Impact of Nitrogen Source and Trinexapac-ethyl Application on Creeping Bentgrass (*Agrostis stolonifera* L.) Physiology under Neutral Shade, Deciduous Tree Shade, and Full Sunlit Conditions

Edward J. Nangle, David S. Gardner¹, James D. Metzger, John R. Street, and T. Karl Danneberger

Department of Horticulture and Crop Science, 2021 Coffey Road, The Ohio State University, Columbus, OH 43210-1086

Additional index words. *Agrostis stolonifera*, Trinexapac ethyl, altered R:FR, shade management, nitrogen source

Abstract. Decreased light quantity or quality affects the growth of turfgrass plants. Shade causes thinning of turfgrass stands and loss in surface quality. Plant changes include increased chlorophyll levels, lower soluble sugars, and loss of canopy cover. The objective of this research was to investigate if applications of foliar nitrogen and trinexapac-ethyl [4-(cyclopropyl- α -hydroxy-methylene)-3,5-dioxo-cyclohexane carboxylic acid ethyl ester] (TE) would result in beneficial biochemical changes in creeping bentgrass (*Agrostis stolonifera* L. cv. Penncross) grown in different shaded environments. Foliar applications of three nitrogen treatments, $(\text{NH}_4)_2\text{CO}$, $\text{Ca}(\text{NO}_3)_2$, or $(\text{NH}_4)_2\text{SO}_4$, were made weekly at 0.43 g N/m^2 . Growth regulator treatments consisted of an untreated control or TE applied biweekly at an a.i. rate of 0.057 kg-ha^{-1} . Plots were established in full sun (FS), neutral shade (NS), and deciduous shade (DS). Chlorophyll content, soluble carbohydrates, flavonoids, clipping yield, and color were measured. Nitrogen treatments caused some variation in levels of soluble carbohydrates in shaded conditions. Chlorophyll (Chl) levels varied between TE treatments, with increased levels of chlorophyll b (Chl b) found in TE-treated plots under FS. Application of TE resulted in higher flavonoid concentrations in leaf tissue in shaded conditions. Repeated applications of $(\text{NH}_4)_2\text{CO}$ significantly improved color ($P = 0.05$). Turfgrass managers maintaining creeping bentgrass in shade may benefit from applications of TE and $(\text{NH}_4)_2\text{CO}$.

Management of turfgrass under NS and DS conditions is difficult. Wear tolerance is reduced as a result of altered plant physiology in response to loss of light. In shaded [NS and DS with photosynthetically active radiation (PAR) less than 90% full sun] conditions there can be lower rates of photosynthetic activity compared with respiration rates (Frantz and Bugbee, 2005), which do not change, causing a decrease in soluble carbohydrate, which may be species-dependent (Beard, 1997; Castrillo et al., 2005; Smith, 1982; Veneklaas and den Ouden, 2005).

Once photosynthetic photon flux (PPF) decreases to a certain point, Chl levels decline rapidly. This results in anatomical, physiological, and morphological plant responses (Beard, 1997; Gardner and Taylor, 2002; Gaussoin et al., 1988; Wilkinson and Beard, 1975). Lower PPF directly changes the internal

leaf structure from thicker mesophyll layers to thinner, wider leaves with larger intercellular spacing in the mesophyll layers (Beard, 1997; Smith, 1982). Plant morphological response to shade is predominantly controlled by the pigment phytochrome (Smith, 1982). Turfgrass photomorphogenic responses such as tillering are affected by PPF to a certain extent, but other characteristics such as increased leaf width and cell ultrastructure are further influenced by changes in the red light:far-red light (R:FR) ratio (Wherley et al., 2005). Anatomical responses include changes in cuticle thickness and decreases in vascular and support tissue in the plant (Wilkinson and Beard, 1975).

The majority of work on turfgrass responses to shade has been carried out under neutral shade canopies, which simulate the percentage of light lost over the period of the day. Neutral density shade does not alter light quality similar to what occurs under tree canopies. Different shade sources cause variation in both intensity and spectral composition of sunlight. There is an increase in far red light found under tree lines (Bell et al., 2000). The alteration has been shown previously on

the levels of red and far red light under the canopy (Bell et al., 2000; Ervin et al., 2002; Goss et al., 2002; Steinke and Stier, 2003; Wherley et al., 2005).

Lower rates of nitrogen (N) fertilization may have beneficial effects on shaded turfgrass canopies (Goss et al., 2002). Excessive amounts of N may decrease carbohydrate levels in the plant, lead to excess shoot succulence, and cause loss of verdure and density (Murphy, 2002; Turgeon, 2008). Excessive levels of N can reduce the availability of carbohydrates, as increased pools of amines occur, increasing synthesis of soluble proteins, which are carbohydrate- and N-rich (Marschner, 1995). Increased levels of tissue N have been found in turfgrass grown in shade suggesting that N use efficiency declines with reduced PPF conditions (Westhafer et al., 1982).

Shade-tolerant plants allocate more N to the thylakoids enhancing light absorption pigment development (Evans, 1989). The form of N delivery may also play a role as timing of granular applications and foliar applications may have different effects. Spring applications of granular N can be successfully combined with summer and fall applications of foliar N on shade-grown turfgrasses (Steinke and Stier, 2003). Different N forms require different levels of adenosine-5'-triphosphate (ATP) for assimilation with ammonium sources requiring less ATP than nitrate sources for amino acid synthesis (Epstein and Bloom, 2005; Marschner, 1995). The assimilation of NO_3^- requires 15% of the root carbon catabolism, whereas NH_4^+ requires only 3% (Bloom et al., 1992; Epstein and Bloom, 2005).

In certain instances combinations of N, sources may prove optimal for grasses (Ruess et al., 1983), whereas in other instances, it has been shown that urea, which has a neutral charge and small size, may be ideally suited to foliar applications (Cook and Boynton, 1952; Impey and Jones, 1960; Wittwer et al., 1963). This may be dependent on rates in turfgrass, because three N sources had negligible differences when applied at high rates to perennial ryegrass (Bowman and Paul, 1992).

On certain species of shade-grown turf, the use of a type II (gibberellin biosynthesis inhibitor) plant growth regulator (PGR) such as TE can delay stand thinning and possibly improve turfgrass growth, color, and Chl content in the plant (Bunnell et al., 2005; Qian and Engelke, 1999; Steinke and Stier, 2003). Trinexapac-ethyl has positive quality effects on turfgrass grown under low PPF conditions (Bunnell et al., 2005; Goss et al., 2002; Qian and Engelke, 1999; Steinke and Stier, 2003). The impact of TE under altered R:FR conditions has been tested only once to date by Gardner and Wherley (2005). Three varieties of turfgrass were used: sheep's fescue (*Festuca ovina* L.), tall fescue [*Schedenorus phoenix* (Scop.) Holub], and rough bluegrass (*Poa trivialis* L.). Applications of TE reduced clipping yields in all environments but the TE effect on clippings was lost by 6 weeks after application. Stand density was increased

Received for publication 28 July 2011. Accepted for publication 9 Jan. 2012.

