Europ.J.Hort.Sci., 77 (6). S. 279–287, 2012, ISSN 1611-4426.

Effects of Seasonal Trinexapac-Ethyl Application on Warm-season Turfgrass Species Growth under Mediterranean Environment

S. Severmutlu[1)], N. Mutlu[2)], E. Gurbuz[3)], R. C. Shearman[4)] and T. P. Riordan[4)]
([1]Department of Landscape Architecture, University of Akdeniz, Antalya-Turkey, [2)]Department of Agricultural Biotechnology, University of Akdeniz, Antalya-Turkey, [3)]Bati Akdeniz Agricultural Research Institute, Antalya-Turkey, [4)]Department of Agronomy and Horticulture, University of Nebraska-Lincoln, U.S.A.)

Summary

Reducing mowing without compromising quality are the main goals of turf managers. Applications of the trinexapac-ethyl (TE) [4-(cyclopropyl-α-hydroxymethylene)-3,5-dioxocyclohexane carboxylic acid ethylester] can restrict leaf growth and hence reduce clipping production of warm-season turfgrass species. The objective was to: study the effects of seasonal TE application on vertical growth suppression and clipping production 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, single TE treatment in summer suppressed the vertical growth up to 8-wk and reduced the clipping production up to 72 %. The sequential summer application extended the suppression up to 5-wk. The mean clipping yield were 21 and 39 % lower than the control throughout the 15-week in summer; and 65 and 67 % lower in fall with single and sequential TE applications, respectively. Results support the use of sequential application of TE for extended growth suppression in summer. Suppressing the growth and accelerating dormancy of warm-season turfgrasses, the fall TE application may aid in transition to over-seeded cool-season grasses.

Key words. plant growth regulators – growth suppression – clipping yield

Introduction

Bermudagrass, buffalograss, zoysiagrass, centipedegrass, seashore paspalum, and bahiagrass are warm-season turfgrasses that possess aggressive summer growth and relative stress tolerance. They are predominantly used in temperate regions with relatively mild winters, which define Mediterranean type climates. In the Mediterranean, the warm-season grasses grow actively for 8 to 10 months each year; therefore, frequent mowing is needed to maintain a desirable appearance throughout the growing season. Because mowing makes up a large part of the cost of maintaining an acceptable turf, one of the main objectives of plant growth regulator (PGR) application to warm-season turfgrass species is to restrict leaf growth and the subsequent need for frequent mowing. Trinexapac-ethyl (TE) represents a newer generation of growth inhibitors. It disrupts 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). By inhibiting cell elongation, TE was shown to increase mesophyll cell density and chlorophyll concentration, resulting in more dwarf shoots (Ervin and Koski 2001; Heckman et al. 2005; McCullough et al. 2006a, 2006c).

Reducing turfgrass shoot growth with TE effectively reduces mowing requirements, improves sod strength, and enhances turfgrass tolerance to shade, disease, and drought stress (Johnson 1992a, 1994; Golembiewski and Danneberger 1998; Hongfei and Fry 1998; Jiang and Fry 1998; Qian and Engelke 1999; Fagerness and Yelverton 2000; Heckman et al. 2001; Goss et al. 2002; Steinke and Stier 2003; McCarty et al. 2004; Bunnell et al. 2005). Several studies have shown that single or sequential TE applications both suppress the growth of bermudagrass and enhance colour and quality (Fagerness and Yelverton 2000; Richardson 2002; McCullough et al. 2006a, 2006b, 2006c; Ervin and Zhang 2007). However, the duration of growth suppression depends on application timing and ambient temperature (LICKFELDT et al. 2001). TE effectively reduced vertical shoot growth, and increased stolon production, turf density, and quality when applied at high temperatures (FAGERNESS et al. 2002; MCCULLOUGH et al. 2006c). However, reports are limited and inconsistent as to the effect of fall TE applications on warm-season turfgrass species growth response.

Although PGRs have been evaluated extensively on both cool- and warm-season grasses, studies were limited to one to a few cultivars of a given species. Most of the TE studies was on bermudagrass and limited reports were 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. Our objective was to evaluate the effects of seasonal (summer and fall) TE applications with single and sequential application schedule on vertical growth and clipping production of six warm-season species under Mediterranean environmental conditions. Results are expected to aid turfgrass managers by elucidating the growth response of the warm-season turfgrass species to TE during periods of both optimum and suboptimum temperatures.

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 made 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

Evaluation of tissue production was based on clipping harvest, beginning 1 WAIT to 15 WAIT in the summer and from 1 WAIT to 9 WAIT in the fall study. Before the weekly collection of clippings, strips at the front and rear of each block were mowed to ensure a consistent clipping collection area. A 53 cm swath through the center of each strip was mowed to a 50-mm height. The reel mower used (Honda HLM 530 P) had a clipping collection device attached to it. Clippings were collected, dried at 72 °C for 48 h, and the dry weight of turfgrass clippings was determined for each treatment.

Vertical growth suppression (VGS) on each plot was measured as the difference in weekly vertical growth. A strip from the middle of plots was mowed at 50 mm and weekly growth, as difference in height between mowed and un-mowed parts of the turf, was recorded with a disk ruler method where a plastic disk was placed on the mowed area and the distance to canopy measured. The six measurements for each plot were averaged for each sampling date. Both dry clipping yield and vertical growth suppression was converted to percent of non-treated turf for the presentation of results. The equation used was:

Percent change = 100 ×
$[(response_x - response_0)/(response_0)]$

where $response_x$ equalled response of treated turf and $response_0$ equalled response of non-treated turf (McCullough et al. 2007).

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-season 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 vertical growth suppression and clipping yield 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 $P \leq 0.05$. Simple linear contrasts were performed on both clipping yield and vertical growth suppression data so that inferences about the single or sequential application patterns of TE could be determined.

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 growth suppression on most evaluation dates; thus, data were not reported separately. 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.

The effects of summer and fall TE applications on vertical growth suppression and clipping yield of warm-season turfgrass species were evaluated. There were single or sequential applications of TE 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.

Growth Reduction

TE suppressed growth of warm-season turfgrass species at both high and low temperatures and vertical growth suppression (VGS) was greater at the lower temperatures in the fall (Table 1–2). Single summer TE application on 18 June effectively reduced vertical growth on warm-season turfgrass species. Significant growth reduction, compared to non-treated control that began 1 WAIT lasted for 5 weeks for seashore paspalum and centipedegrass, for six weeks for buffalograss, for seven weeks for bermudagrass, and for eight weeks for zoysiagrass and bahiagrass

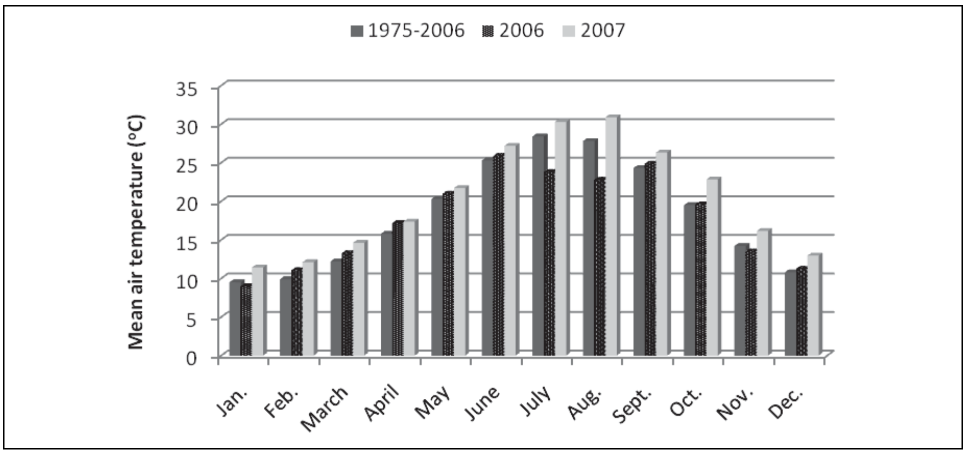

Fig. 1. Average monthly temperatures (°C) in Antalya, Turkey for 2006 and 2007 compared with the historical average (Antalya Turkish Climatologist Office 2008).

Table 1. The influence of summer trinexapac-ethyl (TE) application on warm-season grass species vertical growth in 2007, Antalya, Turkey.

S.	Treatm./ Contrast[1]	Weeks After Initial Treatment													
		1	2	3	4	5	6	7	8	9	10	11	12	14	15
		Reduction of vertical growth (% of untreated control)[2]													
Be[3]	1 TE[4]	−38	−62	−50	−28	−16	−14	−17	−16	−13	−5	0	4	3	7
	2 TE[5]	−42	−63	−49	−33	−48	−50	−56	−35	−24	−19	−9	−4	−5	−5
	0[6] *vs.* 1 TE	0.005	0.004	0.004	NS[7]	0.008	0.043	0.024	NS	NS	0.034	NS	NS	NS	NS
	0 *vs.* 2 TE	0.003	0.004	0.005	0.033	0.000	0.000	0.000	0.003	0.003	0.003	NS	NS	NS	NS
	1 *vs.* 2 TE	NS	NS	NS	NS	0.001	0.001	0.001	0.021	0.004	0.036	0.042	NS	NS	NS
Bu	1 TE	−44	−66	−51	−24	−14	−10	−5	−1	0	5	0	6	8	3
	2 TE	−35	−63	−53	−24	−36	−45	−37	−16	−13	−3	6	13	14	12
	0 *vs.* 1 TE	0.003	0.001	0.001	0.046	NS	0.005	NS	NS	NS	NS	NS	NS	NS	NS
	0 *vs.* 2 TE	0.006	0.002	0.001	0.045	0.003	0.000	0.002	0.013	0.040	NS	NS	0.011	0.023	NS
	1 *vs.* 2 TE	NS	NS	NS	NS	0.018	0.000	0.003	0.018	0.040	NS	NS	NS	NS	NS
Zo	1 TE	−44	−75	−75	−79	−45	−34	−19	−15	−9	−9	−6	6	14	14
	2 TE	−37	−76	−78	−82	−64	−74	−56	−50	−41	−26	−16	6	11	8
	0 *vs.* 1 TE	0.001	0.000	0.001	0.000	0.004	0.001	0.046	0.006	NS	NS	NS	NS	NS	NS
	0 *vs.* 2 TE	0.002	0.000	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.002	0.011	NS	NS	NS
	1 *vs.* 2 TE	NS	NS	NS	NS	NS	0.001	0.005	0.008	0.001	0.012	NS	NS	NS	NS
Ba	1 TE	−49	−65	−59	−50	−50	−33	−22	−22	−7	−5	−1	0	4	4
	2 TE	−48	−66	−63	−54	−69	−65	−67	−60	−40	−26	−22	−9	−7	−3
	0 *vs.* 1 TE	0.001	0.000	0.001	0.000	0.001	0.001	0.028	0.009	NS	0.020	NS	NS	NS	NS
	0 *vs.* 2 TE	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.004	0.000	0.001	NS	NS	NS
	1 *vs.* 2 TE	NS	NS	NS	NS	0.019	0.001	0.002	0.001	0.008	0.000	0.001	NS	NS	NS
Sp	1 TE	−28	−66	−64	−38	−28	−20	−14	−9	−7	−2	0	5	6	15
	2 TE	−24	−71	−64	−46	−62	−62	−69	−41	−34	−29	−10	−1	1	−1
	0 *vs.* 1 TE	0.023	0.000	0.004	0.009	0.044	NS	NS	NS	NS	NS	NS	NS	NS	NS
	0 *vs.* 2 TE	0.035	0.000	0.004	0.005	0.003	0.011	0.010	0.014	0.040	0.010	NS	NS	NS	NS
	1 *vs.* 2 TE	NS	NS	NS	NS	0.023	0.010	0.020	0.027	0.031	NS	NS	NS	NS	0.022
Ce	1 TE	−36	−67	−80	−71	−50	−35	−21	−18	−12	−10	−11	−6	15	6
	2 TE	−36	−73	−78	−66	−61	−81	−73	−62	−36	−36	−25	−8	13	15
	0 *vs.* 1 TE	0.020	0.001	0.000	0.000	0.002	NS	NS	NS	NS	NS	NS	NS	NS	NS
	0 *vs.* 2 TE	0.020	0.001	0.000	0.000	0.001	0.003	0.004	0.004	0.018	0.010	NS	NS	NS	NS
	1 *vs.* 2 TE	NS	NS	NS	NS	NS	0.023	0.015	0.014	0.020	0.030	NS	NS	NS	NS

S = Species

[1] Linear contrast between untreated control and treatments, and their respective P-values

[2] Means for vertical growth were based on six samples per plot, measured as the difference in weekly vertical growth.

[3] BE = bermudagrass; Bu = buffalograss; Zo = zoysiagrass; Ba = bahiagrass (Ba), Sp = seashore paspalum; CE = centipedegrass

[4] 1 TE = Single TE application was made at 0.38 kg ha^{-1} on 18 June 2007.

[5] 2 TE = Sequential TE application was made four weeks after single application at 0.38 kg ha^{-1}on 17 July 2007.

[6] 0 TE = NT = nontreated control.

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

(Table 1). The amount of VGS was the highest at 2 WAIT ranging from 60 to 75 % compared to the control plots. Ervin and Zhang (2007) reported similar findings where 'Tifway' bermudagrass showed the highest canopy height reduction (up to 65 %) at 2 WAIT. Johnson (1992a) reported that TE treatment at 0.2 kg ha^{-1} in each of two

Table 2. The influence fall trinexapac-ethyl (TE) application on warm-season grass species vertical growth in Antalya, Turkey, averaged over 2006 and 2007.

Species	Treatm./ Contrast[1)]	Weeks After Initial Treatment (WAIT)				
		1	3	5	7	9
		Reduction of vertical growth (% of untreated control)[2)]				
Bermudagrass	1 TE[3)]	−52	−55	−69	−74	−49
	2 TE[4)]	−50	−52	−74	−86	−58
	0[5)] vs. 1 TE	0.001	0.0002	0.0001	0.0003	0.005
	0 vs. 2 TE	0.0017	0.0001	0.0001	0.0001	0.002
	1 vs. 2 TE	NS[6)]	NS	0.05	NS	NS
Buffalograss	1 TE	−37	−44	−52	−71	−28
	2 TE	−38	−47	−61	−81	−31
	0 vs. 1 TE	0.001	0.001	0.001	0.0003	0.045
	0 vs. 2 TE	0.001	0.001	0.0008	0.0002	0.032
	1 vs. 2 TE	NS	NS	NS	NS	NS
Zoysiagrass	1 TE	−38	−45	−67	−71	0
	2 TE	−36	−42	−75	−71	0
	0 vs. 1 TE	0.005	NS	0.0001	0.002	NS
	0 vs. 2 TE	0.002	0.02	0.0001	0.002	NS
	1 vs. 2 TE	NS	NS	NS	NS	NS
Bahiagrass	1 TE	−29	−35	−48	−73	−34
	2 TE	−31	−38	−47	−82	−41
	0 vs. 1 TE	0.002	0.005	0.002	0.005	0.047
	0 vs. 2 TE	0.002	0.005	0.002	0.003	0.024
	1 vs. 2 TE	NS	NS	NS	NS	NS
Seashore paspalum	1 TE	−51	−59	−78	−79	−57
	2 TE	−54	−64	−84	−90	−67
	0 vs. 1 TE	0.018	0.0068	0.0008	0.011	NS
	0 vs. 2 TE	0.01	0.005	0.0007	0.006	NS
	1 vs. 2 TE	NS	NS	NS	NS	NS
Centipedegrass	1 TE	−28	−51	−64	−54	−50
	2 TE	−32	−48	−72	−62	−53
	0 vs. 1 TE	0.037	0.019	0.029	NS	0.036
	0 vs. 2 TE	0.029	NS	0.018	NS	NS
	1 vs. 2 TE	NS	NS	NS	NS	NS

1) Linear contrast between untreated control and treatments, and their respective P-values

2) Means for vertical growth were based on six samples per plot, measured as the difference in weekly vertical growth.

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

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

5) NT = nontreated control.

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

applications suppressed common bermudagrass 5 to 7 weeks. Our results show that single TE application at 0.38 kg ha^{-1} in summer also suppressed seeded-type bermudagrass effectively for seven weeks. A single TE application was reported to suppress the 'Diamond' zoysiagrass vertical growth by 76 % in the shade (Qian and Engelke 1999). We also observed 79 % VGS at 4 WAIT on zoysiagrass plots receiving a single summer TE application. It was reported that one application of TE at 0.8 kg ha^{-1} effectively suppressed vegetative growth of bahiagrass for 4 WAIT (JOHNSON 1990), and centipedegrass for 8 WAIT (JOHNSON 1992b). In our study, a single TE treatment at about half of this rate suppressed bahiagrass for eight weeks and centipedegrass for five weeks. JOHNSON (1992b) also reported that sequential TE application at 0.4 kg ha^{-1} on centipedegrass suppressed growth so that mowing was not needed for 10 weeks. With similar sequential TE rates, we observed that centipedegrass growth was suppressed over 36 % for 10 weeks, which may nullify the need to mow. Sequential TE application on 17 July (4 WAIT) resulted in extending VGS period for 3 weeks for bermudagrass, buffalograss, zoysiagrass, and bahiagrass, and for 5 weeks for seashore paspalum and centipedegrass beyond the effect of single application (Table 1). Seashore paspalum was reported to show up to 96 % reduction in growth with sequential summer treatment (FERRELL et al. 2003), and we observed up to 69 % growth suppression with similar TE rate and timing in summer. Overall, the highest VGS occurred in centipedegrass and the lowest in buffalograss. The significant post-inhibition-growth enhancement, where growth is suppressed for four to six weeks but in the absence of followup applications growth surge above normal levels, was only observed on buffalograss at 12 and 14 WAIT with the sequential application.

A single fall TE application on 8 October in 2006 and 6 October in 2007 resulted in inhibition of vertical growth at all evaluation dates (Table 2). The mean inhibition rate ranged from 44 to 65 % with a single TE application, and from 48 to 72 % with sequential TE applications made in early November. Zoysiagrass was fully dormant at 9 WAIT. Both the amount and duration of VGS were higher with fall TE treatments compared to summer treatments. The post-inhibition-growth enhancement was not observed in the fall treatments. There was significant difference between the control and single or sequential TE treatments, but not between the single and two applications for VGS on most evaluation dates. However, the amount of growth suppression in fall was always greater than that in summer. FAGERNESS et al. (2002) also observed greater growth suppression at lower temperatures, which may have been due to a longer half-life of TE in cooler temperatures (BEASLEY et al. 2005), or that TE catabolism was reduced or the TE was simply more effective with slower growth as suggested by FAGERNESS et al. (2002).

Clipping Production

Averaged over all species and cultivars, clipping production was suppressed up to 72 % following the single summer TE application. In other studies, summer TE treatment reduced clipping yields of St. Augustinegrass by 63 % (MCCARTY et al. 2004), and six dwarf-type bermudagrasses by 46 to 69 % (MCCULLOUGH et al. 2005). Overall clipping yield throughout the 15 WAIT were 21 and 39 % lower than control plots with single and sequential TE application, respectively. The highest rate of suppression was on the second and third weeks of post-TE treatments for both single and sequential applications (Table 3). Clipping yield suppression was significant for five weeks after initial application and the sequential treatment of TE at 4 WAIT resulted in extension of the clipping suppression period through 9 WAIT, after which growth rates increased to that of the non-treated controls. The percent suppression of sequential application was significantly higher than that of single application from 5 to 9 WAIT. There were non-significant post-inhibition growth enhancements

Table 3. The influence of summer trinexapac-ethyl (TE) application on warm-season grass species clipping yield in 2007, Antalya, Turkey.

Treatm./ Contrast[1]	Weeks After Initial Treatment													
	1	2	3	4	5	6	7	8	9	10	11	12	14	15
	Dry weight reduction of clippings (% of untreated control)[2]													
1 TE[3]	−47	−72	−67	−41	−22	−3	4	11	14	16	−3	21	17	26
2 TE[4]	−47	−71	−65	−42	−60	−62	−55	−30	−12	1	−4	20	13	18
0[5] *vs.* 1 TE	0.007	0.003	0.002	0.0006	0.04	NS[6]	NS	NS	NS	NS	NS	NS	NS	0.03
0 *vs.* 2 TE	0.007	0.003	0.002	0.0005	0.0004	0.0002	0.0020	0.04	NS	NS	NS	NS	NS	NS
1 *vs.* 2 TE	NS	NS	NS	NS	0.004	0.0003	0.0012	0.028	NS	NS	NS	NS	NS	NS

1) Linear contrast between untreated control and treatments, and their respective P-values

2) Percent change = 100*[(single TE or sequential TE – nontreated control)/(nontreated control)]

3) 1 TE = Single TE application was made at 0.38 kg ha^{-1} on 18 June 2007.

4) 2 TE = Sequential TE application was made four weeks after single application at 0.38 kg ha^{-1} on 17 July 2007.

5) 0 TE = NT = nontreated control.

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

Table 4. The influence of Fall trinexapac-ethyl (TE) application on warm-season grass species clipping yield averaged over 2006 and 2007, in Antalya, Turkey.

Treatm./ Contrast[1)]	Weeks After Initial Treatment (WAIT)				
	1	3	5	7	9
	Dry weight reduction of clippings (% of untreated control)[2)]				
1 TE[3)]	−36	−78	−92	−86	−68
2 TE[4)]	−39	−78	−93	−91	−80
0[5)] vs. 1 TE	0.0018	0.0016	0.0004	0.0006	0.0001
0 vs. 2 TE	0.0014	0.0016	0.0004	0.0005	0.0001
1 vs. 2 TE	NS[6)]	NS	NS	NS	NS

1) Linear contrast between untreated control and treatments, and their respective P-values

2) Percent change = 100*[(single TE or sequential TE − nontreated control)/(nontreated control)]

3) 1 TE = Single TE applications were made at 0.38 kg ha^{-1} on 8 October 2006 and 6 October 2007.

4) 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.

5) 0 TE = NT = nontreated control.

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

from 8 to 15 WAIT for a single application and 12 to 15 WAIT for sequential application in summer (Table 3).

In the fall TE treatments, clipping production was suppressed at all evaluation dates, up to 92 %, following both single and sequential applications (Table 4). However, mean suppression over the 9 week period were 65 and 67 % lower than control plots with single and sequential TE treatments, respectively. The warm-season grasses could not recover from suppressive effect of TE 9 WAIT in the fall. Growth suppression by TE was more effective and persistent in the fall than in summer. Comparison of total seasonal clipping production for the warm-season turfgrasses showed that summer TE treatments significantly reduced the clipping yield for 5 to 9 weeks with single or sequential applications, followed by slight post-inhibition-growth enhancement. Clipping reduction in fall with both treatments was greater and longer than in summer.

In summary, TE treatments in summer and fall resulted in different responses for growth suppression. The difference may be attributed to TE × temperature interactions. The TE effects were positive at higher temperatures with slower growth and reduced mowing need without compromising from colour and quality after recovering initial negative impact. In the fall at lower temperatures, TE significantly extended the dormancy period of the warm-season turfgrasses by both shortening fall colour retention and delaying spring green-up (Severmutlu et al. 2012). Growth suppression effect was more pronounced with fall treatments than in summer due probably to differences in metabolic activity and half-life of TE at different temperatures. Mowing can be reduced over 60 % for most warm-season turfgrass species with sequential TE application in summer under Mediterranean conditions. Application of TE in the fall can result in decreased competitiveness with broadleaf weeds because of the slower growth and earlier dormancy. However, this response may be advantageous in turf areas where winter overseeding is practiced. Fall TE application would reduce competiveness of bermudagrass and help transition to cool season species. Slower growth and decreased competiveness are indicated as the mechanistic basis for enhanced transition to an overseeded cool-season species (Fagerness et al. 2002).Therefore, TE application in fall may be a useful management tool for managers who practice winter overseeding on bermudagrass and seashore paspalum turfgrass species.

In conclusion, for most of the warm-season species, a 4 to 5 week sequential application schedule would be necessary to achieve significant and continuous growth reduction during summer months.

Acknowledgement

We extend special thanks to Drs. R.E. Gaussoin, Dept. of Agronomy and Horticulture, Univ. of Nebraska, and T. Heng-Moss, Dept. of Entomology, Univ. of Nebraska for critically reviewing the manuscript and Dr. K. M. Eskridge, Dept. of Statistics, Univ. of Nebraska, for his advice in statistical analysis

References

Baker, R.D., L.B. McCarty, D.L. Colvin, J.M. Higgins, J.S. Weinbrecht and J.E. Moreno 1999: Bahiagrass (*Paspalum notatum*) seedhead suppression following consecutive yearly applications of plant growth retardants. Weed Tech. **13**, 378–384.

Beasley, J.S., B.E. Branham and L.M. Ortiz-Ribbing 2005: Trinexapac-ethyl affects Kentucky bluegrass root architecture. HortScience **40**, 1539–1542.

Bunnell, B.T., L.B. McCarty and W.C. Bridges 2005: 'TifEagle' bermudagrass response to growth factors and mowing height when grown at various hours of sunlight. Crop Sci. **45**, 575–581.

Carson, P.L. 1980: Recommended potassium test. Recommended chemical soil test procedures for the North Central Region. North Dakota Agr. Exp. Stanci. Bulletin **499**, 17–18.

Ervin, E.H. and A.J. Koski 2001: Kentucky bluegrass growth responses to trinexapac-ethyl, traffic, and nitrogen. Crop Sci. **41**, 1871–1877.

Ervin, E.H., C.H. Ok, B.S. Fresenburg and J.H. Dunn 2002: Trinexapac-ethyl restricts shoot growth and prolongs stand density of 'Meyer' zoysiagrass fairway under shade. HortScience **37**, 502–505.

Ervin, E.H. and X.Z. Zhang 2007: Influence of sequential trinexapac-ethyl applications on cytokinin content in creeping bentgrass, Kentucky bluegrass, and hybrid bermudagrass. Crop Sci. **47**, 2145–2151.

Fagerness, M.J. and F.H. Yelverton 2000: Tissue production and quality of 'Tifway' bermudagrass as affected by seasonal application patterns of trinexapac-ethyl. Crop Sci. **40**, 493–497.

Fagerness, M.J., F.H. Yelverton, D.P. Livingston and T.W. Rufty 2002: Temperature and trinexapac-ethyl effects on bermudagrass growth, dormancy, and freezing tolerance. Crop Sci. **42**, 853–858.

Ferrell, J.A., T.R. Murphy, R.R. Duncan and W.K. Vencill 2003: Seashore paspalum response to trinexapac-ethyl and paclobutrazol. HortScience **38**, 605–606.

Golembiewski, R.C. and T.K. Danneberger 1998: Dollar spot severity as influenced by trinexapac-ethyl, creeping bentgrass cultivar, and nitrogen fertility. Agron. J. **90**, 466–470.

Goss, R.M., J.H. Baird, S.L. Kelm and R.N. Calhoun 2002: Trinexapac-ethyl and nitrogen effects on creeping bentgrass grown under reduced light conditions. Crop Sci. **42**, 472–479.

Hartley, H.O. 1950: The maximum F-ratio as a shortcut test for heterogeneity of variance. Biometrika **37**, 308–312.

Heckman, N.L., G.L. Horst, R.E. Gaussoin and K.W. Frank 2001: Storage and handling characteristics of trinexapac-ethyl treated Kentucky bluegrass sod. HortScience **36**, 1127–1130.

Heckman, N.L., R.E. Gaussoin, G.L. Horst and C.G. Elowsky 2005: Growth regulator effects on cellular characteristics of two turfgrass species. Intl. Turfgrass Soc. Res. J. **10**, 857–861

Hongfei, J. and J. Fry 1998: Drought responses of perennial ryegrass treated with plant growth regulators. HortScience **33**, 270–273.

Jiang, H.F. and J. Fry 1998: Drought responses of perennial ryegrass treated with plant growth regulators. HortScience **33**, 270–273.

Johnson, B.J. 1990: Response of Bahiagrass (*Paspalum notatum*) to plant-growth regulators. Weed Tech. **4**, 895–899.

Johnson, B.J. 1992a: Response of Bermudagrass (*Cynodon* spp.) to CGA-163935. Weed Tech. **6**, 577–582.

Johnson, B.J. 1992b: Response of Centipedegrass (*Eremochloa ophiuroides*) to plant-growth regulators. Weed Tech. **6**, 113–118.

Johnson, B.J. 1993: Frequency of plant-growth regulator and mowing treatments – Effects on injury and suppression of Centipedegrass. Agron. J. **85**, 276–280.

Johnson, B.J. 1994: Influence of plant-growth regulators and mowing on 2 Bermudagrasses. Agron. J. **86**, 805–810.

Lickfeldt, D.W., D.S. Gardner, B.E. Branham and T.B. Voigt 2001: Implications of repeated trinexapac-ethyl applications on Kentucky bluegrass. Agron. J. **93**, 1164–1168.

McCarty, L.B., J.S. Weinbrecht, J.E. Toler and G.L. Miller 2004: St. Augustinegrass response to plant growth retardants. Crop Sci. **44**, 1323–1329.

McCullough, P.E., H.B. Liu and L.B. McCarty 2005: Response of six dwarf-type bermudagrasses to trinexapac-ethyl. HortScience **40**, 460–462.

McCullough, P., H.B. Liu, L.B. McCarty, T. Whitwell and J. Toler 2006a: Nutrient allocation of 'TifEagle' bermudagrass as influenced by trinexapac-ethyl. J. Plant Nutr. **29**, 273–282.

McCullough, P.E., L.B. McCarty and H.B. Liu 2006b: Response of 'TifEagle' bermudagrass (*Cynodon dactylon* × *C. transwalensis*) to fenarimol and trinexapac-ethyl. Weed Tech. **20**, 1–5.

McCullough, P.E., H.B. Liu, L.B. McCarty, T. Whitwell and J.E. Toler 2006c: Bermudagrass putting green growth, color, and nutrient partitioning influenced by nitrogen and trinexapac-ethyl. Crop Sci. **46**, 1515–1525.

McCullough, P.E., H.B. Liu, L.B. McCarty and J.E. Toler 2007: Trinexapac-ethyl application regimens influence growth, quality, and performance of Bermuda grass and creeping bentgrass putting greens. Crop Sci. **47**, 2138–2144.

Qian, Y.L., M.C. Engelke, M.J.V. Foster and S. Reynolds 1998: Trinexapac-ethyl restricts shoot growth and improves quality of 'Diamond' zoysiagrass under shade. HortScience **33**, 1019–1022.

Qian, Y.L. and M.C. Engelke 1999: Influence of trinexapac-ethyl on diamond zoysiagrass in a shade environment. Crop Sci. **39**, 202–208.

Rademacher, W. 2000: Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Ann. Rev. Plant Physiol. Plant Mol. Biol. **51**, 501–531.

Richardson, M.D. 2002: Turf quality and freezing tolerance of 'Tifway' bermudagrass as affected by late-season nitrogen and trinexapac-ethyl. Crop Sci. **42**, 1621–1626.

SAS Institute 1999: SAS/STAT user's guide. Release 8.0. SAS Ins. Cary, NC.

Severmutlu, S., N. Mutlu, E. Gurbuz, R.C. Shearman and T.P. Riordan 2012: Effects of Seasonal Trinexapac-Ethyl Application on Warm-season Turfgrass color, quality and spring green-up under Mediterranean Environment. Europ. J. Hort. Sci. **77**, 226–236.

Steinke, K. and J.C. Stier 2003: Nitrogen selection and growth regulator applications for improving shaded turf performance. Crop Sci. **43**, 1399–1406.

Watschke, T.L. and J.M. Dipaola 1995: Plant growth regulators. Golf Course Manag. **63**, 59–62.

Received 10/17/2011 / Accepted 03/01/2012

Addresses of authors: Songul Severmutlu (corresponding author), Dept. of Landscape Architecture, and Nedim Mutlu, Dept. of Agricultural Biotechnology, University of Akdeniz, Antalya, Turkey; Ercan Gürbüz and Bati Akdeniz, Agricultural Research Institute, Antalya, Turkey; Robert C. Shearman and Terrance P. Riordan, Dept. of Agronomy and Horticulture, University of Nebraska-Lincoln, U.S.A., e-mail (corresponding author): songulmutlu@akdeniz.edu.tr.