.90	6.8 ab	5.8 c	5.5 d	5.3 c	3.5 d	3.8 d
Study 3							
Control	---	7.0 a	7.0 bc	7.0 b	7.0 b	6.8 b	6.8 b
Trinexapac-ethyl	0.05	7.3 a	8.0 a	8.0a	8.0 a	8.0 a	8.0 a
Paclobutrazol	0.38	7.3 a	7.8 ab	7.8 a	7.0 b	6.8 b	5.5 c
Flurprimidol	0.38	7.5 a	7.0 bc	6.3 c	4.8 d	2.8 d	3.3 d
Mefluidide	0.14	7.0 a	7.3 ab	7.0 b	7.0 b	6.8 b	6.5 b
Fenarimol	3.05	7.0 a	7.0 bc	7.0 b	6.8 b	6.5 b	6.5 b
Maleic hydrazide	0.84	7.0 a	7.3 ab	7.0 b	7.0 b	7.0 b	6.5 b
Ethephon	4.90	6.0 b	6.3 c	6.0 c	5.5 c	4.0 c	5.5 c

^zTurf quality was rated on a 1 to 9 scale, with 9 = highest quality and dark green. Ratings below 7 were considered unacceptable.

^yMean separations are week after initial treatment for individual studies. Different letters indicate a significant difference at *P* = 0.05 according to Fishers protected LSD test.

Table 3. Chlorophyll a and b concentrations for TifEagle bermudagrass treated with seven plant growth regulators (PGRs).

		Chlorophyll concn ^z (mg·g ⁻¹), WAIT ^y									
		3				6					
		Study									
		1		3		1		2		3	
PGR ^x	Rate (kg a.i./ ha/3 weeks)	a	b	a	b	a	b	a	b	a	b
None	---	2.3 cd ^w	2.2 c	3.2 ab	3.3 bcd	4.7 abc	5.5 ab	3.1 ab	3.7 abc	3.6 ab	3.5 abc
TE	0.05	4.0 ab	4.1 ab	3.5 a	3.6 abc	5.1 ab	5.5 ab	3.7 a	4.5 a	6.8 a	3.9 a
PB	0.38	4.9 a	5.5 a	3.4 ab	3.8 ab	5.4 a	7.1 a	2.2 cd	2.9 bc	3.5 abc	3.4 bc
FP	0.38	4.8 a	4.8 a	3.1 ab	3.9 a	3.4 c	4.0 b	1.8 d	3.1 abc	2.4 d	2.8 d
MF	0.14	2.0 d	2.1 c	2.9 b	2.9 d	5.8 abc	7.0 ab	2.5 bcd	3.2 abc	3.3 bc	3.6 ab
FN	3.05	2.7 bcd	2.9 bc	3.6 a	3.6 abc	5.8 abc	7.0 ab	2.8 abc	2.4 c	3.7 ab	3.6 abc
MH	0.84	3.4 bc	4.5 ab	2.9 b	3.1 d	4.6 abc	7.5 a	3.1 ab	3.9 ab	3.3 bc	3.5 abc
EP	4.90	2.5 cd	2.2 c	2.9 b	3.2 cd	4.0 bc	4.5 b	2.7 bc	3.4 abc	3.1 c	3.2 cd

^zChlorophyll concentrations were taken before second applications, 3 weeks after initial treatment.

^yWAIT = week after initial treatment.

^aTE = trinexapac-ethyl, PB = paclobutrazol, FP = flurprimidol, MF = mefluidide, FN = fenarimol, MH = maleic hydrazide, EP = ethephon.

^wDifferent letters indicate a significant difference at *P* = 0.05 according to Fishers protected LSD test.

Fig. 2. Total dry weight clippings (g·m⁻²) from six sampling dates and averaged across Studies 2 and 3 for 'TifEagle' bermudagrass treated with seven growth regulators. Different letters indicate a significant difference at $P = 0.05$ according to Fishers protected LSD test. MF = mefluidide; FN = fenarimol; EP = ethephon; MH = maleic hydrazide; TE = trinexapac-ethyl; PB = paclobutrazol; FP = flurprimidol.

fluctuations. While trinexapac-ethyl is the most promising PGR from this experiment, information will be needed on appropriate rates and application intervals for other PGRs for long-term dwarf bermudagrass culture.

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