¹To whom reprint requests should be addressed; e-mail Gardner.254@osu.edu.

by TE only in sheep fescue. This was not consistent with previous research; however, the methods used by Gardner and Wherley (2005) involved the use of a natural tree line creating a reduction in the R:FR ratio.

The use of TE can be possibly detrimental, however; TE exhibits structural similarities to 2-oxoglutaric acid (Rademacher, 2004). The regulator can compete for dioxygenases that are dependent on the 2-oxoglutaric acid for the formation of flavonoids (Rademacher, 2000). This might explain the reported slight phytotoxic effect seen after TE applications (Wiecko and Couillard, 1997). Flavonoid production is induced by far red light and it has been found that ultraviolet light can inhibit their formation (Buchholz et al., 1995). Plants with reduced flavonoids have reduced ability to absorb ultraviolet-B causing the leaf to suffer photodamage (Lau et al., 2006).

The objective of this study was to investigate the impact of N source and TE treatments on creeping bentgrass growth and development under conditions of shaded quality and quantity. Our hypothesis was that an amino-based source in combination with TE would affect creeping bentgrass physiology in a beneficial manner by reducing elongation resulting from shade, thereby delaying loss of surface quality.

Materials and Methods

The research was conducted at The Ohio Turfgrass Foundation Research and Education Center, The Ohio State University, Columbus, OH. Three 21.9 × 5.8-m field plots were excavated to a depth of 25.4 to 30.48 cm in accordance to California greens style construction (Harivandi, 1998) with a modification of adding peat for organic matter on an immature root zone. The plots were backfilled with 80/20 v/v sand/peat medium/fine mix, pH ≈ 7.2 (Oglebay Norton Inc., Columbus, OH), packed, and watered to reduce soil movement. Phosphorous was initially applied at a rate of 15.7 g·m⁻². Three treatment areas of ≈ 1500 m⁻² each were then established in June 2006 with washed creeping bentgrass ‘Pennncross’ (*Agrostis stolonifera* L. cv. Pennncross) sod (H&E Sod Nursery, Momence, IL) and allowed to acclimate for 3 weeks before initiation of routine maintenance and treatments.

Plots were established under the following three light environments: 1) under an east–west-oriented mature native deciduous tree line with an altered R:FR ratio measured using a LI-Cor 1800 spectroradiometer (LI-Cor, Lincoln, NE) (DS = 0.39); 2) black perforated cloth acting as neutral density shade that reduced PPF by ≈ 90% but did not alter the R:FR (NS = 1.28) (Dewitt Co., Sikeston, MO); and 3) under full sun with a similar R:FR (FS = 1.30) within ≈ 20 m of the NS. The three environments were within a 500-m radius of each other. Within each light environment, treatment plots were set up as three rows of randomized complete blocks 1.5 m × 1.8 m for a four N treatment × two TE treatment factorial experiment with the blocking run-

ning north–south. Calcium nitrate Ca(NO₃)₂, ammonium sulfate (NH₄)₂SO₄ urea, or untreated control (control) was applied at a rate of 0.43 g·m⁻² N using a CO₂ backpack sprayer with 6503 Teejet flat fan nozzles (Teejet Inc., Minneapolis, MN) at a pressure of 275.7 kPa at a rate of 815 L·ha⁻¹ to each of the three light environments. This occurred on a weekly basis from June to September in 2006 and May to October in 2007 in a foliar application. Applications of TE at 0.397 L·ha⁻¹ a.i. were made on a 14-d schedule. Applications began 1 week after the first applications of N and TE were applied at the same time as the N treatments thereafter. Treatments were applied from 21 July to Sept. 2006 and 24 May to 11 Oct. in 2007. A CO₂ backpack sprayer with 6503 Teejet flat fan nozzles (Teejet Inc.) at a pressure of 275.7 kPa was used to apply materials at a rate of 815 L·ha⁻¹. The NS shade canopy completely shaded east to west with the canopy on the north and south sides raised 0.75 m off the ground to allow for air movement. The tree line surrounding on east, south, and north of the DS plot was composed of mature hardwoods (mainly *Acer saccharinum* and *Platanus occidentalis*) and reduced PPF (DS) reaching the underlying turf by ≈ 90% and was set 2.5 m above the ground to allow work to proceed unrestricted underneath. The shade structures were removed each year to coincide with leaf fall. The NS structure was vertically constructed with shadecloth laid vertically on top and horizontally on the sides. Under DS, the tree line was directly above the plots reducing light at solar noon with shading from the south, east, and north.

The later start date in 2006 was the result of plot construction. Measurements were taken from 14 July 2006 to 21 Sept. 2006 and again from 15 May 2007 to 26 Oct. 2007. Top dressing [medium/fine mason sand (Kurtz Bros., Columbus, OH)] was applied (0.635 cm·m⁻²) at the end of the 2006 trial to smooth the surface to allow for closer mowing. Plots in 2006 established slower in the shade plots compared with FS, whereas all plots were consistent in 2007 before trial initiation.

Urea (46N–0P–0K) (Andersons Co., Maumee, OH) was applied in a granular form using a rotary spreader (Scotts Co., Marysville, OH) and irrigated in at a rate of 2.5 g·m⁻² during plot establishment to improve bentgrass growth and vigor before shade stress initiation in 2006. Other nutrients [phosphorus (P) and potassium (K)] were applied to prevent any deficiencies in both years based on root zone analysis (Bray P-1 for P and samples were subjected to atomic emission spectrophotometry for K) (CLC Laboratories, Westerville, OH). Urea was again applied in early 2007 at a rate of 3.66 g·m⁻² before initiation of treatments to help improve turfgrass quality and vigor coming out of the first winter season. The plots were all irrigated using 2.54-cm polyethylene aboveground piping and four Hunter PGJ (Hunter Industries Inc., San Marcos, CA) irrigation heads per plot. Irrigation was provided daily to prevent onset of drought stress with schedules of 3 min·d⁻¹ in shaded conditions and 10 total

min in FS. Chlorothalonil (Syngenta AG, Greensboro, NC) (2,4,5,6-tetrachloro-1,3-benzenediacetonitrile) was applied in both years on 14- to 21-d intervals for prevention of dollar spot (*Sclerotinia homeocarpa*) with morning applications, post-mowing. Pro-piconazole [1-[[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]-1H-1,2,4-triazole] Syngenta AG was alternately used with the chlorothalonil. Azoxystrobin [(E)-2-{2-[6-(2-cyanophenoxy) pyrimidin-4-yl]phenyl} 3-methoxyacrylate] (Syngenta AG, Greensboro, NC) was applied for control of pythium (*Pythium*) and brown patch (*Rhizoctonia solani*) in July and August of both years. Imidacloprid (1-[(6-chloro-3-pyridinyl) methyl]-N-nitro-2-imidazolidinimine) was applied in June of both years for cutworm (*Agrotis ipsilon*) and white grub control at a rate of 0.34 mg a.i./92.9 m² and irrigated in.

The daily photosynthetic integral was measured in 2006 and 2007 on each area using PPF (cosine-corrected PAR) quantum sensors (#36681; Spectrum Technologies, Plainfield, IL) with watchdog data loggers (Spectrum Technologies). The three sensors were placed in central areas in all plots ≈ 30 cm above soil surface. The PPF was measured on 15-min intervals from 21 July to 10 Sept. 2006 and from 25 May to 26 Oct. 2007. Spectral distribution for the 400- to 800-nm wavelength range was determined for the three light environments using the portable spectroradiometer LI-Cor 1800. The data were collected six times for each plot hourly over a 3-d period on the summer solstice. The R:FR ratio (Table 1) was calculated using the 10-nm bandwidths surrounding 660 nm (red light) and 730 nm (far red light) (Smith, 1982). The turfgrass canopy was mowed three times weekly from June to September in 2006 and May to October in 2007 to a height of 1.7 cm using a Toro Greensmaster 1000 (Toro Corp., Minneapolis, MN) and clipping yield was completely removed. Clipping yield was collected from a single strip in the middle of each plot 1 d after mowing, dipped in liquid N, and stored at –20 °C in a laboratory freezer (White

Table 1. Daily light intensities and R:FR under three light environments in trials conducted in 2006 and 2007.

Treatment	Avg daily PPF (mol·m ⁻² ·d ⁻¹)	R:FR ^z
Full sun (FS)	39.2	1.30
Neutral density shade (NS)	2.7	1.28
Deciduous shade (DS)	3.1	0.39

^zThe red:far red ratio (R:FR) is the 10-nm bandwidth around 660 nm divided by the 10-nm bandwidth centered around 730 nm (Smith, 1982). Values were collected over 3-d periods surrounding 21 June in 2006 and 2007 at hourly periods and then averaged. Light intensity measurements were taken from 21 July 2006 through 10 Sept. and 25 May through 10 Oct. 2007. Daily PPF was collected with instantaneous measurements every 15 min and then calculated intervals and then calculated for total daily light quantities. PPF = photosynthetic photon flux.

Westinghouse, Martinez, GA). Every other week clipping yield was determined from a single mowing. At the conclusion of each experimental season, the samples were removed from the freezer and dried for a minimum of 48 h at 60 °C and weighed. The samples were then used for carbohydrate, flavonoid, and Chl analysis. Turf plots were rated visually for turf color from June to September in 2006 and May to October in 2007 (1 = yellow, 6 = acceptable, 9 = dark green).

Samples of turfgrass clippings were ground to a fine powder to be analyzed for soluble carbohydrate using an analytical mill (Tekmar Company, Cincinnati, OH) and stored in 25-mL glass vials at -20 °C in the laboratory. Samples of 0.150 g were placed in 15-mL conical tubes and 10 mL of distilled H₂O was added as described by Morris (1948). The solution was vortexed and allowed to incubate for a minimum of 10 min at room temperature. Anthranol reagent was prepared using 0.1 g anthrone (Sigma Aldrich, St. Louis, MO) dissolved in 50 mL of 95% sulfuric acid H₂SO₄ (Fisher Scientific, Pittsburgh, PA). A sucrose (Fisher Scientific) stock solution of 10 mM was prepared, and a standard curve was prepared using 0, 0.25, 0.5, 0.75, 1.0, 1.5, 2.0 µmol·mL⁻¹ of sucrose. Sample absorbance was measured at 620 nm with a UV160U spectrophotometer (Shimadzu, Columbia, MD). Tissue Chl levels were determined as described by Moran (1982) and Moran and Porath (1980). Fresh samples, weighing 0.01 g were placed in 15-mL glass-capped tubes. N,N dimethyl formamide (Sigma Aldrich) was added to a volume of 10 mL and the tubes were placed in the dark at 4 °C for 24 to 48 h. Absorbances were then measured at 664, 647, 625, and 603 nm. Total Chl, Chl a, and Chl b were calculated according to Moran (1982). Chlorophyll content was reported in µg·mg⁻¹. Soluble flavonoids were measured as described by Pourmorad et al. (2006). Turfgrass mowing samples of 0.025 g dry weight were added to 10 mL of methanol and vortexed in 15-mL conical centrifuge tubes. The samples were then centrifuged at 2055 g for 5 min. A standard curve was prepared using quercetin (Sigma Aldrich) solutions at concentrations of 0, 25, 50, 75, and 100 µg·mL⁻¹ in methanol (Sigma Aldrich). Extract was then placed into a tube with 1.5 mL CH₃OH, 0.1 mL of 10% AlCl₃ (Sigma Aldrich) 0.1 mL potassium acetate (Sigma Aldrich) and 2.8 mL distilled H₂O. The absorbance was measured at 415 nm with a UV160U spectrophotometer (Shimadzu). Linear regression analysis was used to determine flavonoid concentration in each sample.

The data were first analyzed by year using two sample *t* tests to determine if data could be pooled (*P* = 0.05). The different light environments were treated as separate locations and analyzed as a combined analysis experiment for each year separately (McIntosh, 1983) with repeated measures on clipping yield over weeks using PROC MIXED to take into account unequal errors resulting from location randomness. Locations were

analyzed separately, although treatments had similar results within the locations (Wherley et al., 2005), and each separate location was tested with the block (treatment) error term. Light was considered as a random variable, whereas fertilizer and TE treatments were considered fixed variables. The F-test for location was analyzed using error from mean square location/mean square (block), whereas analysis of treatments was carried out using mean square light/mean square rep. Least square means were separated using the PDIF option of LSMEANS in SAS PROC MIXED (SAS Institute Inc., Cary, NC). Least significant differences (LSD) at *P* = 0.05 are reported to allow readers to easily make means comparisons. The LSD was computed by multiplying the appropriate *t*-value by the SE of the difference provided in the output from the PDIF option of the LSMEANS statement. Other effects were tested with the residual error (SAS Institute Inc.).

Results

The R:FR ratio was influenced by the tree line (Table 1). Shade levels across the tree line were consistent throughout the day and shade variability within individual subplots exceeded the shade variability between subplots contained in main plots. The light intensities and R:FR ratios among the three light environments varied (Table 1). FS had the highest average daily PPF, whereas the reduction in PPF levels in the shaded areas was similar with NS and DS attaining 6.9% and 7.9% of normal sunlight, respectively. The R:FR values in the FS and NS plots were similar but the R:FR in the DS plot was reduced over threefold, FS/DS = 3.33 and NS/DS = 3.28 (Table 1).

Data analysis indicated that overall in 2006 and 2007 there was a difference (*P* =

0.05) between all the data when pooled together between years and so all data were analyzed separately for light environment and year (Tables 2, 3, 4, 5, and 6). There was no interaction with the exception of color analysis for TE × N (Table 6) and so data are not shown for that analysis.

Chlorophyll totals decreased in all light environments across both years and there was no significant impact from either TE applications or N source on Chl levels on turfgrasses in DS, whereas TE increased Chl b levels in 2007 in FS (Tables 2, 3, and 4). Overall levels of Chl were higher in both the NS and FS environments with lower levels in DS (Tables 2, 3, and 4). There was a decrease in all environments in 2007 with the greatest decrease in total Chl being found in DS, 33% (Table 3). Applications of N influenced Chl a, Chl b, and Chl total levels in NS in 2006 with the control plots having the greatest quantities of the pigment, whereas N sources varied between the years with lower pigment quantities found in 2007 compared with 2006 (Table 4). Creeping bentgrass treated with applications of (NH₂)₂CO or TE had similar pigmentation content to the untreated (Tables 3 and 4). Clipping yield increased in all N treatments from 2006 to 2007, although there was a difference (*P* = 0.05) only between control plots and N-treated plots overall. Applications of TE reduced clipping yield compared with non-TE-treated plots (*P* = 0.05) in either case (Table 2).

In this study in 2006, there was no effect seen within locations in total flavonoids resulting from treatments. In 2007, there was a significant increase in flavonoid levels under FS, DS, and NS compared with 2006 (Table 5). The use of TE resulted in a significant (*P* = 0.05) decrease in flavonoids in the same period

Table 2. Chlorophyll pigment changes and clipping yields in 2006 and 2007 for creeping bentgrass (*Agrostis stolonifera* L.) grown in full sun (FS).

	Date								
	2006	2007	2006	2007	2006	2007	2006	2007	
	Chlorophyll b	Chlorophyll a		Chlorophyll total		Clipping yield			
	(µg·g ⁻¹)				----- (g·m ⁻¹) -----				
N source									
Control	3.6 (0.2) ^z	2.3 (0.1)	9.0 (0.4)	5.5 (0.4)	12.7 (0.5)	9.3 (0.5)	1.8 (0.5)	0.8 (0.2)	
(NH ₂) ₂ CO	3.6 (0.2)	2.3 (0.1)	8.9 (0.4)	5.7 (0.4)	12.4 (0.5)	9.7 (0.5)	2.8 (0.5)	1.6 (0.2)	
(NH ₄) ₂ SO ₄	3.5 (0.2)	2.2 (0.1)	9.3 (0.4)	5.6 (0.4)	12.9 (0.5)	9.4 (0.5)	2.2 (0.5)	1.0 (0.2)	
Ca(NO ₃) ₂	3.3 (0.2)	2.3 (0.1)	8.5 (0.4)	5.3 (0.4)	11.8 (0.5)	9.5 (0.5)	2.6 (0.5)	1.0 (0.2)	
Regulator									
TE	3.5 (0.1)	2.4 (0.1)	9.1 (0.2)	5.6 (0.3)	12.6 (0.3)	9.8 (0.3)	1.8 (0.4)	0.8 (0.1)	
No TE	3.4 (0.1)	2.1 (0.1)	8.8 (0.3)	5.5 (0.3)	12.3 (0.4)	9.1 (0.3)	2.8 (0.4)	1.4 (0.1)	
----- ANOVA -----									
Source	df	<i>P</i> > <i>F</i>							
Error	15								
Year	1	**		**		**		**	
TE	1	NS	**	NS	NS	NS	NS	***	***
N	3	NS	NS ^y	NS	NS	NS	NS	NS	***
TE × N	3	NS	NS	NS	NS	NS	NS	NS	NS

^zSE.

^yNS = nonsignificant (*P* = 0.05).

*Significant (*P* = 0.05); **significant (*P* = 0.001) of Fisher's protected means tests.

N = nitrogen; TE = trinexapac-ethyl [4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxo-cyclohexane carboxylic acid ethyl ester]; ANOVA, analysis of variance.

Table 3. Chlorophyll pigment changes and clipping yields in 2006 and 2007 for creeping bentgrass (*Agrostis stolonifera* L.) grown in deciduous shade (DS).

	Date								
	2006	2007	2006	2007	2006	2007	2006	2007	
	Chlorophyll b		Chlorophyll a		Chlorophyll total		Clipping yield		
	----- (µg·g ⁻¹) -----						----- (g·m ⁻¹) -----		
N source									
Control	2.0 (0.1) ^z	1.2 (0.1)	5.5 (0.3)	2.7 (0.2)	7.6 (0.4)	4.7 (0.4)	0.7 (0.1)	1.2 (0.2)	
(NH ₂) ₂ CO	2.2 (0.1)	1.2 (0.1)	5.6 (0.3)	3.3 (0.2)	7.9 (0.4)	5.4 (0.4)	0.6 (0.1)	1.9 (0.2)	
(NH ₄) ₂ SO ₄	2.0 (0.1)	1.2 (0.1)	5.3 (0.3)	3.0 (0.2)	7.3 (0.4)	5.1 (0.4)	0.5 (0.1)	1.6 (0.2)	
Ca(NO ₃) ₂	2.1 (0.1)	1.2 (0.1)	5.6 (0.3)	3.1 (0.2)	7.9 (0.4)	5.2 (0.4)	0.4 (0.1)	1.9 (0.2)	
Regulator									
TE	2.1 (0.1)	1.2 (0.1)	5.4 (0.2)	3.1 (0.2)	7.5 (0.3)	5.2 (0.3)	0.4 (0.1)	1.5 (0.2)	
No TE	2.1 (0.1)	1.2 (0.1)	5.7 (0.2)	3.0 (0.2)	7.8 (0.3)	5.1 (0.3)	0.7 (0.1)	1.8 (0.2)	
----- ANOVA -----									
Source	df	<i>P</i> > <i>F</i>							
Error	15								
Year	1	**		**		**		**	
TE	1	NS	NS ^y	NS	NS	NS	NS	**	NS
N	3	NS	NS	NS	NS	NS	NS	**	**
TE × N	3	NS	NS	NS	NS	NS	NS	NS	NS

^zSE.

^yNS = nonsignificant ($P = 0.05$).

*Significant ($P = 0.05$); **significant ($P = 0.001$) of Fisher's protected means tests.

N = nitrogen; TE = trinexapac-ethyl [4-(cyclopropyl- α -hydroxy-methylene)-3,5-dioxo-cyclohexane carboxylic acid ethyl ester]; ANOVA, analysis of variance.

Table 4. Chlorophyll pigment changes and clipping yields in 2006 and 2007 for creeping bentgrass (*Agrostis stolonifera* L.) grown in neutral density shade (NS).

Date									
	2006	2007	2006	2007	2006	2007	2006	2007	
	Chlorophyll b		Chlorophyll a		Chlorophyll total		Clipping yield		
	----- (µg·g ⁻¹) -----								
	----- (g·m ⁻²) -----								
N source									
Control	3.5 (0.1) ^z	2.3 (0.1)	9.2 (0.3)	5.3 (0.3)	12.6 (0.4)	9.4 (0.6)	0.6 ^x (0.1)	0.9 (0.1)	
(NH ₂) ₂ CO	3.0 (0.1)	2.5 (0.1)	7.8 (0.3)	5.8 (0.3)	10.8 (0.4)	9.9 (0.6)	0.7 (0.1)	1.1 (0.1)	
(NH ₄) ₂ SO ₄	3.4 (0.1)	2.3 (0.1)	8.7 (0.3)	5.6 (0.3)	12.0 (0.4)	9.5 (0.6)	0.5 (0.1)	0.7 (0.1)	
Ca(NO ₃) ₂	3.2 (0.1)	2.3 (0.1)	8.4 (0.3)	5.5 (0.3)	11.6 (0.4)	9.2 (0.6)	0.5 (0.1)	0.8 (0.1)	
Regulator									
TE	3.2 (0.1)	2.5 (0.1)	8.3 (0.2)	5.7 (0.2)	11.5 (0.3)	9.7 (0.4)	0.5 (0.1)	0.7 (0.1)	
No TE	3.3 (0.1)	2.3 (0.1)	8.7 (0.2)	5.4 (0.2)	12.1 (0.3)	9.4 (0.4)	0.7 (0.1)	1.1 (0.1)	
----- ANOVA -----									
Source	df	<i>P</i> > <i>F</i>							
Error	15								
Year	1	**		**		**		**	
TE	1	NS	NS ^y	NS	NS	NS	NS	NS	**
N	3	*	NS	*	NS	*	NS	NS	NS
TE × N	3	NS	NS	NS	NS	NS	NS	NS	NS

^zSE.

^yNS = nonsignificant ($P = 0.05$).

*Data averaged for whole season.

*Significant ($P = 0.05$); **significant ($P = 0.001$) of Fisher's protected means tests.

N = nitrogen; TE = trinexapac-ethyl [4-(cyclopropyl- α -hydroxy-methylene)-3,5-dioxo-cyclohexane carboxylic acid ethyl ester]; ANOVA, analysis of variance.

in DS. Shade-grown turfgrass had higher overall quantities of flavonoids than FS-grown turf (Table 5).

In this study, turfgrass color was impacted by both N source and TE treatments as well as light. In 2006, turfgrass growth was inhibited by TE applications in all environments (Table 6). This did not happen in 2007 when there was only main effect variation resulting from light and TE applications with no interactions (data not shown). Results from color analysis indicated that TE applications with (NH₂)₂CO resulted in the most

favorable color response, seen in 2007 (Table 6). There was a significant difference ($P = 0.05$) between (NH₂)₂CO and the other two sources on N across the light environments also.

There were no differences between years in shaded conditions from soluble carbohydrates, whereas there was a significant difference ($P = 0.05$) in FS with higher quantities of sugars in 2006 compared with 2007 (data not shown). Treatments had no significant effect ($P = 0.05$) on sucrose levels across the light environments also.

Discussion

Alteration of the light spectrum is the main difference between artificial shade structures and the impact that biologically active plants has on the distribution of certain wavelengths, which leads to increased far red light available to plants (Bell et al., 2000). The reduction of *PPF* is seen under physical structures but they do not alter the light spectrum and ratio of red to far red light. The substantial loss of light in NS seemed to elicit similar shade responses to DS including leaf elongation, changes in Chl pigments, and growth rates (Andersen et al., 1985; Wherley et al., 2005).

The differences in color, pigment response, and yield noted by year were thought to be related to the establishment period, which was limited in 2006 compared with a full winter with sufficient sunlight in the fall as well as standard management practices occurring in the fall including topdressing and late-season fertilization before the 2007 trial. This aided the shade plots in the second season in particular. The lower removal of clippings resulting from TE applications could be beneficial because there is less need to replace material lost, which has been discussed previously in bermudagrass (McCullough et al., 2006).

The effects of the experimental treatments on Chl varied by year. The decrease of total Chl in FS was possibly the effect of excess light damage (Lichtenthaler et al., 1981; Maunders and Brown, 1983) seen in senescing sycamore (*Acer pseudoplatanus* L.) leaves and algae. This may be dependent, however, on whether samples are measured on a mass or area basis (Lichtenthaler et al., 1981). This effect occurred regardless of N or TE treatments in all light environments, however (Tables 2, 3, and 4). The decrease may be the result of establishment of the sod in the first year compared with the more mature turf in the second year. In barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), and wheat (*Triticum aestivum* L.) it has been shown that TE applications resulted in greater tillering increases in more mature plants (Rajala and Peltonen-Sainio, 2001). The loss of color seen in some turfgrasses (Gardner and Wherley, 2005), leaving brown turfgrass in shaded conditions, seems to vary by turfgrass species. This was not noted with the use of TE on creeping bentgrass turf in either of the shaded conditions and agrees with previous results found under NS (Goss et al., 2002), who indicated that applications of TE in limited available light conditions led to a darker green color. Monthly applications of TE with a combination of foliar and granular urea applications also resulted in the best turf stand of *Supina* bluegrass *Poa supina* Schrad. (Steinke and Stier, 2003) in 80% NS conditions. The variation between the results noted here and in Gardner and Wherley's work could be the result of phytotoxic responses of different grasses to TE rather than reduced performance qualities in shaded conditions.

Table 5. Pooled flavonoid quantities in 2006 and 2007 for creeping bentgrass (*Agrostis stolonifera* L.) grown in three light environments.

	FS ^x		DS		NS	
	2006	2007	2006	2007	2006	2007
----- Quercetin equivalents (μg·g ⁻¹) -----						
N source						
Control	23.6 (2.8) ^z	29.5 (2.9)	37.6 (2.9)	46.6 (3.6)	32.9 (3.5)	47.0 (3.5)
(NH ₂) ₂ CO	26.2 (2.8)	43.0 (2.9)	36.9 (2.8)	59.3 (3.5)	32.0 (3.3)	43.6 (3.5)
(NH ₄) ₂ SO ₄	25.4 (2.8)	39.8 (2.9)	37.4 (3.0)	53.2 (3.6)	29.0 (3.4)	42.2 (3.5)
Ca(NO ₃) ₂	28.8 (2.8)	42.3 (2.9)	30.3 (3.1)	48.9 (3.5)	32.7 (3.3)	47.2 (3.5)
Growth regulator						
TE	25.5 (2.0)	37.1 (2.0)	33.5 (2.1)	47.3 (2.5)	31.3 (2.4)	43.3 (2.5)
No TE	26.5 (2.0)	40.2 (2.0)	37.6 (2.1)	56.8 (2.5)	32.0 (2.4)	46.7 (2.5)
----- ANOVA -----						
Source	df	P > F				
Error	15					
Year	1		**	**		**
TE	1	NS ^y	NS	NS	NS	NS
N	3	NS	**	NS	NS	NS
TE × N	3	NS	NS	NS	NS	NS

^zStandard error.

^yNS = nonsignificant (*P* = 0.05).

^xData analyzed separately for each light environment

**Significant (*P* = 0.05) Fisher's protected means tests.

N = nitrogen; TE = trinexapac-ethyl [4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxo-cyclohexane carboxylic acid ethyl ester]; ANOVA, analysis of variance.

Table 6. Color interactions between trinexapac-ethyl and N source in creeping bentgrass turfgrass stands grown in three light environments in 2006 and 2007.^z

	Date					
	2006	2007	2006	2007	2006	2007
	FS ^w		DS		NS	
	----- Color rank (1–9 scale) ^y -----					
N source						
Control	7.4 (0.1) ^v	6.4 (0.1)	7.3 (0.1)	7.4 (0.1)	7.4 (0.1)	7.3 (0.1)
(NH ₂) ₂ CO	7.9 (0.1)	7.7 (0.1)	7.3 (0.1)	7.6 (0.1)	7.2 (0.1)	7.5 (0.1)
(NH ₄) ₂ SO ₄	7.6 (0.1)	7.5 (0.1)	7.3 (0.1)	7.1 (0.1)	7.2 (0.1)	6.9 (0.1)
Ca(NO ₃) ₂	7.7 (0.1)	7.3 (0.1)	7.1 (0.1)	7.0 (0.1)	7.2 (0.1)	6.8 (0.1)
LSD	0.2	0.1	0.1	0.1	0.1	0.1
Growth regulator						
TE	7.9 (0.1)	7.5 (0.0)	7.7 (0.1)	7.8 (0.0)	7.6 (0.1)	7.7 (0.1)
No TE	7.5 (0.1)	6.9 (0.0)	6.8 (0.1)	6.8 (0.0)	6.9 (0.1)	6.6 (0.1)
LSD	0.1	0.1	0.1	0.1	0.1	0.1
TE with control	7.5 (0.1)	6.5 (0.1)	7.9 (0.1)	7.9 (0.1)	7.9 (0.1)	8.1 (0.1)
TE with (NH ₂) ₂ CO	8.0 (0.1)	8.1 (0.1)	7.7 (0.1)	8.2 (0.1)	7.6 (0.1)	8.1 (0.1)
TE with (NH ₄) ₂ SO ₄	7.8 (0.1)	7.9 (0.1)	7.6 (0.1)	7.5 (0.1)	7.7 (0.1)	7.3 (0.1)
TE with Ca(NO ₃) ₂	7.8 (0.1)	7.7 (0.1)	7.6 (0.1)	7.4 (0.1)	7.6 (0.1)	7.3 (0.1)
Control	7.2(0.1)	6.3 (0.1)	6.8 (0.1)	6.8 (0.1)	6.9 (0.1)	6.7 (0.1)
(NH ₂) ₂ CO	7.7 (0.1)	7.3 (0.1)	6.8 (0.1)	7.1 (0.1)	6.9 (0.1)	6.9 (0.1)
(NH ₄) ₂ SO ₄	7.3 (0.1)	7.0 (0.1)	6.9 (0.1)	6.8 (0.1)	6.9 (0.1)	6.5 (0.1)
Ca(NO ₃) ₂	7.3 (0.2)	7.0 (0.1)	6.9 (0.1)	6.8 (0.1)	6.9 (0.1)	6.4 (0.1)
LSD	0.3	0.2	0.2	0.2	0.2	0.2
----- ANOVA -----						
Source	df	P > F				
Light*block	3					
Year	1		***	NS		NS
TE	1	**	**	***	***	***
N	3	NS	***	NS	***	***
TE × N	3	NS ^x	**	NS	**	NS

^zColor ranking 1 to 9 scale^y (1 = brown, 6 = acceptable, 9 = dark green).

^yColor was ranked on a 1 to 9 scale, 1 = brown, 9 = dark green 6 = acceptable.

^xNS = nonsignificant (*P* = 0.05)

^wLight environment: FS = full sun, NS = neutral density, DS = deciduous shade.

^vSE.

*Significant (*P* = 0.05); **significant (*P* = 0.001) of Fisher's protected means tests.

N = nitrogen; LSD = least significant difference; TE = trinexapac-ethyl [4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxo-cyclohexane carboxylic acid ethyl ester]; ANOVA, analysis of variance.

There was no impact, however, from N sources in either year on the level of either Chl a/Chl b or total Chl content in DS, which leaves some argument as to why color rankings were different between the N sources. There may be a difference, however, with the testing method because Chl quantities on a mass basis may not show differences as clearly as over a set area in leaves (Bowyer and Leegood, 1997).

Carbohydrates have also been investigated in relation to energy requirements needed to support adequate growth in shaded conditions. Insufficient photosynthetic activity resulting from low light reduces the ability of turfgrass plants to recover from wear as well as meeting the daily respiratory requirements (Turgeon, 2008). The difference between 2006 and 2007 under FS was likely the result of an extended period of high temperatures in 2007 leading to depletion of sugars. The measurement of sucrose did not produce consistent results. This may be the result of the fact that sucrose is a very rapidly used sugar and not an ideal form of carbohydrate to measure in grasses (Narra et al., 2005). Applications of (NH₂)₂CO did have some effect on turfgrass carbohydrate levels. Based on previous research, there is some evidence to suggest that there may have been greater uptake and N availability from (NH₂)₂CO application (Nangle et al., 2009). This would presumably have caused the plant to use soluble carbohydrates at a higher rate, thus depleting them below levels of the other N sources. The uptake of N has been linked to carbohydrate availability (Huppe and Turpin, 1994) and so it may point to more efficient use of N.

Flavonoids are thought to offer protection in high-intensity sunlight while also requiring larger amounts of carbon in their structure. Flavonoids are also thought to be affected by applications of TE resulting from inhibition of 2-oxoglutaric acid, the cosubstrate for dioxxygenases, which catalyze late-stage gibberellin metabolism and light-absorbing flavonoid formation (Rademacher, 2000). The decrease in flavonoid levels associated with applications of TE could have been associated with damage from higher light intensities than found in either of the shaded conditions. This result along with the significant decrease in flavonoid levels under FS in 2007 would seem to indicate that light conditions play a greater role in flavonoid content than the impact of applications of TE. This would agree with some previous work indicating that applications of TE increased flavonoids and possibly enhanced tolerance to disease attack (Spinelli et al., 2006). The change in allocation of carbohydrate could also be influenced by these carbon-rich compounds in shaded conditions. The enhanced levels of flavonoids in the shaded situation may also aid in disease resistance and offer a potential area for future research (Schlösser, 1994; Spinelli et al., 2006).

The reduction in clipping yields resulting from applications of TE has been noted before in neutral density light-limited

conditions and in full sun (Ervin et al., 2002; McCullough et al., 2007) and the effect continued in the altered R:FR conditions while creating a darker color compared with untreated plots. The observation regarding color disagrees with previous work under DS conditions (Gardner and Wherley, 2005), but different grasses were used in that trial and a phytotoxic response to TE was observed in rough bluegrass, *Poa trivialis* L. The creeping bentgrass in this trial did not show adverse effects to the applications of TE in shaded conditions agreeing with Goss et al. (2002) and color rankings indicated that there was a positive effect from both the application of (NH₂)₂CO and TE.

Overall the application of TE offered a benefit in the management of creeping bentgrass turf under altered R:FR conditions and offers an option for turfgrass managers to retain turfgrass quality during the playing season in areas where the tree line affects light conditions. The reduction in clipping removal may play an important role in plant energy requirement where TE is applied. There was also possibly variation resulting from more mature turfgrass being in the trial in 2007. The work also demonstrates that the phytotoxic response sometimes observed after TE application is not the result of TE having a deleterious effect on flavonoid levels. Additional work in this area should include the addition of wear on the trial areas as well as investigation into the change in allocation of resources that turfgrasses undergo when placed in shaded conditions over a playing season.

Literature Cited

- Andersen, R.R., M.J. Kasperbauer, and H.R. Burton. 1985. Shade during growth—Effects on chemical composition and leaf color of air-cured burley tobacco. *Agron. J.* 77:543–546.
- Beard, J.B. 1997. Shade stresses and adaptation mechanisms of turfgrasses. *Intl. Turfgrass Soc. Res. J.* 8:1186–1194.
- Bell, G.E., T.K. Danneberger, and M.J. McMahon. 2000. Spectral irradiance available for turfgrass growth in sun and shade. *Crop Sci.* 40:189–195.
- Bloom, A.J., S.S. Sukrapanna, and R.L. Warner. 1992. Root respiration associated with ammonium and nitrate absorption and assimilation by barley. *Plant Physiol.* 99:1294–1301.
- Bowman, D.C. and J.L. Paul. 1992. Foliar absorption of urea, ammonium, and nitrate by perennial ryegrass turf. *J. Amer. Soc. Hort. Sci.* 117: 75–79.
- Bowyer, J.R. and R.C. Leegood. 1997. Photosynthesis, p. 49–104. In: Dey, P.M. and J.B. Harborne (eds.). *Plant biochemistry*. Academic Press, San Diego, CA.
- Buchholz, G., B. Ehmann, and E. Wellmann. 1995. Ultraviolet light inhibition of phytochrome-induced flavonoid biosynthesis and DNA photolyase formation in mustard cotyledons (*Sinapis alba* L.). *Plant Physiol.* 108:227–234.
- Bunnell, B.T., L.B. McCarty, and W.C. Bridges, Jr. 2005. ‘TifEagle’ bermudagrass response to growth factors and mowing height when grown at various hours of sunlight. *Crop Sci.* 45:575–581.
- Castrillo, M., D. Vizcaino, E. Moreno, and Z. Latorraca. 2005. Specific leaf mass, fresh: Dry weight ratio, sugar and protein contents in species of *Lamiaceae* from different light environments. *Rev. Biol. Trop.* 53:23–28.
- Cook, J.A. and D. Boynton. 1952. Some factors affecting the absorption of urea by McIntosh apple leaves. *Proc. Amer. Soc. Hort. Sci.* 59: 82–90.
- Epstein, E. and A.J. Bloom. 2005. Mineral nutrition of plants: Principles and perspectives. 2nd Ed. Sinauer Assoc. Inc., Sunderland, MA.
- 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.
- Evans, J.R. 1989. Photosynthesis and nitrogen relationships in leaves of C3 plants. *Oecologia* 78:9–19.
- Frantz, J.M. and B. Bugbee. 2005. Acclimation of plant populations to shade: Photosynthesis, respiration, and carbon use efficiency. *J. Amer. Soc. Hort. Sci.* 130:918–927.
- Gardner, D.S. and J.A. Taylor. 2002. Change over time in quality and cover of various turfgrass species and cultivars maintained in shade. *HortTechnology* 12:465–469.
- Gardner, D.S. and B.G. Wherley. 2005. Growth response of three turfgrass species to nitrogen and trinexapac-ethyl in shade. *HortScience* 40:1911–1915.
- Gaussoin, R.E., A.A. Baltensperger, and B.N. Coffey. 1988. Response of 32 bermudagrass clones to shaded intensity. *HortScience* 23:178–179.
- Goss, R.M., J.H. Baird, S.L. Kelm, and R.N. Calhoun. 2002. Trinexapac-ethyl and nitrogen effects on creeping bentgrass grown under shaded conditions. *Crop Sci.* 42:472–479.
- Harivandi, M.A. 1998. Golf green construction—A review of the California method. *California Turfgrass Culture* 48:17–19.
- Huppe, H.C. and D.H. Turpin. 1994. Integration of carbon and nitrogen metabolism in plant and algal cells. *Ann. Rev. Plant Physiol. Plant Mol. Biol.* 45:577–507.
- Impey, R.L. and W.W. Jones. 1960. Rate of absorption of urea by intact leaves of Washington navel orange. *Proc. Amer. Soc. Hort. Sci.* 76: 181–185.
- Lau, T.S.L., E. Eno, G. Goldstein, C. Smith, and D.A. Christopher. 2006. Ambient levels of UV-B in Hawaii combined with nutrient deficiency decrease photosynthesis in near-isogenic maize lines varying in leaf flavonoids: Flavonoids decrease photoinhibition in plants exposed to UV-B. *Photosynthetica* 44:394–403.
- Lichtenthaler, H.K., C. Buschmann, M. Döll, H.J. Fietz, T. Bach, U. Kozel, D. Meier, and U. Rahmsdorf. 1981. Photosynthetic activity, chloroplast ultrastructure, and leaf characteristics of high-light and low-light plants and of sun and shade leaves. *Photosyn. Res.* 2:115–141.
- Marschner, H. 1995. Mineral nutrition of higher plants. Academic Press, New York, NY.
- Maunder, M.J. and S.B. Brown. 1983. The effect of light on chlorophyll loss in senescing leaves of sycamore (*Acer pseudoplatanus* L.). *Planta* 158:309–311.
- McCullough, P.E., H. Liu, L.B. McCarty, and J.E. Toler. 2007. Trinexapac-ethyl application regimens influence growth, quality, and performance of bermudagrass and creeping bentgrass putting greens. *Crop Sci.* 47:2138–2144.
- McCullough, P., H. Liu, L.B. McCarty, T. Whitwell, and J.E. Toler. 2006. Bermudagrass putting green growth, color, and nutrient partitioning influenced by nitrogen and trinexapac-ethyl. *Crop Sci.* 46:1515–1525.
- McIntosh, M.S. 1983. Analysis of combined experiments. *Agron. J.* 75:153–155.
- Moran, R. 1982. Formulae for determination of chlorophyllous pigments extracted with N,N-dimethylformamide. *Plant Physiol.* 69:1376–1381.
- Moran, R. and D. Porath. 1980. Chlorophyll determination in intact tissues using n,n-dimethylformamide. *Plant Physiol.* 65:478–479.
- Morris, D.L. 1948. Quantitative determination of carbohydrates with dreywoods anthrone reagent. *Sci.* 107:254–255.
- Murphy, J.A. 2002. Cultural management solutions for shade problems on turf. In *Proc. 2002. Rutgers Turfgrass Proceedings*. p. 193–194.
- Nangle, E.J., D.S. Gardner, T.K. Danneberger, A.K. Studzinska and J.R. Street. 2009. Nitrogen absorption and movement in creeping bentgrass *Agrostis stolonifera* L. as affected by nitrogen source and shade. *Proc. 2nd Ann. Conf. European Turfgrass Soc.* p. 148–150.
- Narra, S., T.W. Fermanian, and J.M. Swiader. 2005. Analysis of mono- and polysaccharides in creeping bentgrass turf using near infrared reflectance spectroscopy. *Crop Sci.* 45:266–273.
- Pourmorad, F., S.J. Hosseini-mehr, and N. Shahabimajd. 2006. Antioxidant activity, phenol and flavonoid contents of some selected Iranian medicinal plants. *African J. of Biotech.* 5:1142–1145.
- Qian, Y.L. and M.C. Engelke. 1999. Influence of trinexapac-ethyl on diamond zoysiagrass in a shaded environment. *Crop Sci.* 39:202–208.
- Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 51:501–531.
- Rademacher, W. 2004. Prohexadione-Ca induces resistance to fire blight and other diseases. *OEPP/EPPO Bulletin* 34:383–388. 2004.
- Rajala, A. and P. Peltonen-Sainio. 2001. Plant growth regulator effects on spring cereal root and shoot growth. *Agron. J.* 93:936–943.
- Ruess, R.W., S.J. McNaughton, and M.B. Coughenour. 1983. The effects of clipping, nitrogen source and nitrogen concentration on the growth responses and nitrogen uptake of an east african sedge. *Oecologia* 59:253–261.
- Schlösser, E. 1994. Preformed phenols as resistance factors. In: *International symposium on natural phenols in plant resistance*. In: Geibel, M., D. Treutter, and W. Feucht (eds.). *Acta Hort.* 381:615–630.
- Smith, H. 1982. Light quality, photoperception and plant strategy. *Ann. Rev. Plant. Physiol.* 33:481–518.
- Spinelli, F., G. Costa, J.L. Vanneste, D.A. Cornish, and J. Yu. 2006. Growth-regulating acylcyclohexadiones, trinexapac-ethyl and prohexadione-calcium decrease blossom blight incidence in pome fruits. In: Bazzi, C. and U. Mazzucchi (eds.). *Proc. 10th Intl. Workshop on Fire Blight. Acta Hort.* 704:245–248.
- Steinke, K. and J. Stier. 2003. Nitrogen selection and growth regulator applications for improving shaded turf performance. *Crop Sci.* 43: 1399–1406.
- Turgeon, A.J. 2008. *Turfgrass management*. 8th Ed. Prentice-Hall, Engelwood Cliffs, NJ. p. 126–130.
- Veneklaas, E.J. and F. den Ouden. 2005. Dynamics of non-structural carbohydrates in two *Ficus*

- species after transfer to deep shade. *Environ. Exp. Bot.* 54:148–154.
- Westhafer, M.A., J.T. Law, and D.T. Duff. 1982. Carbohydrate quantification and relationships with N nutrition in cool-season turfgrasses. *Agr. J.* 74:270–274.
- Wherley, B.G., D.S. Gardner, and J.D. Metzger. 2005. Tall fescue photomorphogenesis as influenced by changes in the spectral composition and light intensity. *Crop Sci.* 45:562–568.
- Wiecko, G. and A-A. Couillard. 1997. Response of 'tifway' bermudagrass to trinexapac-ethyl and chelated iron. *J. Turfgrass Management* 2:15–21.
- Wilkinson, J.F. and J.B. Beard. 1975. Anatomical responses of 'merion' kentucky bluegrass and 'pennlawn' red fescue at shaded intensities. *Crop Sci.* 15:189–194.
- Wittwer, S.H., M.J. Bukovac, and H.B. Tukey. 1963. Advances in foliar feeding of plant nutrients, p. 429–455. In: McVickar, M.H., G.L. Bridger, and L.B. Nelson (eds.). *Fertilizer technology and usage*. Amer. Soc. Agron., Madison, WI.