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This field study was conducted at the University of Maryland on 'Providence' creeping bentgrass (*Agrostis stolonifera* L.) grown on a sand-based rootzone and maintained as a putting green. The objectives of this study were to measure several creeping bentgrass performance and physiological factors as influenced by light and frequent versus deep and infrequent irrigation. Creeping bentgrass subjected to deep infrequent irrigation developed a less thick thatch-mat layer, which contained 23% less organic matter than was found in light frequently irrigated plots. In addition, slightly more than twice the amount of water was applied to the light frequent- versus deep infrequent-irrigated plots.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 350 projects at a cost of $29 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Creeping Bentgrass Putting Green Turf Responses to Two Irrigation Practices: Quality, Chlorophyll, Canopy Temperature, and Thatch-Mat

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SUMMARY

Frequent versus infrequent irrigation are two common irrigation practices. This field study was conducted on 'Providence' creeping bentgrass (*Agrostis stolonifera* L.) grown on a sand-based rootzone and maintained as a putting green. The objectives of this study were to measure several creeping bentgrass performance and physiological factors as influenced by light and frequent (LF) versus deep and infrequent (DI) irrigation. The LF plots were irrigated daily to moisten the upper 4 to 6 cm (1.6 to 2.4 inches) of soil, while DI plots were irrigated at leaf wilt to wet soil to a depth of approximately 24 cm (9.5 inches). The key findings of the study were:

- Creeping bentgrass quality generally was better in LF- than DI-irrigated bentgrass. The negative effects of DI on visual quality were greatest in the first summer following establishment and less objectionable in the second year in mature turf. The LF-irrigated creeping bentgrass exhibited very good color and quality throughout most of 2006 and 2007; whereas, DI-irrigated bentgrass exhibited acceptable quality in 2007, but not in 2006.
- The DI-irrigated bentgrass had lower chlorophyll levels in leaf and sheath tissue in 2006, but developed better color and quality and had higher chlorophyll levels in late summer of 2007 versus LF-irrigated bentgrass. This indicated that the turf was adapting to wilt stress or was a function of turf maturity.
- Canopy temperatures measured on sunny days between 11 a.m. and 3 p.m. in June, July, and August ranged from 33 to 40º C (91 to 104º F) . On dates when there were significant differences between irrigation treatments, canopy temperatures were higher in DI (two year average 39.2º C = 103º F) than LF (two year average 36.9º C = 98º F) bentgrass.
- Creeping bentgrass subjected to DI-irrigation developed a less thick thatch-mat layer, which contained 23% less organic matter than was found in LF-irrigated plots.
- Slightly more than twice the amount of water was applied to the LF- versus DI-irrigated plots.
- Allowing young creeping bentgrass greens to wilt prior to irrigating during the first summer of establishment probably should be avoided. The DI method, however, did result in less thatch-mat production and improved chlorophyll levels overtime, while significantly reducing water usage.

The decline of creeping bentgrass putting greens in summer is a common problem and largely is a response to environmental and mechanical stresses (4, 6). Careful water management is critical to growing quality creeping bentgrass during summer stress periods. Golf course superintendents often use daily irrigation combined with hand-watering and syringing practices when managing creeping bentgrass in the summer. Frequent or excessive irrigation, however, not only increases costs associated with water consumption, but can reduce environmental stress tolerance and predispose turf to injury from mechanical stresses, cyanobacteria (blue-green algae), moss, and disease (1, 4, 22).

Two contrasting practices that can be used to maintain putting greens are light and frequent and deep and infrequent irrigation. Light and frequent irrigation involves maintaining soil at field capacity; whereas, deep and infrequent irrigation is imposed at the first sign of leaf wilt (6). Deep and infrequent irrigation at the time turf shows signs of wilt generally is recommended in summer for cool-season grasses (1, 6).

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Some researchers have found that moderate drought does not greatly affect the summer performance of turfgrasses (3, 11, 12, 16). For example, Fu et al. (11) reported that tall fescue, hybrid bermudagrass, and zoysiagrass displayed the same level of turf quality as well-watered turfgrass when irrigated at 60 or 80% of evapotranspiration (ET). Gilbeault et al. (12) reported that tall fescue, Kentucky bluegrass, and perennial ryegrass produced best turf quality when irrigated at 100% ET, but quality was only slightly lower at 80% ET. Jordan et al. (16) observed that creeping bentgrass putting green turf irrigated every four days, compared to irrigation every one or two days, had significantly improved turf quality in one of two study years. DaCosta and Huang (3), however, observed a significant decrease in creeping bentgrass quality when irrigated at 60 versus 100% ET.

Creeping bentgrass is aggressively stoloniferous and produces a well defined thatch and/or mat layer at the soil surface. Thatch-mat accumulation can have a multitude of negative effects on turfgrasses (17). There is a dearth of information on the influence of irrigation practices on thatch-mat accumulation, as well as chlorophyll production and canopy temperature in creeping bentgrass. The objectives of this field study were to evaluate deep infrequent versus light frequent irrigation for their impacts on creeping bentgrass foliar color and quality, chlorophyll production, thatch-mat accumulation, and canopy temperature during summer.

Materials and Methods

The study was conducted on a research green built using USGA recommendations at the University of Maryland Turfgrass Research Facility in College Park in 2006 and 2007. Soil was a modified sand mix (97% sand, 1% silt, and 2% clay) with a pH of 6.5 and 10 mg of organic matter per gram of soil (1%). In September 2005, the study site was treated with glyphosate [N-(phosphonomethyl) glycine], the sod was removed, and the site was seeded with 'Providence' creeping bentgrass (50 kg seed ha^{-1}) as described by Fu and Dernoeden (9).

Fertilizer was applied as outlined in Fu and Dernoeden (9). Briefly, a total of 250 kg N ha^{-1} (5.0 lb N/1000 ft^2) were applied between September 20 and November 11, 2005. A total of 78 kg N ha^{-1} (1.6 lb N/1000 ft^2) from urea was applied in multiple applications in small quantities during the 2006 experimental period. Another 71 kg N ha^{-1} (1.4 lb N/1000 ft^2) were applied between September 20 and November 17, 2006. In 2007, the bentgrass was fertilized weekly (4.9 kg N ha^{-1}; 0.1 lb N/1000 ft^2) with urea between April 30 and August 27 to provide a total of 88 kg N ha^{-1} (1.8 lb N/1000 ft^2) during the experimental period. Pest control and core cultivation were performed as described by Fu and Dernoeden (9).

Each plot measured 1.8 by 2.4 m and was bordered by fiber glass polymer edging (Easy Gardener Products Inc, Waco, TX) set 10 cm deep in soil to minimize lateral movement of water. There also was a 60-cm creeping bentgrass perimeter border separating individual plots. Each plot was individually irrigated between 7:00 and 8:00 a.m. using a hand-held hose equipped with a shower head nozzle and calibrated as described by Fu and Dernoeden (9).

Two irrigation regimes were assessed as follows: i) light and frequent (LF) irrigation and; ii) deep and infrequent (DI) irrigation. In the light and frequent irrigation regime, water was applied daily to replace moisture lost due to evapotranspiration (ET). This ensured that soil was maintained in a moistened state to a depth of about 4 to 6 cm each morning. In the deep and infrequent irrigation regime, water was provided at the first visual sign of leaf wilt as determined by foot printing and/or the appearance of a bluish-gray leaf color. Irrigation frequency was variable for the deep and infrequent treatment and depended on weather conditions. Therefore, deep and infrequent irrigation frequency was sometimes as often as every 3 days or as infrequent as 7 days. A standard amount of 50 L (11.6 mm) water was applied to each deep and infrequent plot when irrigated. Using a soil probe and ruler, it was determined that this amount of water wet soil to a depth of 6

Soil depth	Irrigation	2006			2007		
		June 11	July 21	Aug. 18	June 19	July 15	Aug. 31
······(cm)······		······Soil moisture (kg kg^{-1} x 100)······					
0-5	LF †	8.0 a§	12.6 a	13.0 a	14.5 a	15.8 a	15.7 a
	DI *	3.4 b	8.0 b	5.3 b	6.0 b	7.4 b	6.9 b
5-10	LF	7.8 a	10.2 a	9.6 a	7.4 a	8.6 a	8.4 a
	DI	4.5 b	8.9 b	7.9 b	5.5 b	6.9 b	7.2 b
10-15	LF	7.9 a	10.8 a	10.3 a	7.4 a	8.1 a	8.2 a
	DI	6.6 a	10.2 a	9.7 a	7.0 a	7.6 a	7.6 a

† Light and frequent (LF) irrigation was performed daily in the absence of rain to wet soil to a 4 to 6 cm depth.

* Deep and infrequent (DI) irrigation was performed at leaf wilt to wet soil to a depth of approximately 24 cm.

§ Means in a column for each soil depth followed by the same letter are not significantly different based on Fisher's protected least significant difference test (P=0.05).

Table 1. Percent soil moisture in response to light frequent versus deep infrequent irrigation in 'Providence' creeping bentgrass in 2006 and 2007.

to 8 cm within 5 minutes, and water penetrated to a depth of approximately 24 cm within 20 minutes after irrigation ceased.

On sunny days, plots were hand-syringed about three times daily depending on weather conditions. To minimize the impact of rain, two tarps were used to cover all eight plots prior to the onset of rain between May 22 and August 31 in 2006 and 2007 as described Fu and Dernoeden (9). Six rain events in 2006 (total 16.3 mm) and five events in 2007 (21.6 mm) occurred before plots could be covered. On those days, light frequent-irrigated plots were not irrigated. An additional 59.7 mm of rain inadvertently fell on uncovered plots on August 20 and 21, 2007. Irrigation treatments were initiated on May 22 and ended in early September in both years.

To measure soil moisture, two soil cores (2.5 cm diameter and 15 cm deep) were taken from each plot and the foliage and thatch were removed. Soil cores were collected about 1 day prior to irrigating deep and infrequent-irrigated plots on the dates shown in Table 1. Each core was separated into 0 to 5 cm; 5 to 10 cm, and 10 to 15 cm segments, and each segment was placed in an envelope and weighed. Soil cores were dried at 80^{o} C for 72 hours and re-weighed to obtain percent soil moisture. The average of the two soil cores from each plot was used in the statistical analysis.

Turf color and quality were assessed visually on a weekly basis using a 0 to 10 scale where 0 = brown or dead turf; 7.0 = minimum acceptable color or quality; 8.0 = very good summer color or quality; and 10 = optimum greenness, uniformity, and cover. Clippings, which contained mostly leaf and some sheath tissue (hereafter leaf or leaves), were collected every 4 weeks from late May until late August and analyzed for chlorophylls a and b. Clippings were placed immediately in liquid nitrogen and stored in a freezer at -80 ^{o} C until analyzed. Chlorophyll was extracted by soaking about 0.05 g leaf and sheath tissue in dimethyl sulfoxide for 48 hours as described by Fu and Huang (2001). Absorbance of the extract was measured at 663.2 nm (OD663.2) and 646.8 nm (OD646.8) with a spectrophotometer (Beckman Coulter, Inc., Fullerton, CA).

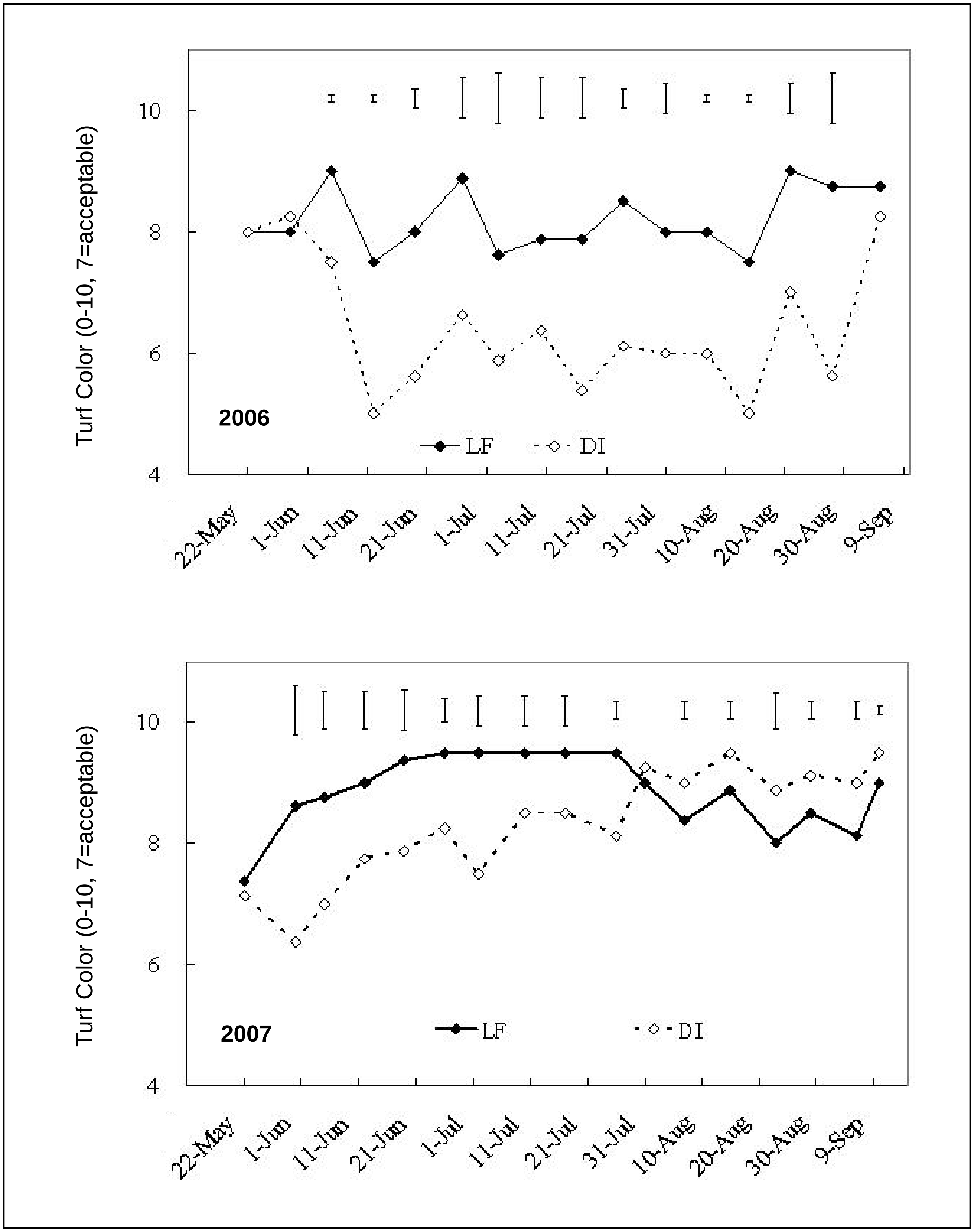


Figure 1. Turf color of 'Providence' creeping bentgrass in response to light and frequent (LF) irrigation (daily in the absence of rain to a wet soil to a 4 to 6 cm depth) and deep and infrequent (DI) irrigation (at leaf wilt to wet soil to soil depth of approximately 24 cm) in 2006 and 2007. Bars indicate significantly different means based Fisher's protected least significant difference test (P=0.05).

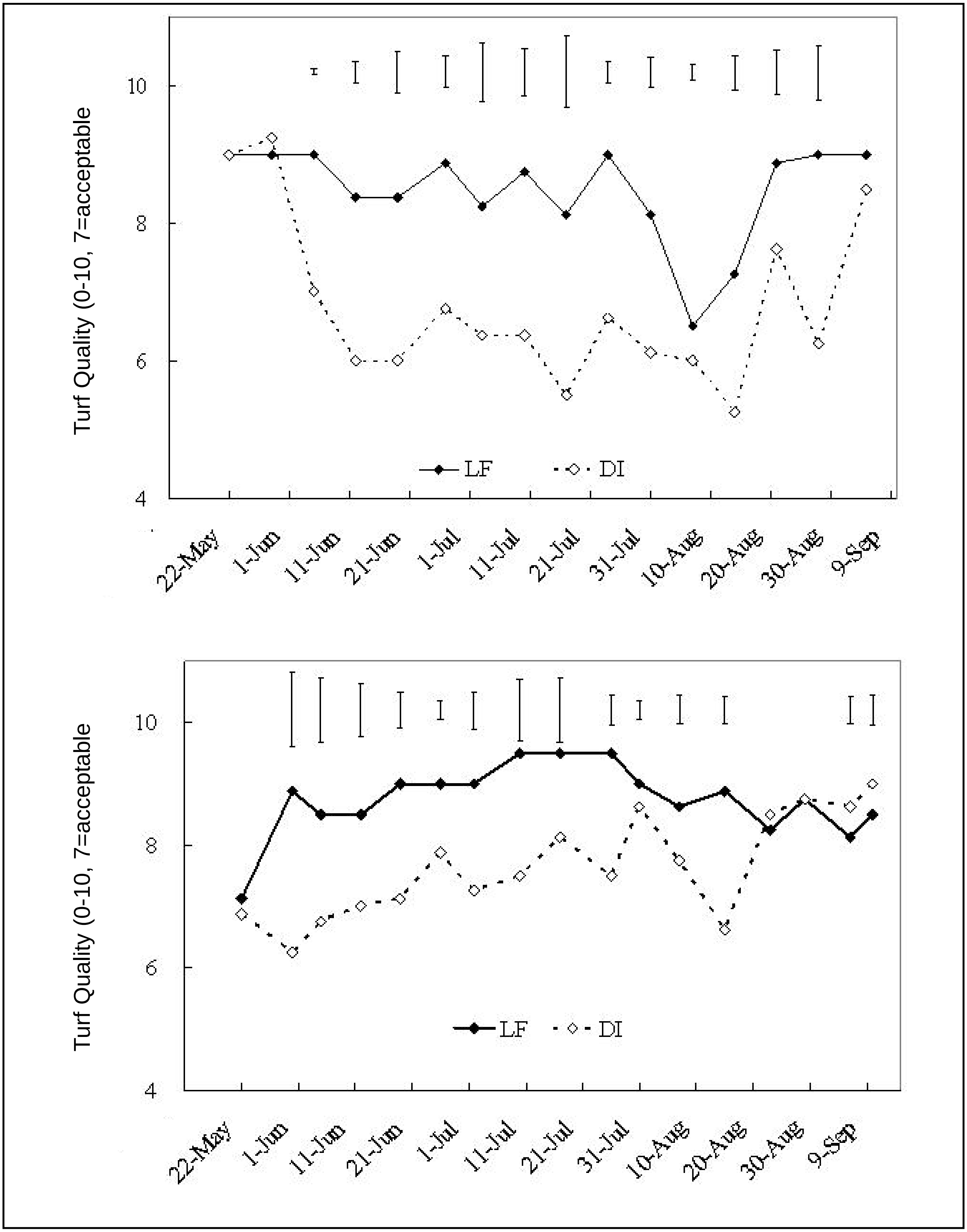
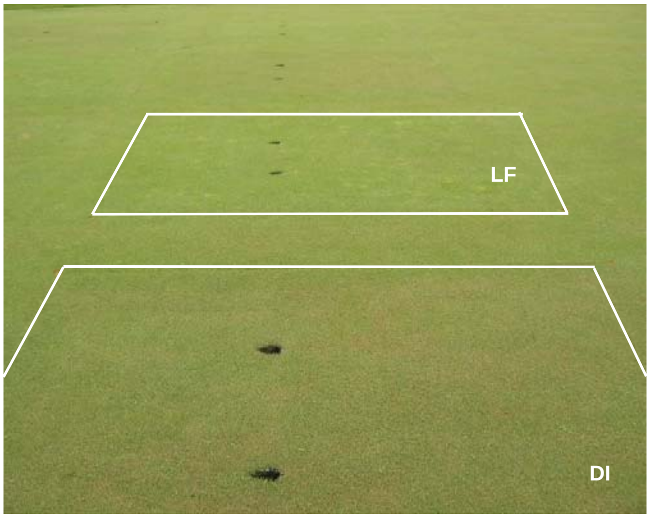


Figure 2. Turf quality of 'Providence' creeping bentgrass in response and light and frequent (LF) irrigation (daily in the absence of rain to wet soil to a 4 to 6 cm depth) and deep and infrequent (DI) irrigation (at leaf wilt to wet soil to approximately 24 cm) in 2006 and 2007. Bars indicate significantly different means based Fisher's protected least significant difference test (P=0.05).



Wilt injury to DI plot in foreground and improved green color of LF plot in the middle. Note "yellow spots" in LF plots and the two tubes used for the minirhizotron camera in all plots.

Chlorophyll a and b were quantified using the equations described by Fu and Huang (8).

For thatch-mat depth and organic matter measurements, 2.5 cm diam. by 8 cm deep cores were taken from each plot. Two cores were taken on June 11, July 21, and August 18, 2006 and five soil cores were removed from each plot on September 28, 2006 and May 22, July 18, and September 5, 2007. The uncompressed thatch-mat depth of each core was measured with a ruler. Green leaf and sheath tissue and soil below the thatch-mat layer of each soil core were removed with scissors. Thatch-mat samples taken between September 28, 2006 and September 5, 2007 then were dried for 1 hour at 125^{o} C and then weighed. Thatch-mat samples then were combusted for 2 hours at 550^{o} C and reweighed to determine the amount of organic matter present. The average thatch-mat depth or amount of organic matter from either two or five cores per plot was used in the statistical analyses.

Canopy temperature was measured at 1 to 2-week intervals from May 31 through August 29, 2006 and June 8, July 7 and 15, and August 13 and 30, 2007. Measurements were obtained prior to syringing on sunny days using a hand-held infrared thermometer (Raytek; Model Rayst2pu, Santa Cruz, CA). Measurements were obtained between 11:00 a.m. to 3:00 p.m. and the infrared thermometer was held approximately 1.0 m above the canopy surface. Two measurements were taken in each plot, and the average temperature per plot was used in the statistical analyses.

The experiment was arranged in a completely randomized block design with four replications. Treatment effects were determined by the analysis of variance using the general linear model procedure of the Statistical Analysis System (SAS Institute, Cary, NC). Significantly different means were separated using Fisher's protected least significant difference test (P=0.05).

Results

About twice the amount of water was applied to LF- versus DI-irrigated plots in both years between May 22 and August 31. The total amounts of water applied were 339 and 344 mm in LF-irrigated and 168 and 157 mm in DI-irrigated plots in 2006 and 2007, respectively. Hereafter, LF-irrigated and DI-irrigated will be referred to as LF and DI, respectively. Soil moisture was significantly higher in the 0 to 5 cm and 5 to 10 cm soil depths on all dates in both years in LF versus DI plots (Table 1). Soil moisture within the 0 to 5 cm depth ranged from 8.0 to 15.8% in LF plots and 3.4 to 8.0% in DI plots. Soil moisture at the 5 to 10 cm depth ranged from 7.4 to 10.2% in LF and from 4.5 to 8.9% in DI plots. No

Morning dew patterns in response to light and frequent and deep and infrequent irrigation.

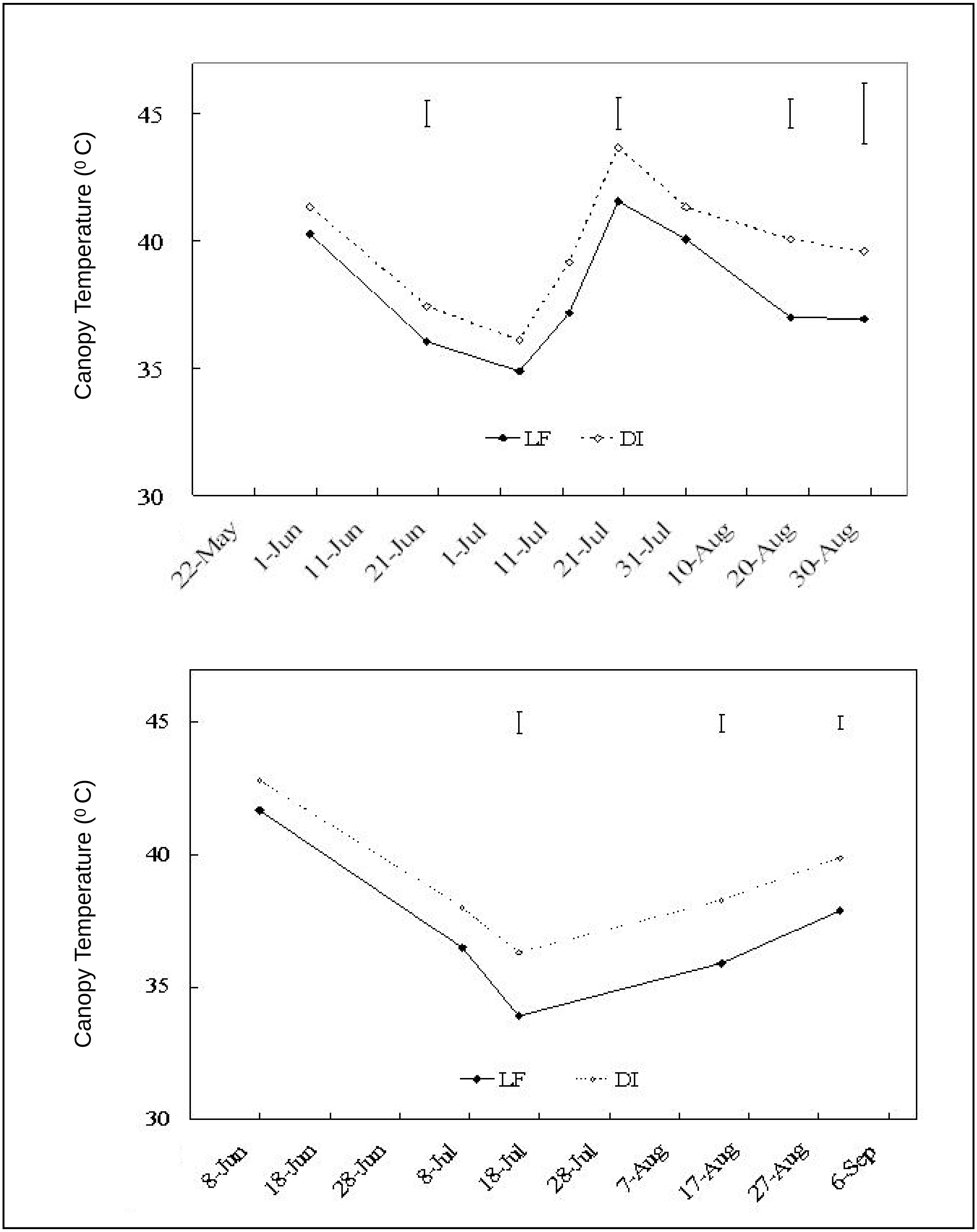


Figure 3. Canopy temperature of 'Providence' creeping bentgrass in response to light and frequent (LF) irrigation (daily in the absence of rain to a soil depth of 4 to 6 cm) and deep and infrequent (DI) irrigation (at leaf wilt to wet soil to a soil depth of approximately 24 cm) in 2006 and 2007. Bars indicate significantly different means based Fisher's protected least significant difference test (P=0.05).

Irrigation	2006				
	19 May	15 June	13 July	8 Aug.	7 Sept.
	Chlorophyll a (micrograms g^{-1} FW)				
LF†	74.5 a§	78.1 a	92.2 a	92.2 a	100.1 a
DI *	74.7 a	73.9 b	90.1 b	93.4 a	92.7 b
	Chlorophyll b (micrograms g^{-1} FW)				
LF	17.5 a	17.9 a	22.7 a	21.9 a	24.5 a
DI	17.7 a	17.4 a	22.6 a	22.4 a	22.6 b
	Total chlorophyll a+b (micrograms g^{-1} FW)				
LF	91.9 a	95.9 a	114.8 a	114.1 a	124.7 a
DI	92.3 a	91.3 b	112.7 b	115.8 a	115.3 b
	2007				
	1 June	28 June	17 July	15 Aug.	6 Sept.
	Chlorophyll a (micrograms g^{-1} FW)				
LF	51.9 a	63.7 a	55.6 b	50.8 b	56.8 b
DI	50.4 a	62.3 a	59.1 a	52.9 a	59.2 a
	Chlorophyll b (micrograms g^{-1} FW)				
LF	12.1 a	15.3 a	12.7 b	11.7 b	12.8 a
DI	11.9 a	15.0 a	13.7 a	12.6 a	13.2 a
	Total chlorophyll a+b (micrograms g^{-1} FW)				
LF	64.0 a	79.0 a	68.4 b	62.5 b	69.6 b
DI	62.3 a	77.3 a	72.8 a	65.5 a	72.3 a

† Light and frequent (LF) irrigation was performed daily in the absence of rain to wet soil to a 4 to 6 cm depth.

* Deep and infrequent (DI) irrigation was performed at leaf wilt to wet soil to a depth of approximately 24 cm.

§ Means in a column within each chlorophyll parameter followed by the same letter are not significantly different based on Fisher's protected least significant difference test (P=0.05).

Table 2. Leaf and sheath chlorophyll a, b and a + b content in 'Providence' creeping bentgrass in response to light and frequent versus deep and infrequent irrigation in 2006 and 2007.

differences in soil moisture (range 9.5 to 15.4%) were observed between irrigation treatments at the 10 to 15 cm soil depth.

Turf color and quality were evaluated between May 22 and September 10, 2006 and 2007. Beginning on June 5, 2006, DI bentgrass exhibited a lower color and quality level compared to LF bentgrass (Figures 1 and 2). Thereafter, DI bentgrass had unacceptable color and quality during most of the experimental period (June 12 to August 14) in 2006. Turf color and quality in LF plots were judged to be very good (i.e., rating 8.0) on most rating dates. There was, however, a decline in turf quality in early August 2006 in LF plots, which was due to the appearance of numerous yellow spots. The etiology of the yellow spots is unknown, but the malady was described by Dernoeden and Fu (2008). Yellow spots did not develop in DI plots and diminished by late August in LF bentgrass. Regardless, quality remained acceptable (i.e., > 7.0) at this time in LF plots, despite the yellow spots.

In 2007, turf color and quality ratings from DI bentgrass generally were lower from mid-May until late August versus LF bentgrass (Figures 1 and 2). On August 20 and 21, 31.8 and 27.9 mm

Irrigation	2006		
	May 31	July 22	August 19
	(mm)		
LF †	1.5 a §	3.3 a	4.4 a
DI *	1.5 a	1.7 b	3.0 b
	2007		
	May 22	July 18	September 5
	(mm)		
LF	7.9 a	9.5 a	10.0 a
DI	6.2 b	6.4 b	6.8 b

† Light and frequent (LF) irrigation was performed daily in the absence of rain to wet soil to a 4 to 6 cm depth.

* Deep and infrequent (DI) irrigation was performed at leaf wilt to wet soil to a depth of approximately 24 cm.

§ Means in a column within each chlorophyll parameter followed by the same letter are not significantly different based on Fisher's protected least significant difference test (P=0.05).

Table 3. Thatch-mat depth (mm) in 'Providence' creeping bentgrass in response to light and frequent (LF) versus deep and infrequent (DI) irrigation in 2006 and 2007.

of rain fell on uncovered plots, respectively. Prior to the rain events, however, turf color began to decline in LF- versus DI-irrigated plots on July 26. Color ratings were higher in DI versus LF plots on August 7 and 15, which was prior to the rain events. The quality of DI plots did not become equal to LF plots until August 23. On September 6 and 10, however, quality of DI-irrigated plots surpassed the quality of LF plots.

In 2006, canopy temperature often ranged from 35 to 40° C, with temperatures as high as 43° C being recorded in DI plots on July 14, 2006 (Figure 3). On four of eight measurement dates in 2006, the average canopy temperature was 2.3° C higher in DI plots (average = 40.2° C) versus LF (average = 37.9° C) plots. In 2007, canopy temperatures generally were lower than were observed in 2006, but were above 33° C on all dates. On three of five measurement dates in 2007, the average canopy temperature was 2.1° C higher in DI (average = 38.2° C) versus LF (average = 35.9 ° C) plots.

Deeply and infrequently irrigated bentgrass leaves had a lower chlorophyll a content on three (June 15, July 13, and September 7) out of five 2006 measurement dates compared to LF bentgrass (Table 2). Chlorophyll b level also was lower on September 7, 2006 for DI versus LF bentgrass. Total chlorophyll (i.e, a + b) levels were similar between irrigation regimes on 19 May 19 and 8 August 8, but were higher in LF bentgrass on June 15, July 13, and September 7, 2006.

On June 1 and 28, 2007, there were no differences in leaf chlorophyll a, b, or a + b levels between the irrigation regimes. By July 17, 2007, and thereafter, leaf tissue from DI plots generally exhibited greater chlorophyll a, b, and a + b levels compared to LF bentgrass (Table 3). The only exception was on September 6 when leaf chlorophyll b levels were similar between irrigation regimes. Hence, leaf chlorophyll levels increased prior to the observed improvement of turf color in DI plots on July 26 (Figure 1) and well in advance of the 59.7 mm of rainfall on August 20 and 21.

Thatch-mat thickness data were collected on three dates in both years. The thatch-mat layer was thicker in LF versus DI bentgrass on all dates, except May 13, 2006 when similar thatch-mat depths were observed (Table 3). The largest

Irrigation	2006	2007		
	September 28	May 22	July 18	September 5
	............(mg g^{-1} soil)............			
LF †	233 a§	285 a	242 a	247 a
DI *	249 a	223 b	222 b	200 b

† Light and frequent (LF) irrigation was performed daily in the absence of rain to wet soil to a 4 to 6 cm depth.

* Deep and infrequent (DI) irrigation was performed at leaf wilt to wet soil to a depth of approximately 24 cm.

§ Means in a column followed by the same letter are not significantly different based on Fisher's protect ed least significant difference test (P=0.05).

Table 4. Total organic matter (mg loss on ignition per gram of soil) in the thatch-mat layer of 'Providence' creeping bentgrass in response to light and frequent (LF) versus deep and infrequent (DI) irrigation in 2006 and 2007.

increase in thatch-mat thickness occurred between August 19, 2006 and May 20, 2007, which was during the period when plots were not subjected to wilt and when a considerable amount of N was applied. Total organic matter (loss on ignition) in the thatch-mat layer was found to be less in the DI plots compared to LF plots on all dates (Table 4).

Discussion

It should be noted that this study site had an infiltration rate of nearly 50 cm hr^{-1} and water percolated to a depth of approximately 24 cm in 20 minutes. Soil moisture was measured at the 0 to 5 cm, 5 to 10 cm, and 10 to 15 cm rootzone depths. When compared to LF, DI plots had significantly lower soil moisture levels in the 0 to 5 cm (average of 6.2 versus 13.2%) and 5 to 10 cm soil depths (average of 6.8 versus 8.7%). Similar moisture levels were observed at the 10 to 15 cm (average of 8.2 versus 8.8%) depth between irrigation treatments. These data show the importance of obtaining soil moisture measurements at various levels in the rootzone when assessing the influence of LF- and DI-irrigation practices. Slightly over twice the amount of water was applied to LF (average = 342 mm) versus DI (average = 162 mm) plots in both years. Hence, substantial reductions in water usage can be achieved by irrigating to a soil depth of approximately 24 cm in sand-based rootzones when visual symptoms of wilt are evident compared to watering every day to replace ET.

Excessive irrigation can promote numerous negative effects in turfgrasses including reduced soil aeration; accelerated root loss in summer; increases in cyanobacteria, moss, and disease; and increased susceptibility to environmental and mechanical stresses (1, 4, 6, 13, 14). The overwhelming preponderance of data from this study, however, showed that continuously applying water to ensure a moist 4 to 6-cm rootzone each morning resulted in very good summer color and quality. Indeed, on most rating dates, creeping bentgrass subjected to LF irrigation achieved quality ratings above 8.0 (i.e., very good summer quality); whereas, DI plots had an average quality rating of 6.8 (range 5.7 to 9.3) in 2006.

Creeping bentgrass quality ratings in DI plots averaged 7.7 (range 6.3 to 9.0) in 2007, which was above the minimum acceptable level (i.e., 7.0). The lower quality ratings in 2006 in DI bentgrass were attributed to the relative immaturity of the creeping bentgrass, which may have been more adversely affected by wilt stress during the first summer of establishment.

Creeping bentgrass color and quality in DI plots improved after mid-June 2007 and exceeded LF bentgrass by September. This improvement may have been due in part to the 59.7 mm of rainfall that occurred on August 20 and 21, when plots were not covered. Improvements in color and increased chlorophyll levels in DI plots, however, were detected in mid-to-late July and exceeded LF plots prior to rainfall on August 20 and 21. Quality of DI plots, however, did not exceed LF plots until August 23, 2007. