Cool-season Turfgrass Color and Growth Habit Response to Elevated Levels of Ultraviolet-B Radiation

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Additional index words. *Schedonorus arundinaceus*, *Agrostis stolonifera*, *Lolium perenne*, ultraviolet radiation, turfgrass growth and development, home lawn

Abstract. Ultraviolet (UV) radiation poses a potential stress for plant growth and development due to its effect on photosynthesis and plant productivity. In the northern hemisphere, peak UV radiation exposure is predicted to occur from 2010 to 2020, with reduced color from UV-related injury, a possibility for turfgrasses. The objective of this study was to investigate the effects of ultraviolet-B (UV-B) light on turfgrass growth and morphology in three cool-season grasses. Cultivars Barvado tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.], Penncross and L-93 creeping bentgrass (*Agrostis stolonifera* L.), and Barlenium perennial ryegrass (*Lolium perenne* L.), were selected because of limited information on their growth and development in elevated UV conditions at heights of cut above 10 cm. The impact of UV-B light treatment on color, relative growth rate, and tillering was measured over a 4-week period in repeated experiments. Ultraviolet-B radiation levels were measured at 16 kJ·m⁻²·d⁻¹ biologically effective UV-B light in growth chambers programmed for a day/night regime of 14/10 hours. Chamber temperatures were maintained at 20 °C day/17 °C night. Ultraviolet-B light significantly inhibited tiller production in the first experiment in all grasses except PR, whereas no grasses were inhibited in the second experiment. Relative growth rates in all grasses were significantly lower in UV-B conditions 3 weeks after treatment initiation. Turfgrasses exposed to this level of UV-B light at typical lawn heights-of-cut had lower color ratings compared with the non-UV-B-treated control at 2 weeks after treatment initiation. The experiments demonstrated that exposure to UV-B resulted in a decline of growth rate and color in cool-season turfgrasses within a timeframe of 2 weeks. Coarse-textured turfgrasses [tall fescue (TF)/perennial ryegrass (PR)] may be more adapted to higher UV-B conditions due to morphological differences compared with the finer textured varieties [creeping bentgrass (CB)].

Light plays a crucial role in turfgrass growth and development and is considered most important in wavelengths of 400–700 nm or photosynthetically active radiation (PAR) (Pons et al., 1993). Light wavelengths and spectral distribution vary with environmental conditions (Bell et al., 2000), and there is interest in how degradation of the ozone layer will influence spectral distribution on the earth's surface (Manney et al., 2011). The decrease in ozone is predicted to significantly increased exposure to

wavelengths in the ultraviolet (UV-A 400–320 nm/UV-B 320–290 nm/UV-C 290–100 nm) range (Kerr and McElroy, 1993). The UV-B wavelengths that contact the earth's surface are predicted to increase in springtime radiation by 50% to 60% from 2010 to 2020 in the northern hemisphere (Taalas et al., 2000). Ultraviolet-B occurs at the range of 290–320 nm (ISO, 2007) and the energy associated with these wavelengths is considered damaging when compared with PAR (Fiscus and Booker, 1995). The reduction in ozone and resulting increase in UV-B has been linked to increased chlorofluorocarbons in the upper atmosphere (Rowland, 1990).

Exposure to UV-B causes several morphological and physiological responses in plants. The leaf area index of some *Poaceae* can vary in response to different levels of UV-B irradiance with increases from 0% to 80% of ambient UV-B resulting in an 88%

decrease in TF leaf area. Increased ambient UV-B from 80% to 90%, however, resulted in a 20% increase in specific leaf area (Deckmyn and Impens, 1999). Leaf area increases of 10% and axillary shoot production of 5% were noted in response to UV-B exposure in wheat (monocot, *Triticum aestivum* L.), and a bean (dicot, *Phaseolus vulgaris* L.) (Barnes et al., 1990). Root length of *Arabidopsis* was inhibited by almost 80% after exposure to 2.1 μmol·m⁻²·s⁻¹ UV-B (Kim et al., 2002). Reductions in stem elongation and leaf expansion in young plants of long-spined thorn apple (*Datura ferox* L.) occur in UV-B light (Ballare et al., 1996). Smaller leaf sizes in white clover (*Trifolium repens* L.) have been linked to intolerance to UV-B exposure as part of lower constitutive productivity (Hofmann, 2000). In bean plants, low levels of PAR (9.9 mol·m⁻²·d⁻¹) combined with UV-B (0.09 mol·m⁻²·d⁻¹) treatments led to a decrease in leaf area of 47% and a decrease in leaf dry weight of ≈25% (Cen and Bornman, 1990). Ultraviolet light exposure can reduce photosynthesis by 30% due to direct damage to photosystem II (Brandle et al., 1977).

