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Effects of Seasonal Trinexapac-Ethyl Application on Warm-season Turfgrass Colour, Quality and Spring Green-up under Mediterranean Environment

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Summary

Applications of the plant growth regulator trinexapac-ethyl (TE) [4-(cyclopropyl-α-hydroxymethylene)-3,5-dioxocyclohexane carboxylic acid ethylester]can enhance turfgrass colour, quality, and delay winter dormancy of warm-season turfgrass species. The objective of this study was to: study the effects of seasonal TE application on turfgrass quality, colour, fall colour retention and spring green-up of warm-season turfgrass species: *Cynodon dactylon* (L.) Pers., *Buchloë dactyloides* Engelm., *Zoysia japonica* Steudel, *Paspalum notatum* (Flügge), *Paspalum vaginatum* Swartz, and *Eremochloa ophiurioides* (Munro) Hack in the Mediterranean region. Applications of TE to the nineteen seeded-type cultivars were made to fully established turf plots at a 0.38 kg active ingredient (a.i.) ha^{-1} rate in summer or fall. Application schedule included a single application, followed by zero or one sequential application at 4-wk. Overall, TE enhanced turfgrass colour and quality in summer. The late season TE application decreased the quality, fall green colour retention up to 3-wk and delayed spring green-up by 15 d to 30 d. Results support the use of sequential application of TE for improved turfgrass colour and quality in summer. Reduced early fall TE applications should be examined to extend fall colour retention in future studies.

Key words. plant growth regulators – colour retention – winter dormancy

Introduction

Plant-Growth Regulators (PGR) that inhibit the biosynthesis of gibberellic acid (GA) are effective agents in enhancing turfgrass quality and colour while effectively controlling growth of turfgrass species (Fagerness and Yelverton 2000; Fagerness et al. 2002). One of the examples of such PGR is Trinexapac-ethyl (TE). TE represents a newer generation of growth inhibitors that disrupt GA biosynthesis by blocking the 3-β-hydroxylase conversion of GA_{20} to GA_1 (Rademacher 2000), and was introduced for use in 1991 (Watschke and Dipaola 1995). Inhibition of cell elongation with TE has been shown to increase mesophyll cell density and chlorophyll concentration that results in darker green and more dwarf shoots (Ervin and Koski 2001; Heckman et al. 2005; McCullough et al. 2006a, c).

Studies showed that single or sequential TE applications suppressed the growth of bermudagrass and enhanced colour and quality (Fagerness and Yelverton 2000; Richardson 2002; McCullough et al. 2006a, b, c; Ervin and Zhang 2007). TE increased stolon production, turf density, and quality when applied at high temperatures (Fagerness et al. 2002; McCullough et al. 2006c). Enhancing fall colour retention and promoting early spring green-up may shorten the dormancy period. However, reports are limited and inconsistent as to the effect of fall TE applications on warm-season turfgrass species dormancy and spring green-up. Late season nitrogen (N) and TE applications enhanced fall colour retention and promoted early spring green-up of bermudagrass (Richardson 2002), and repeated use of TE in late summer and early fall delayed 'TifEagle' bermudagrass winter dormancy (Fagerness and Yelverton 2000; McCullough et al. 2006c). However, Fagerness et al. (2002) noted that late season TE application accelerated dormancy, reduced turfgrass density and quality of 'Tifway' bermudagrass in North Carolina.

Although effects of PGRs have been studied extensively on both cool- and warm-season grasses, they were limited to one to a few cultivars of a given species. Hybrid bermudagrass encompassed the majority of the TE studies and there are limited reports on zoysiagrass (QIAN et al. 1998; QIAN and ENGELKE 1999; ERVIN et al. 2002), seashore paspalum (FERRELL et al. 2003), bahiagrass (JOHNSON 1990; BAKER et al. 1999), and centipedegrass (JOHNSON 1992b, 1993) and no reports for buffalograss. In this study eight bermudagrasses, five buffalograsses, two zoysiagrasses and bahiagrasses, and one seashore paspalum and centipedegrass seeded type cultivars were used. Separate summer and fall experiments were conducted with single and sequential TE applications to study the effects of TE application on turfgrass quality, colour; and of late season TE application on fall colour retention and spring green-up using multiple cultivars of six warm-season species under Mediterranean environmental conditions.

Materials and Methods

Plant Material

The study was conducted at the West Mediterranean Agricultural Research Institute in Antalya province located at 36°52' N and 30°43' E, Turkey in 2006 and 2007 for the fall study and in 2007 for the summer study. The soil was a silty-clay loam (61 % sand, 18 % silt, and 21 % clay) with 1.4 % organic matter, and an electrical conductivity (i.e. measure of the soluble salts) of 0.24 dS m^{-1}. Soil on the site had a pH = 8.4, Olsen extractable Phosphorus (P) of 22 mg kg^{-1}, and potassium (K) of 117 mg kg^{-1} (CARSON 1980). Warm-season turfgrass species evaluated included bermudagrass [(cvs. 'SWI-1044', 'SWI-1045' ('Contessa'), 'Princess 77', 'Riviera', 'Mohawk', 'Sultan', 'NuMex Sahara', and 'Blackjack')], buffalograss (cvs. 'Cody', 'Bowie', 'SWI-2000', 'Bison' and 'Texoka'), zoysiagrass (cvs. 'Zenith' and 'Companion'), bahiagrass (cvs. 'Argentina' and 'Pensacola'), seashore paspalum (cv. 'Sea Spray'), and centipedegrass (cv. 'Tifblair'). The species were seeded at the following rates; bermudagrass and buffalograss at 15 g m^{-2}, centipedegrass and seashore paspalum at 5 g m^{-2}, zoysiagrass at 10 g m^{-2}, and bahiagrass at 30 g m^{-2}. Seeds were sown on 12 August 2005.

During establishment, turfs were fertilized at 5 g N m^{-2} with 15N-6.6P-12.5K, a complex fertilizer, at seeding, and were irrigated three times daily to maintain a moist soil surface for three weeks after seeding. Subsequently, turf was irrigated to prevent visual wilt symptoms. After establishment, turfs received 17.5 g N m^{-2} per season with applications made as 5 g N m^{-2} in May, June, and July, and 2.5 g N m^{-2} in August using a slow release 33N-3P-6K granular fertilizer (Anderson's, Maumee, OH). Analysis and soil tests from the samples taken in April 2006 and 2007 before fertilizer applications indicated sufficient P (41 and 38 mg kg^{-1}) and K (102 and108 mg kg^{-1}) levels for turfgrass growth. Foliar applications of 0.6 g m^{-2} ferrous sulfate ($FeSO_4$) were applied throughout the growing season to alleviate iron chlorosis. Plots were mowed weekly at 50 mm with clippings removed.

Treatments

Spray applications of TE (Primo MAXX, Syngenta Crop Protection, Greensboro, NC) were made in fall 2006 and 2007, and summer 2007. The single application was made on 8 October 2006 (22 °C air temperature, 73 % relative humidity), and 6 October 2007 (24 °C air temperature, 69 % relative humidity) for the fall studies; and 18 June 2007 (26 °C air temperature, 82 % relative humidity) for the summer study. Sequential applications were made four weeks after initial treatments on 9 November 2006 (13 °C air temperature, 65 % relative humidity), and 6 November 2007 (16 °C air temperature, 88 % relative humidity) for the fall studies; and 17 July 2007 (32 °C air temperature, 27 % relative humidity) for the summer study. Wind speed was negligible (< 5 km h^{-1}) at the time of applications. TE (120 g a.i. L^{-1} emulsifiable concentrate) was applied at 0.38 kg ha^{-1} with a backpack sprayer calibrated at 800 L ha^{-1}.

Three treatments were applied: untreated (control), single TE application at 0.38 kg a.i. ha^{-1} (single), and one sequential application four weeks later (sequential) at the same rate. Turf was mowed 2 d prior to applications. Control plots were sprayed with water.

Measurements

Turfgrass quality and colour were evaluated weekly for 15 weeks after initial treatment (WAIT) in summer and 1 to 9 WAIT (until full dormancy for zoysiagrass and partial dormancy for other species) in fall. Spring green-up ratings were made every other week each spring from Feb 15 to May 30 in 2007 and 2008 until all the warm-season turfgrass species had achieved full green-up. Turfgrass quality ratings take into consideration the colour, density, uniformity, texture, weed, and disease infestation or sensitivity to environmental stress of the turfgrass as recommended by the National Turfgrass Evaluation Program (NTEP) guidelines using a 1–9 visual rating scale, where 1 = poorest, 6 = minimally acceptable, and 9 = best (NTEP 2010). Turfgrass colour ratings were made on the same days as visual quality and were based on the scale of 9 = dark green colour, 6 = light green, and 1 = straw brown. Turfgrass spring green-up was rated using a visual scale of 0 to 100 %, with 100 % = green vegetation over the entire plot, and 0 % = no green vegetation.

The climate was typical Mediterranean with dry-hot summers and mild-wet winters. Mean monthly ambient temperatures from the West Mediterranean Agricultural Research Station in 2006 and 2007 are shown in Fig. 1. Mean minimum air temperatures were 5–10 °C during winter, and maximum air temperatures were ca. 30–38 °C during summer.

Experimental Design and Statistical Analysis

The study consisted of 171 plots, 1.5 × 1.5 m in size, containing 19 turfgrass cultivars from six different warm-sea-

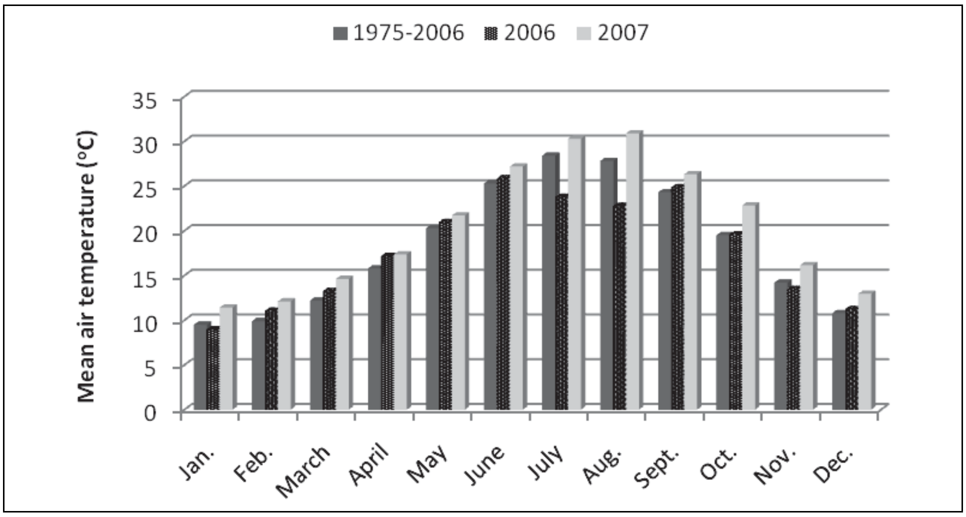

Fig. 1. Average monthly temperatures (°C) in Antalya, Turkey for 2006 and 2007 compared with the historical average (Antalya Turkish Climatologist Office, 2008).

son turfgrass species. The experimental design was a randomized complete block with three replications and treatment design was a split-split plot. Main plots were TE treatments, turfgrass species were split-plots and cultivars nested within species were split-split plots. Species within a replicate were randomized (blocked) across the field and cultivars were randomized within each species. Hartley's F max test (Hartley 1950) was performed to determine homogeneity of variance between the 2006 and 2007 fall TE applications. Data for the summer application was analyzed separately. Treatment differences for turfgrass colour, quality, and spring green-up of a given species were tested using analysis of variance procedures with PROC MIXED (Sas Institute 1999). Means were separated using Fisher's protected least significant difference procedure when the F-test indicated significance at $P \leq 0.05$.

Results and Discussions

Hartley's F max test (Hartley 1950) indicated homogenous variance between the 2006 and 2007 fall TE applications; therefore, combined data were analyzed for the fall TE treatment. The year and treatment interactions were not significant for turfgrass colour, quality, and spring green-up on most evaluation dates; thus, data from each year were combined. TE × cultivar interaction was not significant for bermudagrass, buffalograss, zoysiagrass and bahiagrass on most evaluation dates. Therefore, pooled means of cultivars were used to analyze TE effects on the species.

Summer and fall TE effects on turf quality, colour, fall-colour retention, and spring green-up of warm-season turfgrass species were evaluated. Single or sequential applications of TE were made during the warmest periods of summer (June; and June and July) and fall applications were carried out in October; and November when air temperatures were 10 to 20 °C cooler than for the summer treatments.

Turf Colour

Single summer TE application on 18 June caused 5 to 12 % discoloration on all species at 1 WAIT (Table 1). After 9 % initial discoloration, bermudagrass recovered quickly and exhibited 5 to 11 % colour enhancement from 2 to 7 WAIT compared to the control. These results are in contrast to Johnson (1992a) who reported injury through the 7 WAIT and up to 28 % injury on common bermudagrass with a 0.4 kg ha^{-1} single summer TE treatment 3 WAIT. Buffalograss showed 8 % discoloration at 1 WAIT but recovered and was similar to the untreated control at 2 WAIT and had enhanced colour of TE plots up to 5 % until 8 WAIT. Zoysiagrass discoloration ranged from 10 to 15 % which lasted five weeks. Zoysiagrass showed 4 to 11 % enhanced colour from 6 to 10 WAIT. Bahiagrass discoloured 6 % at 1 WAIT but its colour values increased up to 17 % until 11 WAIT. Seashore paspalum showed the highest discoloration 1 WAIT with 12 %, but recovered quickly and exhibited up to 9 % enhanced colour from 2 to 7 WAIT when compared to the untreated control. Centipedegrass had less than 5 % initial discoloration and its colour enhanced 5 to 10 % from 5 to 8 WAIT. These results are in contrast to those of Johnson (1992b) who reported injury levels of 26 to 32 % on common centipedegrass treated once with TE at 0.4 kg ha^{-1} with summer applications.

Sequential summer TE applications 4 WAIT increased bermudagrass colour significantly over the single application until 13 WAIT and enhanced colour 5 to 14 % (Table 1). Sequential application increased buffalograss colour over non-treated plots until 10 WAIT, but the difference from single treatment was not significant at the same period. The second application decreased zoysiagrass colour slightly between 4 and 7 WAIT and enhanced

Table 1. Mean turfgrass colour after trinexapac-ethyl (TE) applications in the summer period for bermudagrass (Be), buffalograss (Bu), zoysiagrass (Zo), bahiagrass (Ba), seashore paspalum (Sp) and centipedegrass (Ce) species in Antalya, Turkey, in 2007.

S.	Treat-ment	Weeks After Initial Treatment (WAIT)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Turfgrass Colour[1)]														
Be	0 TE	7.8	7.6	7.6	7.6	7.6	7.8	7.6	7.7	8.1	8.2	7.9	7.9	7.5	7.9	7.9
	1 TE[2)]	7.1	8.0	8.2	8.4	8.4	8.5	8.1	7.8	8.2	8.3	7.9	7.9	7.6	7.9	7.9
	2 TE[3)]	7.2	8.2	8.1	8.5	8.7	8.7	8.6	8.6	8.8	8.7	8.4	8.2	7.9	8.1	8.0
	LSD[4)]	0.3	0.2	NS	0.1	0.2	0.3	0.4	0.2	0.2	0.4	0.4	0.1	0.3	NS[5)]	NS
Bu	0 TE	8.0	8.0	8.0	8.4	8.3	8.4	8.0	8.3	8.4	8.5	8.1	7.9	7.9	8.1	7.8
	1 TE	7.3	7.9	8.1	8.6	8.6	8.8	8.3	8.5	8.6	8.5	8.0	8.0	8.0	8.0	7.8
	2 TE	7.3	7.9	8.0	8.6	8.7	8.8	8.6	8.7	8.8	8.8	8.2	8.3	8.1	8.3	8.1
	LSD	0.2	NS	NS	NS	0.3	0.1	0.3	0.3	0.2	NS	NS	0.2	0.2	NS	NS
Zo	0 TE	7.6	7.5	7.3	7.1	6.9	7.1	6.7	6.6	6.8	6.5	6.9	6.9	6.9	6.7	6.8
	1 TE	7.1	6.8	6.7	6.0	6.4	7.5	7.4	7.0	7.0	6.9	7.0	7.1	6.9	6.8	6.9
	2 TE	7.2	7.0	6.8	6.0	6.2	7.3	7.3	7.3	7.4	7.6	7.3	7.3	7.0	6.9	7.0
	LSD	0.3	0.6	0.5	0.2	0.2	NS	0.5	0.4	0.3	0.5	0.4	0.3	NS	NS	0.3
Ba	0 TE	6.2	6.0	6.1	6.1	6.0	6.8	5.5	5.9	6.0	5.8	6.1	6.4	6.4	6.5	6.4
	1 TE	5.9	6.0	6.4	6.7	6.6	7.2	6.4	6.2	6.2	6.3	6.3	6.5	6.4	6.4	6.3
	2 TE	5.8	6.0	6.3	6.6	6.2	7.2	6.3	6.4	6.5	7.2	6.9	6.8	6.7	6.7	6.5
	LSD	0.4	NS	NS	NS	NS	0.3	0.3	NS	0.3	0.5	NS	NS	0.2	0.2	NS
Sp	0 TE	7.0	7.0	6.8	6.8	6.8	7.5	7.5	6.7	6.9	6.7	7.8	7.3	6.6	6.6	6.7
	1 TE	6.2	7.5	7.3	7.3	7.4	7.8	7.8	6.7	6.9	6.8	7.9	7.3	6.4	6.4	6.7
	2 TE	6.2	7.5	7.2	7.3	7.2	7.9	8.3	7.4	7.4	7.6	8.4	7.4	6.4	6.5	6.7
	LSD	0.8	0.1	NS	0.5	0.4	0.1	0.4	0.6	0.3	0.6	0.3	NS	NS	NS	NS
Ce	0 TE	7.1	7.0	7.0	6.9	6.8	7.0	6.8	6.4	6.8	6.7	6.9	7.0	7.0	6.5	6.5
	1 TE	6.8	6.8	7.0	7.1	7.1	7.3	7.5	6.9	6.7	6.8	7.0	7.1	6.9	6.7	6.5
	2 TE	6.8	6.9	7.3	7.0	7.2	7.6	7.6	7.5	7.5	7.8	7.5	7.4	7.1	6.7	6.6
	LSD	NS	NS	NS	NS	0.2	0.3	0.4	0.9	0.4	1.0	0.5	0.3	NS	NS	NS

S = Species

1) Turfgrass colour ratings were based on a 1–9 visual rating scale, with 1 = straw brown, 6 = light green, 9 = dark green.

2) Single TE application was made at 0.38 kg ha^{-1} on 18 June 2007.

3) Sequential TE application was made four weeks after single application at 0.38 kg ha^{-1} on 17 July 2007.

4) LSD values indicate significant means separation at $\alpha = 0.05$.

5) NS = not significant at P = 0.05 probability level.

colour over single application from 8 to 12 WAIT, enhanced bahiagrass colour from 8 to 14 WAIT, seashore paspalum colour from 7 to 11 WAIT, and centipedegrass colour from 8 to 12 WAIT. Ferrell et al. (2003) reported seashore paspalum cv. 'Sea Isle 1' to have 18 % and 31 % injury with the same TE rates used in our study, 4 WAIT with a single TE application and 8 WAIT with sequential TE applications, respectively. However, we observed only a 12 % colour loss 1 WAIT and enhanced colour through 7 WAIT, and a sequential TE treatment (at 4 WAIT) extended the enhanced colour through 11 WAIT without significant post-treatment injury.

All the species exhibited similar colour values between TE treated plots and respective non-treated control plots by 14 WAIT (Table 1). In summer, either one or two application of TE resulted in increased turf colour of warm-season turfgrasses, after recovering from initial discoloration, compared with the control. There was an added advantage of a sequential application compared with a single application.

Single fall TE applications on 8 October in 2006 and 6 October in 2007 caused significant colour reduction on all species except bahiagrass in the first 4 WAIT. Colour lost from 1 WAIT to 9 WAIT in bermudagrass progressed from 8 to 20 %, in buffalograss from 8 to 40 %, in zoysiagrass from 8 % to 35 %, in bahiagrass from 1 to 12 %, in seashore paspalum from 3 to 15 %, and in centipedegrass from 7 to 30 % (Table 2).

Sequential fall TE applications on 9 November in 2006 and 6 November in 2007 further accelerated the colour decline with additional reduction of 8 to 20 % over the single TE applications (Table 2). Suboptimal temperatures either at the time or soon after TE application seem to exacerbate the chlorosis. FAGERNESS et al. (2002) noted that applications of TE to 'Tifway' bermudagrass caused leaf chlorosis and reduced turf density when temperatures were < 20 °C. MCCULLOUGH et al. (2007) reported more than 20 % discoloration 3-weeks after TE application in May. JOHNSON (1994) reported similar leaf discoloration of 'Tifway' bermudagrass following single TE treat-

Table 2. Mean turfgrass colour after trinexapac-ethyl (TE) applications in the fall period for bermudagrass (Be), buffalograss (Bu), zoysiagrass (Zo), bahiagrass (Ba), seashore paspalum (Sp) and centipedegrass (Ce) species in Antalya, Turkey, averaged over 2006 and 2007.

S.	Treatment	Weeks After Initial Treatment (WAIT)							
		1	3	4	5	6	7	8	9
		Turfgrass Colour[1]							
Be	0 TE	7.5	7.6	5.8	5.8	5.4	4.9	4.2	4.2
	1 TE[2]	6.9	6.8	5.1	4.6	4.2	3.9	3.4	3.4
	2 TE[3]	6.9	6.9	5.5	4.7	3.7	3.1	2.6	2.5
	LSD[4]	0.2	0.5	NS[5]	0.9	0.6	0.9	0.8	0.6
Bu	0 TE	7.7	7.0	6.4	5.5	4.5	3.1	2.6	2.6
	1 TE	7.1	5.9	5.2	4.5	3.3	2.0	1.8	1.6
	2 TE	7.2	6.0	5.1	4.1	3.0	1.8	1.6	1.4
	LSD	0.3	0.8	0.7	0.8	0.8	0.8	0.8	0.3
Zo	0 TE	6.9	6.9	6.4	5.8	5.5	4.6	3.8	3.4
	1 TE	6.5	6.4	5.5	4.9	3.8	3.7	2.3	2.2
	2 TE	6.3	6.1	5.1	4.6	3.2	3.1	2.1	1.9
	LSD	0.2	0.4	0.7	0.4	0.7	1.2	1.1	1.0
Ba	0 TE	6.5	7.1	6.8	6.6	6.2	5.4	5.3	5.3
	1 TE	6.4	7.2	6.6	6.3	5.6	4.8	4.7	4.7
	2 TE	6.5	7.1	6.6	5.9	5.3	4.4	4.4	4.3
	LSD	NS	NS	NS	NS	0.3	0.5	0.5	0.4
Sp	0 TE	7.5	7.7	5.7	5.9	6.0	5.3	5.0	4.1
	1 TE	7.2	7.5	4.8	4.8	4.4	4.3	3.6	3.5
	2 TE	7.3	7.3	5.2	5.0	4.6	4.0	3.3	3.2
	LSD	NS	NS	0.8	0.7	0.9	1.2	0.8	0.4
Ce	0 TE	6.8	7.6	5.1	5.0	5.0	4.4	4.0	4.0
	1 TE	6.4	7.2	4.1	4.0	3.9	3.5	3.0	2.8
	2 TE	6.6	7.5	4.4	4.2	3.9	3.3	2.6	2.5
	LSD	0.3	NS	1.0	0.8	1.0	0.6	0.7	1.3

S = Species

1) Turfgrass colour ratings were based on a 1–9 visual rating scale, with 1 = straw brown, 6 = light green, 9 = dark green.

2) Single TE applications were made at 0.38 kg ha^{-1} on 8 October 2006 and 6 October 2007.

3) Sequential TE application were made four weeks after single application at 0.38 kg ha^{-1} on 9 November 2006 and 6 November 2007.

4) LSD values indicate significant means separation at $\alpha = 0.05$.

5) NS = not significant at P = 0.05 probability level.

ments of 0.2 kg ha^{-1} in late May, but turf generally recovered to acceptable levels within 1 to 2 wk. Fagerness and Yelverton (2000) also noted discoloration of 'Tifway' bermudagrass from initial spring TE treatments at 0.11 kg ha^{-1}.

In fall as the temperatures dropped below 12 °C, warm-season turfgrasses begin to discolour and initiate dormancy as the rate of chlorophyll degradation appears to accelerate beyond the rate of chlorophyll synthesis. Addition of gibberellic acid (GA) blocked chlorophyll and protein degradation, inhibiting senescence in leaf disks for several days (Goldthwaite and Laetsch 1968). GA was absent in senesced leaves of lettuce and showed an age-related decline caused by the conversion of free GA to a bound inactive form (Aharoni and Richmond 1978). The GA_1 and GA_3 are the most biologically active in terms of promoting elongation growth in stems and grass leaves at the intercalary meristem (Cleland 1999). GA products labeled for use in turf are recommended to reverse the effect of an over-application of GA-blocking PGRs (i.e. TE, paclobutrozol, and flurprimidol) and to initiate or maintain growth and prevent colour changes during cold stress and light frost on bermudagrass (Dipaola et al. 1981; Karnok and Beard 1983; Dudeck and Peacock 1985; Murphy et al. 2005). Thus, it is conceivable that blocking conversion of GA_{20} to GA_1 reduced the active GA in leaves, and suboptimal temperatures exacerbated green colour loss by accelerating chlorophyll degradation especially after sequential fall application.

Turf Quality

A single summer TE application on 18 June significantly reduced quality of bermudagrass and seashore paspalum for one week, buffalograss and bahiagrass for four weeks, and zoysiagrass for six weeks when compared to the untreated control (Table 3). TE treatment produced injury symptoms evidenced by leaf-tip chlorosis that resulted in lower quality ratings than the non-treated plots. Bermudagrass plots receiving one TE application exhibited similar qualities to non-treated plots from 2 to 4 WAIT, and thereafter up to 16 % better quality until 8 WAIT. Although buffalograss demonstrated up to 10 % decline in quality until 4 WAIT due to one TE application, treated plots had similar quality to non-treated after 4 WAIT. This TE treatment reduced zoysiagrass quality up to 12 % until 7 WAIT. Thereafter, it recovered and exhibited similar quality to the untreated plots. Bahiagrass plots lost up to 8 % quality until 4 WAIT, and exhibited enhanced quality at 6 and 7 WAIT. Similar to bermudagrass, seashore paspalum lost 10 % quality over non-treated control plots, showed comparable quality to non-treated plots at 2 to 4 WAIT, and significantly enhanced quality from 5 to 7 WAIT. Centipedegrass did not show any loss or gain of quality as a result of one TE application.

Beyond 4 WAIT (the time at which the sequential application was made to appropriate plots on 17 July), quality ratings of bermudagrass, bahiagrass, and centipedegrass were consistently higher in those plots that had received sequential application of TE (Table 3). Sequential TE application on 17 July (4 WAIT) enhanced the bermudagrass quality over the single TE application from 8 to 12 WAIT. In contrast to a report by Johnson (1994) where common bermudagrass showed from 13 to 23 % decline in quality after sequential summer TE treatments, we observed consistently enhanced quality as compared to non-treated plots with the sequential summer TE application. The second TE application reduced the buffalograss and seashore paspalum quality further until 7 WAIT, and zoysiagrass until 10 WAIT. Thereafter, all buffalograss plots showed similar quality values while seashore paspalum plots receiving sequential TE application always exceeded that of non-treated control from 8 to 14 WAIT (Table 3). Enhanced colour and observed increase in density with summer application of TE were the main reasons for enhancement of quality.

A single fall TE applications on 8 October in 2006 and 6 October in 2007 significantly reduced the turf quality below that of the control throughout the nine week evaluation period (Table 4). The treatment accelerated the decline in fall quality to below an acceptable level (> 6) by one week for bermudagrass and zoysiagrass, by two weeks for buffalograss, and by three weeks for seashore paspalum. Sequential fall TE applications on 9 November in 2006 and 6 November in 2007 consistently reduced quality below that of the single TE treated plots throughout the following five weeks evaluation period for all species. Single TE applications in fall occurred when mean daily temperatures were 22–24 °C, and sequential TE applications were made at 13–15 °C. At the time of the second applications, the warm-season species were growing relatively slowly and beginning or progressing into dormancy, which probably exacerbated the initial effects of TE applied late in the growing season. The fall TE treatments decreased colour and visual quality, indicating a more rapid progression into dormancy. Fagerness et al. (2002) reported similar results with a late fall TE application to 'Tifway' bermudagrass. They speculated that the negative TE effect in the fall could be related to a turfgrass that was more sensitive to TE under suboptimal temperatures. This may be caused by slower metabolism of the plant and longer half life of the chemical in the fall (Branham and Beasley 2007).

Spring Green-up

Compared with the non-treated controls, the fall TE treatments delayed the spring green-up of all the warm-season species, and two applications of TE delayed green-up more than single application in both years (Table 5). Bermudagrass, buffalograss and seashore paspalum plots receiving two TE applications in the preceding fall exhibited a 15-d spring green-up delay, while zoysiagrass, bahiagrass and centipedegrass showed a 30-d delayed spring green-up. The effects of fall TE applications on spring green-up dis-

Table 3. Mean turfgrass quality after trinexapac-ethyl applications (TE) in the Summer growing period for bermudagrass (Be), buffalograss (Bu), zoysiagrass (Zo), bahiagrass (Ba), seashore paspalum (Sp) and centipedegrass (Ce) species in Antalya, Turkey, in 2007.

S.	Treat-ment	Weeks After Initial Treatment (WAIT)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Turfgrass Quality[1]														
Be	0 TE	7.8	7.6	7.7	7.9	7.5	7.4	7.5	7.7	8.0	8.1	7.5	7.4	7.5	7.7	7.7
	1 TE[2]	7.2	7.3	7.7	8.1	8.1	8.4	8.1	7.8	8.2	8.2	7.6	7.6	7.6	7.7	7.7
	2 TE[3]	7.1	7.2	7.8	8.1	7.8	8.2	8.2	8.3	8.5	8.6	8.0	8.0	7.7	7.8	7.8
	LSD[4]	0.5	NS[5]	NS	NS	0.2	0.3	0.3	0.3	0.3	NS	0.4	0.3	NS	NS	NS
Bu	0 TE	7.4	7.1	7.4	7.6	7.6	7.8	7.8	7.8	7.9	7.5	7.6	7.4	7.5	7.6	7.0
	1 TE	6.6	6.4	7.0	7.3	7.5	7.9	7.9	7.8	8.0	7.6	7.7	7.4	7.6	7.6	7.1
	2 TE	6.5	6.4	7.1	7.2	6.9	7.5	7.6	7.9	8.1	7.8	7.9	7.8	7.7	7.8	7.3
	LSD	0.8	0.6	0.3	0.2	0.3	0.3	0.2	NS	NS	NS	NS	NS	0.1	NS	NS
Zo	0 TE	7.2	7.3	7.0	7.2	6.8	7.5	7.0	6.8	7.2	7.0	7.0	7.0	7.0	7.2	7.0
	1 TE	7.1	6.5	6.6	6.6	6.0	6.5	6.6	6.6	7.1	7.0	7.1	7.2	7.1	7.3	7.3
	2 TE	7.1	6.6	6.7	6.6	5.8	5.9	5.8	6.0	6.7	7.0	7.2	7.3	7.3	7.4	7.3
	LSD	NS	0.5	0.2	0.2	0.7	0.7	0.8	0.6	0.4	NS	NS	NS	NS	NS	0.3
Ba	0 TE	6.6	6.1	6.1	6.2	6.0	6.0	5.7	5.9	6.0	5.9	5.7	6.0	6.0	6.1	6.0
	1 TE	6.3	5.6	5.8	6.0	6.2	6.3	6.2	5.9	6.0	6.1	5.8	6.1	6.2	6.1	5.9
	2 TE	6.2	5.5	5.7	5.9	5.8	6.1	5.7	6.0	6.1	6.2	6.1	6.2	6.2	6.1	6.0
	LSD	0.2	0.3	0.3	0.2	NS	NS	0.5	NS	NS	NS	NS	NS	0.2	NS	NS
Sp	0 TE	8.3	8.3	8.4	8.5	8.5	8.2	8.1	8.2	8.0	7.9	7.6	8.2	8.0	7.8	7.9
	1 TE	7.5	7.9	8.3	8.6	8.9	8.9	8.8	8.1	8.0	8.0	7.8	8.2	7.9	7.8	7.8
	2 TE	7.6	7.8	8.2	8.3	8.3	7.8	8.0	8.5	8.6	8.4	8.2	8.3	8.2	8.1	7.9
	LSD	0.4	NS	NS	NS	0.2	1.1	0.7	NS	NS	0.3	0.4	NS	NS	0.3	NS
Ce	0 TE	7.0	6.7	6.8	6.8	6.8	6.7	7.2	7.0	7.3	6.9	6.4	7.1	7.0	6.8	6.4
	1 TE	7.0	6.4	6.9	7.0	7.3	7.5	7.8	7.2	7.4	6.9	6.6	7.1	7.0	6.8	6.6
	2 TE	6.9	6.3	7.0	7.0	6.9	7.0	6.9	7.1	7.3	7.4	7.0	7.3	7.1	6.9	6.9
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

S = Species

[1] Turfgrass quality ratings were based on a 1–9 visual rating scale, with 1 = poorest, 6 = acceptable, 9 = best.

[2] Single TE application was made at 0.38 kg ha^{-1} on 18 June 2007.

[3] Sequential TE application was made four weeks after single application at 0.38 kg ha^{-1} on 17 July 2007.

[4] LSD values indicate significant means separation at $\alpha = 0.05$.

[5] NS = not significant at P = 0.05 probability level.

sipated for bermudagrass, buffalograss, bahiagrass, and seashore paspalum by the end of April but zoysiagrass and centipedegrass plots receiving sequential TE application in the fall had significantly lower green-up than their non-treated control at this time. By mid-May however, all plots reached full green-up in both years (Table 5). Richardson (2002) reported that sequential TE applications on August, September and October 15 caused 15-d longer fall colour retention and 10-d earlier spring green-up compared to non-treated control 'Tifway' bermudagrass. However, we observed 7 to 21 d shorter fall colour retention and a 15 to 30 d delayed spring green-up with two TE treatments made on early October and early November. The difference may be due to amount of TE applied (0.15 *vs.* 0. 38 kg a.i ha^{-1}), post-TE treatments mean air temperatures and soil or other environmental differences between the two studies. A high rate of carbohydrate accumulation occurs in warm-season grasses during the late fall prior to the onset of winter dormancy (Lopez et al. 1967; Powell et al. 1967). Spring regrowth after winter dormancy and turf-

Table 4. Mean turfgrass quality after trinexapac-ethyl (TE) applications in the fall growing period for bermudagrass (Be), buffalograss (Bu), zoysiagrass (Zo), bahiagrass (Ba), seashore paspalum (Sp) and centipedegrass (Ce) species in Antalya, Turkey, averaged over 2006 and 2007.

S.	Treatment	Weeks After Initial Treatment (WAIT)							
		1	3	4	5	6	7	8	9
		Turfgrass Quality[1)]							
Be	0 TE	7.3	7.3	6.2	5.8	5.7	4.9	4.3	4.1
	1 TE[2)]	6.7	6.8	5.3	4.8	4.0	3.8	3.3	3.2
	2 TE[3)]	6.8	6.7	5.5	4.8	3.5	3.2	3.0	2.7
	LSD[4)]	0.2	0.4	0.7	0.8	0.7	0.9	0.8	0.7
Bu	0 TE	7.0	6.7	6.4	5.3	3.9	3.0	2.5	2.3
	1 TE	6.7	5.9	5.4	4.2	2.8	1.9	1.6	1.5
	2 TE	6.6	5.8	5.5	4.0	2.1	1.8	1.6	1.3
	LSD	0.2	0.7	0.6	1.0	0.7	0.9	NS[5)]	0.4
Zo	0 TE	6.6	6.6	6.3	5.8	5.5	4.8	4.0	3.9
	1 TE	6.4	6.3	5.4	5.0	4.4	3.8	3.1	2.5
	2 TE	6.2	6.2	5.2	4.6	3.6	3.1	2.6	1.9
	LSD	0.1	NS	0.5	0.5	0.8	0.8	1.1	1.3
Ba	0 TE	5.8	5.9	5.6	5.4	5.6	5.0	5.1	4.7
	1 TE	5.7	5.9	5.5	5.1	4.9	4.1	4.0	4.0
	2 TE	5.7	5.9	5.5	4.8	4.7	3.6	3.7	3.5
	LSD	NS	NS	NS	0.3	0.4	0.6	0.5	0.7
Sp	0 TE	8.8	8.4	6.7	6.5	6.7	5.9	5.0	4.6
	1 TE	8.2	7.8	5.2	5.3	5.1	4.6	3.7	3.4
	2 TE	8.4	7.8	5.2	5.3	5.0	4.5	3.3	3.2
	LSD	0.8	0.3	0.6	0.5	0.8	1.2	NS	0.7
Ce	0 TE	7.2	6.9	5.7	5.0	4.6	4.4	4.0	3.8
	1 TE	6.7	6.8	4.5	4.2	3.5	3.4	3.0	2.8
	2 TE	6.9	6.8	4.2	4.1	3.5	3.1	2.7	2.5
	LSD	0.2	NS	1.2	NS	0.8	0.5	0.8	0.5

S = Species

1) Turfgrass quality ratings were based on a 1–9 visual rating scale, with 1 = poorest, 6 = acceptable, 9 = best.

2) Single TE applications were made at 0.38 kg ha^{-1} on 8 October 2006 and 6 October 2007.

3) Sequential TE application were made four weeks after single application at 0.38 kg ha^{-1} on 9 November 2006 and 6 November 2007.

4) LSD values indicate significant means separation at $\alpha = 0.05$.

5) NS = not significant at P = 0.05 probability level.

grass recovery from excessive traffic and other stresses is dependent on an adequate supply of reserve carbohydrates (Fry and Huang 2004). Therefore fall is a critical period for warm-season species as storage of these reserve carbohydrates in roots occurs at temperatures suboptimal for shoot growth (Youngner 1969). TE treatments, sequential application in particular which accelerated dormancy, may have prevented storage of the reserves causing a delay in spring green-up. Warm-season grasses break dormancy when soil temperatures rise above 10 °C in spring (Beard 1973). They initiate new root and shoot growth from the nodes of stolons, rhizomes, and crown meristematic areas, and carbohydrate reserves are converted to soluble sugars and the first new leaves appear. Another reason for delayed spring green-up may be that TE is absorbed by the plant and translocated into rhizomes, stolons, and roots. This TE may not have been fully metabolized before the onset of dormancy due to low temperatures and contin-

Table 5. Mean turfgrass Spring green-up following fall trinexapac-ethyl (TE) applications for bermudagrass (Be), buffalograss (Bu), zoysiagrass (Zo), bahiagrass (Ba), seashore paspalum (Sp) and centipedegrass (Ce) species in Antalya, Turkey, averaged over 2006 and 2007.

S.	Treatment	Evaluation dates							
		15-Feb	28-Feb	15-Mar	30-Mar	15-Apr	30-Apr	15-May	30-May
		% Spring green-up[1]							
Be	0 TE	4	22	48	62	76	91	100	100
	1 TE[2]	2	19	40	56	73	90	100	100
	2 TE[3]	2	14	31	48	67	88	100	100
	LSD[4]	1	2	5	6	5	4	NS[5]	NS
Bu	0 TE	2	24	61	79	88	98	100	100
	1 TE	1	16	45	63	79	94	100	100
	2 TE	1	12	40	59	78	93	100	100
	LSD	1	2	8	14	NS	NS	NS	NS
Zo	0 TE	4	30	68	84	92	99	100	100
	1 TE	2	21	39	58	77	91	100	100
	2 TE	1	10	19	32	49	76	99	100
	LSD	NS	4	5	12	17	20	NS	NS
Ba	0 TE	8	26	53	71	86	92	100	100
	1 TE	5	16	34	53	76	92	100	100
	2 TE	4	9	19	35	64	88	99	100
	LSD	2	3	11	16	19	10	2	NS
Sp	0 TE	4	23	56	77	89	99	100	100
	1 TE	2	17	38	60	80	98	100	100
	2 TE	2	9	27	49	75	96	100	100
	LSD	1	2	12	21	NS	NS	NS	NS
Ce	0 TE	6	28	60	79	92	97	100	100
	1 TE	2	12	29	43	63	83	100	100
	2 TE	1	9	19	34	59	79	100	100
	LSD	1	4	10	17	21	23	NS	NS

S = Species

[1] Turfgrass spring green-up was rated using a visual scale of 0 to 100 %, with 100 % = green vegetation over the entire plot, and 0 % = no green vegetation.

[2] 1 TE = Single TE applications were made at 0.38 kg ha^{-1} on 8 October 2006 and 6 October 2007.

[3] 2 TE = Sequential TE application were made four weeks after single application at 0.38 kg ha^{-1} on 9 November 2006 and 6 November 2007.

[4] LSD values indicate significant means separation at $\alpha = 0.05$.

[5] NS = not significant at P = 0.05 probability level.

ued dormant state of grasses, and was still able to suppress the biosynthesis of GA during the period of spring green-up. Reports also indicate that GA was effective in enhancing spring green-up and growth of dormant winter turf (Wittwer and Bukovac 1958; Leben et al. 1959).

In conclusion, TE demonstrated potential for enhancing turfgrass colour and quality of several warm season turfgrasses in summer. To alleviate initial negative effects on some species, lower than 0.38 kg ha^{-1} TE rates should be used. An earlier (mid to late September) and lower (< 0.38 kg ha^{-1}) amount of single TE application may be sufficient to enhance fall colour and quality of warm-season species without causing unacceptable discoloration and delayed spring green-up.

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