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Trinexapac-ethyl Restricts Shoot Growth and Prolongs Stand Density of 'Meyer' Zoysiagrass Fairway Under Shade

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Abstract. **'Meyer' zoysiagrass (*Zoysia japonica* Steud.) is a popular turfgrass species for transition zone golf course fairways and tees because it is generally winter hardy while providing an excellent playing surface with minimal chemical and irrigation inputs. However, its functionality declines readily on many of the shaded areas on these courses. Reduced irradiance causes excessive shoot elongation, reduced tillering, and weak plants that are poorly suited to tolerate or recover from traffic and divoting. Trinexapac-ethyl (TE) effectively reduces gibberellic acid (GA) biosynthesis and subsequent shoot cell elongation. The objective of this study was to determine if monthly applications of TE would reduce shoot elongation of 'Meyer' zoysiagrass and improve stand persistence under two levels of shade. Shade structures were constructed in the field that continuously restricted 77% and 89% irradiance. A mature stand of 'Meyer' was treated with all combinations of three levels of shade (0%, 77%, and 89%) and three levels of monthly TE application [0, 48 g·ha^{-1} a.i. (0.5×), and 96 g·ha^{-1} a.i. (1×)] in 1998 and 1999. In full sun, the 0.5×-rate reduced clipping production by 17% to 20% over a four-week period and the 1×-rate by 30% to 37%. Monthly application of TE at the 1×-rate increased 'Meyer' tiller density in full sun and under 77% shade. Both rates of TE consistently reduced shoot growth under shade relative to the shaded control. Only the monthly applications at the 1×-rate consistently delayed loss of quality under 77% shade. The zoysiagrass persisted very poorly under 89% shade whether treated or not with TE and plots were mostly dead at the end of the experiment. Our results indicate TE can be an effective management practice to increase 'Meyer' zoysiagrass persistence in shaded environments. Chemical name used: 4-cyclopropyl-α-hydroxy-methylene-3,5-dioxo-cyclohexanecarboxylic acid ethyl ester (trinexapac-ethyl)**

Up to 25% of the turf managed in the U.S. is shaded (Dudeck and Peacock, 1992; Beard, 1973). Reduced light intensity has a number of deleterious morphological and physiological consequences. These include increased shoot-to-root ratios, decreased specific leaf weight, thinner leaf blades, decreased photosynthesis, decreased carbohydrate production, and less tillering (Qian and Engelke, 1999; Qian et al., 1998; Dudeck and Peacock, 1992; Kephart et al., 1992).

Cool-season (C3) grasses are generally more shade tolerant than C4 grasses, with light saturation points at ≈50% and 100% of full sunlight, respectively (Salisbury and Ross, 1992; Danneberger, 1993). Growth and persistence of C3 turfgrasses has been reported at irradiance levels between 5% to 20% of full sunlight (Beard, 1965; Stier et al., 1999), while some *Zoysia* and *Cynodon* species and varieties have been reported to persist with a minimum acceptable quality at 10% to 40% full sunlight (Qian and Engelke, 1999; Riffell et al., 1995; McBee and Holt, 1966).

Increased biosynthesis of GA has been associated with excessive shoot elongation of field pea (*Pisum sativum* L.) (Gawronska et al., 1995) and Kentucky bluegrass (*Poa pratensis* L.) (Tan and Qian, 2000) in response to low light intensity. Promotion of shoot elongation due to increased GA concentration is a common shade avoidance mechanism of plants, but is a net-energy losing response in turfgrass where such increased leaf area is regularly removed by mowing. This response coupled with a number of other factors such as reduced photosynthesis, reduced rooting, greater tissue succulence, and increased susceptibility to damage from pests imply that shaded portions of zoysiagrass golf course fairways and tees are poorly suited to tolerate or recover from traffic and divoting.

Trinexapac-ethyl (TE) is an effective anti-gibberellic acid type plant growth retardant (PGR) that blocks the 3b-hydroxylase production of GA_1 (Adams et al., 1992) and markedly reduces shoot growth of cool- and warm-season turfgrass species (Ervin and Koski, 1998, 2001; Fagerness and Penner, 1998; Wiecko, 1997, Johnson, 1993, 1994). Use of TE on shaded turf should reduce GA_1 biosynthesis and shoot elongation resulting in conserved photosynthate and greater quality maintenance. In greenhouse and polyhouse studies with shaded Diamond zoysiagrass [*Zoysia matrella* (L.) Merr.] Qian et al., 1998 and Qian and Engelke (1999) reported reduced shoot growth and greater canopy photosynthesis, nonstructural carbohydrates, tiller density, root mass, and quality due to TE treatment. Greatest turf quality under 85% to 90% shade was reported when Diamond zoysiagrass received monthly treatments of TE at 48 g·ha^{-1} a.i. Four years of testing at a live oak [*Quercus virginiana* (Mill.)] site in Texas that provided ≈90% shade indicated that *Z. matrella* genotypes maintained 52% to 75% cover, while the commercial standard—*Z. japonica* 'Meyer'—maintained only 27% cover (Riffell et al., 1995). Given this information, our hypothesis was that TE would improve the persistence of shaded, field-maintained 'Meyer' zoysiagrass, but further information was needed on the limits of 'Meyer''s shade tolerance and the best TE rates for extending those limits. Thus, our objectives were to determine if TE would improve the shade tolerance of field-maintained, fairway-height 'Meyer' zoysiagrass and, if so, which TE rate would be most effective.

Materials and Methods

This study was conducted on a mature stand of 'Meyer' zoysiagrass managed as a fairway at the Univ. of Missouri Turfgrass Research Center. The experimental area was irrigated once a week to replace 100% of estimated evapotranspiration and supplied with N at 49 kg·ha^{-1} from urea in June and August of each year. The experimental 'Meyer' fairway had been in place at least 15 years over a Mexico silt loam (fine, montmorillonitic, mesic Mollic Endoaqualfs) with a pH of 6.5, organic matter of 4.9%, 92 kg·ha^{-1} P, and 442 kg·ha^{-1} K. The study consisted of two factors and four replications arranged in randomized complete blocks. The two factors were shade level and TE rate. Shade levels were: 0% shade, 73% shade cloth, and 92% shade cloth (Stuppy Greenhouse Manufacturing, Kansas City, Mo.). These shade levels were selected based on two factors. First, previous research by Qian and Engelke, indicated that *Zoysia matrella* 'Diamond' persisted under 73% shade without TE-treatment and up to 88% shade when treated monthly with TE. Second, measurements made on shaded and thinning 'Meyer' zoysiagrass fairways on golf courses in the Saint Louis area indicated that many of these fairways were in 90% shade for large portions of the day (Ervin, unpublished data). For the purposes of this study, the 73% treat-

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ment was considered a moderately-heavy shade level, while the 92% was considered heavy shade.

Trinexapac-ethyl rates were: 0, 48 g·ha^{-1} a.i. (0.5×-rate), and 96 g·ha^{-1} a.i. (1×-rate). The 36 experimental units (4 × 3 × 3) were 2.1 m × 1.5 m each, separated by a 1.5 m border. Shade cloths were mounted on copper pipe frames and supported 76 cm above the turf canopy. The shade cloth was draped on all sides down to 15 cm above the turf canopy to prevent the effect of incline light. To quantify relative shade levels, photon flux densities in μmol·m^{-2}·s^{-1} were taken with a quantum radiometer (model LI-190SA; LI-COR, Lincoln, Nebr.) from 1100 to 1400 HR on four cloud free days: 20 Aug. 1998, 26 Sept. 1998, 14 June 1999, and 21 Aug. 1999.

Shade and monthly TE treatments began simultaneously on 14 Aug. 1998. The second TE application was on 13 Sept. 1998. Shade structures were removed on 15 Nov. 1998 to correspond with deciduous leaf fall. Shade structures were replaced on 1 May 1999 and remained until 1 Oct. 1999. The TE treatment dates in 1999 were: 28 May, 25 June, 23 July, and 20 Aug.

Turf quality was visually assessed monthly on a 1 (poorest) to 9 (best) scale; ratings of <6 were considered unacceptable. The estimation of turf quality was based on the primary components of color, density, texture, and uniformity of the zoysiagrass surface.

To determine clipping yield, a 0.6-m^2 swath was cut weekly with a standard reel-type greens-mower at 16 mm, clippings were collected, dried for 24 h at 70 °C, and weighed. Weekly clipping weight data are presented, in g·m^{-2}, as the deviation from that of the full-sun control. Lines connecting data points do not represent actual or mathematically predicted data. These artificially smoothed lines have merely been added by the computer software (SigmaPlot 2000; SPSS, Chicago) so as to provide the reader with a sense of week to week clipping yield dynamics. Shade structures were removed once a week for ≈2 h to facilitate mowing, traffic, and irrigation. Immediately following weekly mowing, and prior to the irrigation event, each experimental unit received 10 evenly distributed golf cart passes. The golf cart has smooth turf tires, was driven at a moderate speed (≈2.7 m·s^{-1}), and weighs 270 kg. Golf cart traffic was applied to all plots in an attempt to make the results of this research more applicable to actual golf course fairway conditions.

Tiller number was determined after using a core sampler (7 cm in diam.) to remove two cores per plot on 17 Aug. 1998 (initial), 02 June 1999, and 09 Aug. 1999. Immediately after harvesting, cores were cut along the soil/thatch interface and tiller numbers were counted.

Average photon flux densities during clear-sky conditions (in μmol·m^{-2}·s^{-1}) were 1634 on unshaded plots, 371 under 73% shade cloth, and 176 under 92% shade cloth. These values correspond to 0% shade, 77% shade, and 89% shade, respectively and will be used to designate the shade levels in this study. Qian and Engelke (1999) reported a light compensation point of 270 μmol·m^{-2}·s^{-1} for *Zoysia matrella* grown under 86% shade. If this value is representative of the light compensation point for *Zoysia japonica*, we would predict that under continuous clear sky conditions the 77% plots would be able to maintain a positive energy balance, while the 89% plots would not.

Analysis of variance was conducted on turf quality, clipping dry weight, and tiller number data for this standard 3 × 3 factorial with the Michigan State Statistical Program v. 2.10 (MSTAT-C, 1993). Treatment means were separated using Fisher's protected least significant difference (LSD).

Results and Discussion

In full sun conditions, the 1×-rate of TE reduced clipping dry weight at 1, 2, 4, 5, 7, and 8 weeks after initial treatment (WAIT) from Aug. to Oct. 1998 (Fig. 1). Overall during this period, clippings were reduced by an average of 37%. As expected, the 0.5× rate did not have as strong an effect as the 1×-rate, reducing clippings at 1, 7, and 8 WAIT. Average reduction over this period was 17%. Similar results were found from June to Aug. 1999, where the 1×-rate reduced clippings at 6, 7, 8, 9, 10, and 11 WAIT and the 0.5×-rate at 6, 7, and 10 WAIT (Fig. 2). As has been reported for other turfgrass species, largest growth suppression generally occurs 2 to 3 weeks after each TE treatment (Ervin and Koski, 1998, 2001; Fagerness and Penner, 1998; Wiecko, 1997).

Under continuous 77% and 89% shade, 'Meyer' that was not treated with TE exhibited a large flush of shoot growth relative to the full sun control from Aug. to Oct. 1998, peaking at 2 weeks after shade was imposed (Fig. 3 and 4).

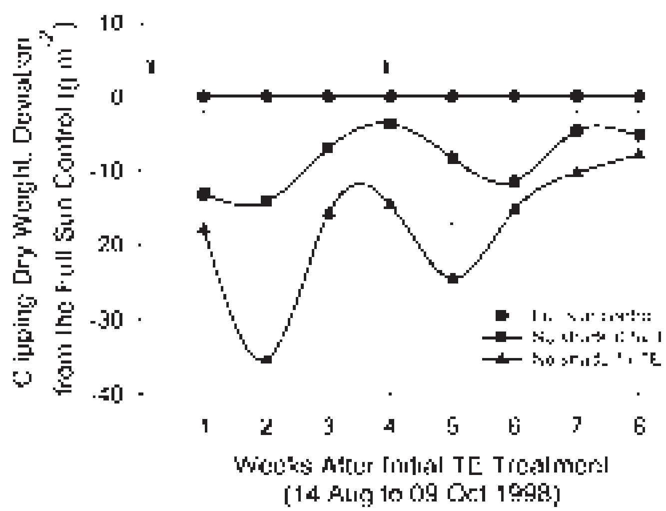

Fig. 1. Clipping dry weight response effected by 0.5× and 1× rates of trinexapac-ethyl (TE) and the control on 'Meyer' zoysiagrass in the field from 14 Aug. to 9 Oct. 1998. Vertical bars represent $LSD_{0.05}$ and arrows indicate TE applications; lines between data points have been smoothed, they are not splined curves.

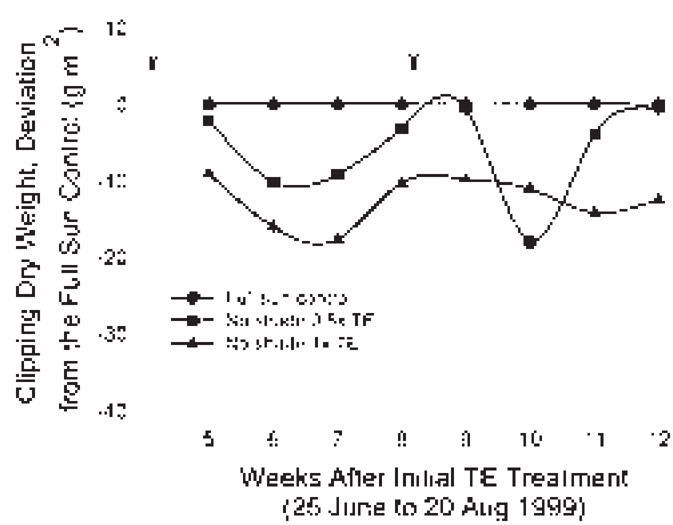

Fig. 2. Clipping dry weight response effected by 0.5× and 1× rates of trinexapac-ethyl (TE) and the control on 'Meyer' zoysiagrass in the field from 25 June to 20 Aug. 1999. Vertical bars represent $LSD_{0.05}$ and arrows indicate TE applications; lines between data points have been smoothed, they are not splined curves.

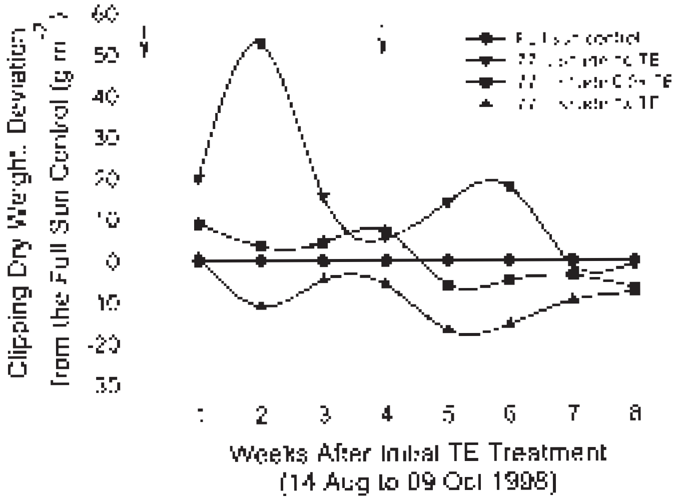

Fig. 3. Clipping dry weight response effected by the interaction of 77% shade and 0.5× and 1× rates of trinexapac-ethyl (TE) and the controls on 'Meyer' zoysiagrass in the field from 14 Aug. to 9 Oct. 1998. Vertical bars represent $LSD_{0.05}$ and arrows indicate TE applications; lines between data points have been smoothed, they are not splined curves.

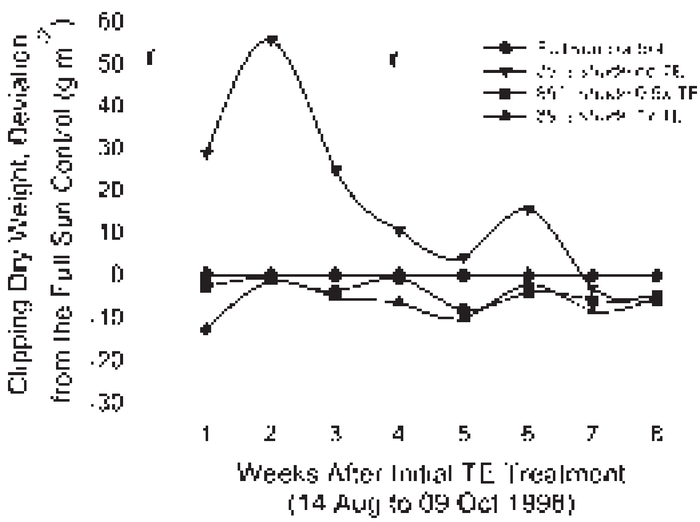

Fig. 4. Clipping dry weight response effected by the interaction of 89% shade and 0.5× and 1× rates of trinexapac-ethyl (TE) and the controls on 'Meyer' zoysiagrass in the field from 14 Aug. to 9 Oct. 1998. Vertical bars represent $LSD_{0.05}$ and arrows indicate TE applications; lines between data points have been smoothed, they are not splined curves.

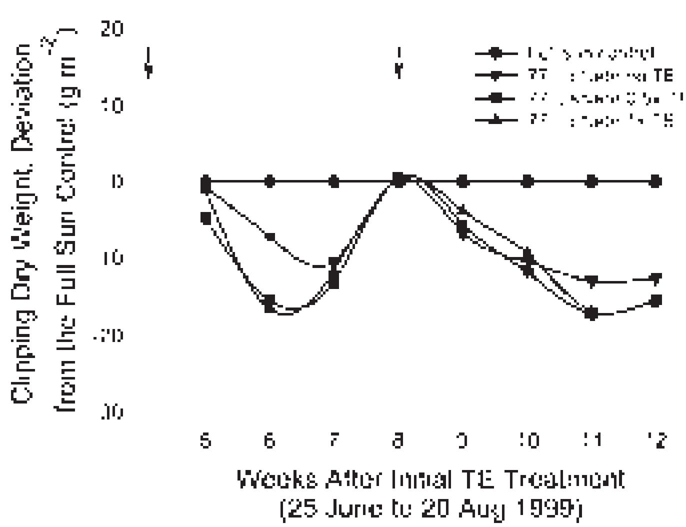

Fig. 5. Clipping dry weight response effected by the interaction of 77% shade and 0.5× and 1× rates of trinexapac-ethyl (TE) and the controls on 'Meyer' zoysiagrass in the field 25 June to 20 Aug. 1999. Vertical bars represent $LSD_{0.05}$ and arrows indicate TE applications; lines between data points have been smoothed, they are not splined curves.

Clipping production remained enhanced from 2 to 6 WAIT under 77% shade and from 1 to 4 WAIT under 89% shade. This expected response was most likely due to increased endogenous GA_1 levels in reduced light, as has been demonstrated recently for Kentucky bluegrass (Tan and Qian, 2000). Growth enhancement under 77% and 89% shade and no TE subsided at 7 WAIT, perhaps indicating a point where energy reserves had been largely depleted.

Trinexapac-ethyl significantly reduced shoot growth at the 1×-rate from 2 to 8 WAIT and 1 to 5 WAIT under 77% and 89% shade, respectively in 1998 (Figs. 3 and 4). Shoot growth of the TE-treated zoysia under 77% and 89% shade was less than or equal to the full sun control for the entire 8-week period. Thus, much energy-consuming shoot growth was eliminated by the use of TE on shaded 'Meyer' zoysiagrass.

From 1 to 4 WAIT in 1999 (28 May to 24 June), clipping production responses were similar to those reported during 1998 (data not shown). For example, in full sun, the 1× TE rate reduced clipping dry weight by an average of 30%, while under 77% shade, clipping production was increased by 20% (no TE) or unchanged (1× TE). Compared to the 1998 data where shade treatment without TE increased growth for up to 6 WAIT, growth enhancement only persisted for 4 WAIT in 1999. These results are most likely an indication of the cumulative energy depleting effects of shade treatment and traffic. This energy depletion supposition is supported by data from 5 to 12 WAIT in 1999, where 'Meyer' clipping production was reduced by similar amounts relative to the full sun control under both levels of shade whether treated with TE or not (Figs. 5 and 6). Both the 1998 and 1999 clipping production data indicate that untreated 'Meyer' zoysiagrass under 77% or greater shade begins to have a negative energy balance after continuous shade for eight weeks or longer. The shaded, TE-treated plants may be using energy faster than they can replace under this situation. However, because less energy was expended on shoot growth during the first eight weeks of shade, the duration of adequate stand persistence should be increased. The visual quality and tiller density data support this supposition.

Trinexapac-ethyl had no effect on the visual quality of 'Meyer' in full sun conditions over the course of the study (Table 1). About 8 weeks of shade treatment, however, reduced 'Meyer' quality significantly (9 Oct. 1998). Two applications of TE over this period, on both 77% and 89% shade plots, served to partially alleviate these quality reductions, especially the 1×-rate. By 18 June 1999, following 7 weeks of shade and 3 WAIT, greater quality was maintained at 77% shade due to the 1×-rate of TE. For the remainder of the study, only the 1×-rate under 77% shade retained higher quality relative to the other shaded treatments.

Tiller density counts at the beginning of the study indicated no differences (Table 2). A second assessment, on 2 June 1999, again indicated no clear differences. However, the final assessment on 9 Aug., indicated clear

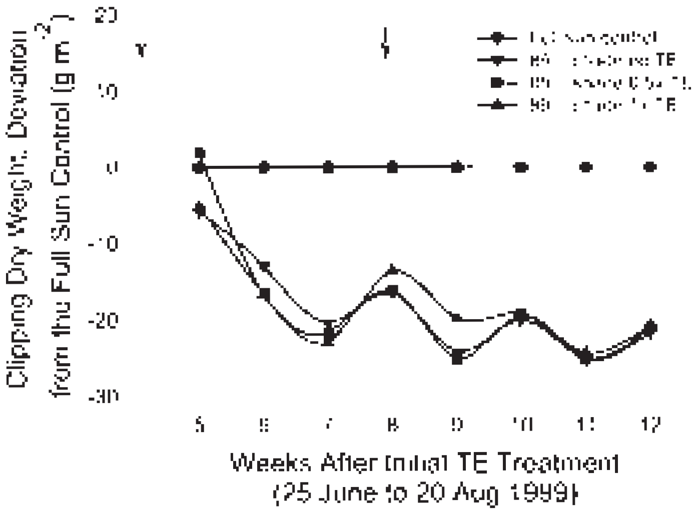

Fig. 6. Clipping dry weight response effected by the interaction of 89% shade and 0.5× and 1× rates of trinexapac-ethyl (TE) and the controls on 'Meyer' zoysiagrass in the field 25 June to 20 Aug. 1999. Vertical bars represent $LSD_{0.05}$ and arrows indicate TE applications; lines between data points have been smoothed, they are not splined curves.

Table 1. Visual quality response of 'Meyer' zoysiagrass to shade and trinexapac-ethyl.

Treatment	15 Aug. 98	09 Oct. 98	18 June 99	18 July 99	23 Aug. 99
	Quality rating (1–9 scale; 9 = best)				
No shade + no TE	7.5	7.5 a	6.9 a	6.0 a	6.3 a
No shade + 0.5× TE	7.5	7.5 a	6.9 a	5.6 a	6.4 a
No shade + 1× TE	7.5	7.4 a	6.8 a	6.3 a	6.0 a
77% shade + no TE	7.5	5.1 de	4.9 c	3.3 c	1.9 c
77% shade + 0.5× TE	7.5	6.3 bc	5.1 bc	3.4 c	2.4 c
77% shade + 1× TE	7.5	6.5 b	5.8 b	4.5 b	3.5 b
89% shade + no TE	7.5	4.3 e	4.5 c	1.6 e	1.0 d
89% shade + 0.5× TE	7.5	5.6 cd	5.0 bc	1.9 de	1.0 d
89% shade + 1× TE	7.5	6.4 b	5.3 bc	2.5 d	1.3 d
$LSD_{0.05}$	NS	0.8	0.8	0.6	1.1

NSNonsignificant.

Table 2. Tiller density response of 'Meyer' zoysiagrass to shade and trinexapac-ethyl.

Treatment	17 Aug. 1998	2 June 1999	9 Aug. 1999
	Tiller density (no. dm^{-2})		
No shade + no TE	204.8	227.6	301.0 b
No shade + 0.5× TE	222.5	256.4	270.3 b
No shade + 1× TE	244.0	232.8	338.0 a
77% shade + no TE	251.6	231.4	45.4 d
77% shade + 0.5× TE	231.4	203.4	63.3 cd
77% shade + 1× TE	211.3	207.9	89.3 c
89% shade + no TE	241.1	222.0	3.3 e
89% shade + 0.5× TE	232.9	249.6	9.3 e
89% shade + 1× TE	231.8	199.8	30.6 de
$LSD_{0.05}$	NS	NS	36.1

NSNonsignificant.

treatment differences. Monthly application of TE at the 1×-rate increased 'Meyer' tiller density in full sun and under 77% shade. Increased tiller density following multiple monthly applications of TE under full sun conditions in the field have been reported for Kentucky bluegrass (Ervin and Koski, 2001). Qian and Engelke (1999) also reported greater maintenance of *Zoysia matrella* tiller density following multiple monthly TE applications under 86% shade in the greenhouse.

Dense shade treatments increased 'Meyer' zoysiagrass clippings for approximately four to six weeks. Shade treatment for six weeks or more resulted in lower shoot growth relative to the full sun control and significant loss of quality due to increased senescence. Monthly 1×-rate applications of the antigibberellic acid PGR, TE, on shaded 'Meyer' zoysiagrass effectively suppressed the promotion of shoot elongation by reduced light intensity and delayed senescence, loss of quality, and tiller thinning. However, TE-treatment still resulted in commercially unacceptable quality levels under 89% shade. Further research is needed investigating lower shade levels (50% to 75%) and the most effective frequency and rates of TE treatment that will enable the maintenance of commercially acceptable 'Meyer' zoysiagrass fairways and tees.

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