Ultraviolet light has varying effects on quality ratings among turfgrasses. Chewings fescue (*Festuca rubra* L. ssp. *commutata* Gaud.) is considered the most UV-B-tolerant turfgrass, and kentucky bluegrass *Poa pratensis* L. is considered the least tolerant (Zhang and Ervin, 2009). Quality ratings were reduced by as much as 74% for kentucky bluegrass maintained at 5 cm after 10 d of exposure to 2.8 mol·m⁻²·d⁻¹ UV-B. There was cultivar variation in the tolerance of UV-B in the Zhang and Ervin (2009) trial. Darker green kentucky bluegrass cultivars were reported to be more tolerant of UV-B conditions (Ervin et al., 2004). Turfgrass photoinhibition occurs in kentucky bluegrass exposed to 2.8 mol·m⁻²·d⁻¹ UV-B, maintained at 6.3 cm through decreasing photochemical efficiency (F_v/F_m) by 70% (Zhang et al., 2005). Physiological responses also vary within turfgrass plants with changes in pigmentation not uniform. CB (*A. stolonifera*) 'L-93' produces more anthocyanins compared with 'Penn-cross' when exposed to UV-B for 7 d (Nangle et al., 2015).

Limited research has been conducted to test the effect of UV-B exposure on turfgrasses at higher heights of cut (10 cm) associated with residential lawns. The estimated area covered by irrigated turfgrass is 163,800 km² (Milesi et al., 2005), and therefore, a large land area could be affected. The objective of this study was to test three cool-season turfgrasses for their growth rate, tillering, and color responses to elevated UV-B conditions. It was hypothesized that coarser textured species, such as PR and TF (Turgeon, 2008), would have greater tolerance to UV-B than finer textured species such as CB.

Materials and Methods

Two separate experiments were initiated in Mar. 2011 and May 2011 at The Ohio State University, Columbus, OH. Turfgrasses were

Received for publication 17 Apr. 2015. Accepted for publication 26 Jan. 2016.

Salaries and research support provided in part by State and Federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. Journal Article HCS-16-12.

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initially seeded into a mason sand root zone containing >97% sand (Hummel & Co, Trumansburg, NY). Seeding occurred 10 weeks before experimental initiation to allow for establishment into a root zone that met United States Golf Association greens root zone recommendations (USGA, 1993), with a pH of 7.4 with 2.7% clay fraction. Single seeds of 'L-93' and 'Pennncross' CB, 'Barlenium' PR, and 'Barvado' TF were seeded into 3.8-cm-diameter, 21-cm-depth conetainers (Steuwe & Sons, Tangent, OR). Two cultivars of CB were used due to anecdotal evidence of varying responses to light quantity and source among cultivars. After seeding, conetainers were placed in a mist house under a 10-min irrigation cycle of 15 s per application to maintain adequate moisture to allow for optimal germination. Turfgrasses were grown under mist for 6 weeks and fertilized with Peters 20N 20P₂O₅ 20K₂O (Scotts-Miracle Gro, Marysville, OH) at a rate of 11.8 kg N/ha every 2 weeks. Turfgrass plants were then mowed at a height of ≈10 cm for the rest of the trial and clippings were removed.

Six weeks after seedling emergence, all conetainers were placed in a greenhouse maintained at ≈20 °C for an additional 4 weeks. Imidacloprid (N-[1-[(6-chloro-3-pyridyl)methyl]-4,5-dihydroimidazol-2-yl] nitramide) (Bayer Environmental Science, Research Triangle Park, NC) was applied at label rates to prevent insect damage. Mefenoxam {(R,S)-2-[(2,6-dimethylphenyl)-methoxyacetylaminol]-propionic acid methyl ester} (Syngenta AG, Greensboro, NC) and thiophanate-methyl [dimethyl 4,4'-o-phenylenebis(3-thioallophanate)] (Cleary Chemicals, Dayton, NJ) were applied at label rates for preventative disease control and fertility treatments were maintained at the same rate as previously described. Water was applied for a 5-min period daily to prevent wilt, using an automated ESP modular irrigation system (Rain Bird, Azusa, CA). Following maturation, plants were placed in two Conviron E15 growth chambers (1.4 m² growth area) and maintained at a height of 116 cm (Controlled Environment Ltd., Winnipeg, Canada). The chambers were programmed for a day/night length of 14/10 h with a coinciding temperature of 20/17 °C. PAR in the range of 400–700 nm was provided in all chambers using 85 J·s⁻¹ high-output fluorescent tubes (F12T12-CW.HO; General Electric, Fairfield, CT).

After 24 h in the growth chambers, UV-B treatment initiation was implemented using UV-B specific lamps having peak wavelength emission at 313 nm, (QUV UV-B 313 nm; Q-Laboratory Corp., Westlake, OH). The control treatment consisted only of PAR. Ultraviolet-B lamps did not produce any extra light in the PAR region and they were burned in for 48 h to prevent any fluctuation before trial initiation. Radiation from UV sources were measured using both UV-B and UV-A sensors attached to a photometer (IL1350; International Light, Newburyport, MA). All UV radiation is reported as kJ·m⁻²·d⁻¹. The PAR was measured every 15 min during the study using a lightscout

quantum cosine corrected light sensor (Spectrum Technologies, Plainfield, IL) connected to a datalogger (Watchdog 300; Spectrum Technologies) and reported as mol·m⁻²·d⁻¹. Water was applied twice daily to prevent wilting. Turfgrass plants were placed 0.8 m below the lighting in an even spacing of 3.8 cm and fertilized as previously described.

The growth rate experiment was designed with 1, 2, 3, or 4 weeks of exposure. Under the UV-B and PAR light regimes, there were three blocks with four replications per block in a randomized complete block design (Hammer and Hopper, 1997) for a total of 12 conetainers of each grass per light regime in two repeated experiments. Conetainers were held in three separate trays in three randomized complete blocks and the trays were placed in a row side by side in the chamber. At the end of each week, complete turfgrass plants were destructively harvested and separated into roots and shoots then oven dried at 70 °C for 2 d. Tissue was dried in an oven (VWR 1350F; Univar USA, Redmond, WA) in 8.9 × 16.5 cm coin envelopes (OfficeMax, Naperville, IL). Roots were washed via submergence in a set of four sieves sized 2.00 mm, 1.00 mm, 850 μm, and 500 μm. The shoot:root ratio was then calculated based on dry weight (Gwynn-Jones and Johanson, 1996). Relative growth rate was calculated based on the formula of Gardner et al. (1985):

$$RGR = (\ln W_2 - \ln W_1) / (T_1 - T_2)$$

where RGR is the relative growth rate, W_2 is the total weight at time T_2 , W_1 is the total weight at time T_1 .

Tillers were counted at weeks 1, 2, 3, and 4. Tillers were classed as lateral shoots emerging from the dominant stem. Color rankings were carried out on a 1–9 visual ranking scale with 1 = dead/brown, 6 = acceptable, and 9 = dark green.

Data were analyzed using the generalized linear model method in SAS Version 9.2 (2008). Means separation was carried out using Fisher's protected least significant difference test ($P = 0.05$) and data were pooled by week for each light environment. Data could only be compared between each specific light environment for each separate week due to complete plant tissue removal after each growth period. Blocks were treated as light environments because of variability in the UV-B + PAR chamber. Replication of the two chambers occurred over time according to the method of Hammer and Hopper (1997).

Results

Turfgrass under PAR + UV-B treatment received a total of 24 kJ·m⁻²·d⁻¹, which was mathematically adjusted for biologically effective UV-B radiation (Caldwell, 1971), taking into account the direct impact of UV-B on DNA and chromophores (Table 1). The total biologically effective UV-B light turfgrasses were exposed to in this trial was then decreased to 16 kJ·m⁻²·d⁻¹ compared with around 6 kJ·m⁻²·d⁻¹ found in midlatitudes. Light energy received in the PAR wavelengths totaled 18.4 mol·m⁻²·d⁻¹ in the PAR + UV-B and 18.6 mol·m⁻²·d⁻¹ in the PAR chamber.

Table 1. Lighting conditions in control and ultraviolet-treated growth chambers for turfgrasses grown in at The Ohio State University, March–May 2011, for both Expts. 1 and 2.

Chamber	Light		
	UV-B (280–320 nm)	UV-A (320–400 nm)	PAR (400–700 nm)
	kJ·m ⁻² ·d ⁻¹		
	mol·m ⁻² ·d ⁻¹		
Control	0.0	0.1	18.6
UV- chamber	24.0 (16.0) ^z	0.4	18.4

UV = ultraviolet; PAR = photosynthetically active radiation.

^zActual biologically effective ultraviolet-B radiation (Caldwell, 1971).

Table 2. Relative growth rate for four cool-season grasses grown in control and enhanced ultraviolet-B light conditions. Data combined from two experiments for each grass.

	Relative growth rate (ln g·m ⁻² ·week ⁻¹)			
	Time			
	Week 1	Week 2	Week 3	Week 4
Tall fescue				
PAR	0.87 a ^z	0.49 a	1.01 a	0.15 a
PAR + UV-B	0.20 b	0.47 a	1.33 a	–0.76 b
LSD	0.47	0.57	0.58	0.74
Perennial ryegrass				
PAR	1.04 a	0.24 b	1.59 a	0.18 a
PAR + UV-B	0.47 b	0.82 a	0.65 b	–0.01 a
LSD	0.44	0.52	0.48	0.22
Creeping bentgrass 'Pennncross'				
PAR	1.05 a	1.35 a	2.43 a	–0.44 a
PAR + UV-B	0.59 a	0.14 b	0.98 b	–0.36 a
LSD	0.54	0.61	0.65	0.97
Creeping bentgrass 'L93'				
PAR	0.88 a	1.13 a	2.09 a	–0.06 a
PAR + UV-B	0.62 a	0.34 b	0.78 b	–0.26 a
LSD	0.46	0.69	0.73	0.62

UV-B = ultraviolet B; PAR = photosynthetically active radiation; LSD = least significant difference.

^zSignificant difference between grasses grown in ultraviolet and control conditions on this date ($P = 0.05$).

After 3-week exposure to light, growth of all grasses except TF in *PAR* + UV-B was significantly inhibited ($P = 0.05$) compared with *PAR* control chamber grasses (Table 2). There was a decrease in growth rate after grasses were exposed to *PAR* for 4 weeks; however, the growth rate in *PAR* + UV-B conditions had become zero as turfgrasses began to decline. There was variability noted within the data, which occurred despite using 12 different samples from each grass at each sampling date.

There was a significant difference ($P = 0.05$) in color ranking for all grasses exposed to *PAR* + UV-B (Fig. 1) at weeks 2–4. PR had a color ranking of 6.4 in *PAR* + UV-B (Fig. 1A) compared with 7.5 in *PAR*. This was above satisfactory levels, but still significantly lower ($P = 0.05$) than PR in *PAR* (Fig. 1A). TF had a rating of 6.1 in *PAR* + UV-B compared with 7.4 when exposed to *PAR* (Fig. 1B). This color rating was above satisfactory, but significantly lower than TF plants exposed to *PAR*. CB ‘L-93’ in *PAR* + UV-B rated 5.7 for color compared with a *PAR* color rating of 7.3 (Fig. 1C). CB ‘Pennncross’ color rankings in *PAR* + UV-B were an unsatisfactory 5.9, whereas in *PAR* environments, color rankings were 7.1 after 4 weeks of treatment (Fig. 1D). The color rankings for the CB cultivars in *PAR* + UV-B were both unsatisfactory and significantly lower ($P = 0.05$) than CB cultivars exposed to *PAR* (Fig. 1C and D). Visible damage was clearly seen with browning and yellowing of the leaf tissues. Dark lesions similar to burn spots were noted on the *PAR* + UV-B-treated CB plants. The loss of color was not observed until week 2 of the experiments and was consistent in both trials. The color differences were consistent after week 2 and noted at each time period after that. There was some reddening of stems and tissue material, but this was not consistently observed.

Under *PAR* + UV-B conditions in Expt. 1, there was a clear inhibition ($P = 0.05$) of plant tillering in CB when compared with *PAR* (Fig. 2). There was a 40% inhibition of tillering in ‘L-93’ and 39% decrease in the ‘Pennncross’. PR was not inhibited significantly in either experiment. There was a 30% decrease of TF tillering in Expt. 1, but this did not occur in Expt. 2. No tillering differences among turfgrass species were noted in Expt. 2. The CB exposed to *PAR* + UV-B had lower tiller numbers in Expt. 1, but they were not significantly different from the *PAR* treatment in Expt. 2 (data not shown). The root: shoot ratio did not change significantly in response to light regime in either experiment (data not shown).

Discussion

The decrease in growth rate in CB after exposure to *PAR* + UV-B light in this study has previously been reported (Schmidt and Zhang, 2001). Reducing the efficiency of the photosynthetic machinery, because of photolytic damage from UV-B exposure, would effectively reduce plant productivity. This

Fig. 1. Color ratings for four cool-season grasses grown in control and enhanced ultraviolet-B light conditions. (A) Perennial ryegrass. (B) Tall fescue. (C) Creeping bentgrass ‘L93’. (D) Creeping bentgrass ‘Pennncross’. Data combined from two experiments for each grass. (1–9 scale, 1 = brown/dead, 9 = dark green optimal color, 6 = acceptable.) *Significant difference between grasses grown in ultraviolet and control conditions on this date ($P = 0.05$).

Fig. 2. Number of tillers per mother plant for four cool-season grasses grown in control and enhanced ultraviolet-B light conditions in Expt. 1. *Bars signify least significant difference between treatments ($P = 0.05$). *Histograms with different letters for each grass signify differences at $P = 0.05$.

effect also occurred but to a lesser extent with the TF and PR. The two coarser textured grasses, TF and PR, produced greater growth rates than the finer textured CB under UV-B stress (Arachevala et al., 1989; Pammenter et al., 1986; Sun and Liddle, 1993). Leaf texture may be crucial in maintaining normal growth rates under high *PAR* + UV-B conditions. Epidermal thickness alters leaf absorbance properties and is a predictor of the effectiveness of a plants ability to screen UV-B light (Day, 1993). Breeding of finer textured cultivars the TF and PR in the last decade, however, could influence the response of these turfgrasses to UV-B in the future.

The inhibition of tillering by *PAR* + UV-B in this study could be considered problematic for turfgrass wear recovery, and growth and

development. Tillering reduction caused by UV-B has been previously noted in rice (Teramura et al., 1991), but the reduction was not linked to hormonal or carbohydrate changes in plants (Mohammed et al., 2007). In Antarctic hairgrass (*Deschampsia antarctica* E. Desv.), tillering was increased by UV-B exposure; however, the levels of UV-B in that study measured at $5 \text{ kJ} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$, lower than in our study (Rozema et al., 2001). The variation in tillering from experiment to experiment may have been linked to seasonal variation in light intensity during establishment. The effect of light intensity can lead to changes in both tiller density and also tiller size (Lemaire and Chapman, 1996). The lack of a difference among species in root and shoot growth was somewhat surprising; however, the light levels may have suppressed the

growth and allocation of carbohydrates equally. This does not agree with previous results (Gwynn-Jones, 2001), but the UV-B levels were higher in our study.

There was some variation in the relative growth rate of the turfgrass varieties, with the CB growth rates reduced by UV-B more than TF and PR. Varietal growth rate differences in rice (*Oryza sativa* L.) following exposure to UV have also been observed. Some rice cultivars had a decrease in leaf area by 28%, whereas others only lost 4% of leaf area. Treatments of UV-B reduced relative growth rate by 7.5% in one cultivar, whereas others showed little response and these effects were not noted until after 2 weeks of UV-B treatment (Dai et al., 1992). Biomass production of PR and orchardgrass (*Dactylis glomerata* L.) was reduced in response to comparable spring and summer treatments of elevated UV levels (Deckmyn and Impens, 1999). Variability in response could be related to other factors such as the leaf surface, air temperature, or concentrations of CO₂ (Krupa and Kickert, 1989).

In an attempt to gain a consistent turfgrass response, UV-B levels in this study were elevated above current levels to control the turfgrass response. Another goal of this approach was to simulate season-long exposure by supplying extended equivalents of UV-B irradiation. Variation in light intensity plays a key role in responsiveness of plants to both PAR + UV-B and PAR irradiance. Its effect varies based on or relative to exposure that is received by plants. In lapland reedgrass (*Calamagrostis lapponica*) and (*Calamagrostis pupurea*), levels of UV-B that simulated 15% loss of ozone resulted in reduced tillering; however, in light levels that simulated 25% ozone depletion, higher numbers of tillers were produced (Gwynn-Jones and Johanson, 1996). The 25% ozone depletion equated to a 6.5 kJ·m⁻²·d⁻¹ UV-B irradiance, which was lower than that turfgrasses were subjected to in this study. Short-term exposure to high UV-B + PAR leads to physiological changes in soybean such as increases in pigmentation, but long-term exposure reduces those responses (Grant et al., 2010).

The visual evaluation of color and differences between ratings were similar to previous studies (Millington and King, 2010). The loss of color is one of the principal factors for evaluating turfgrass performance, and while the coarser leaved plants had significant color loss, they still maintained acceptable color levels compared with the two CB cultivars. This may be an important factor to consider regarding tolerance of cool-season grasses to UV light stress.

If the predicted changes in UV light levels occur over time, further research into leaf cuticle thickness and changes in resins and waxes in the cuticular layers will be required. The use of synthetic, reflective type pigments as protective sunscreen type coatings may be an alternative to breeding for increased UV-B tolerance in turfgrasses. Future study of coatings should be conducted to ascertain the effectiveness of such applications.

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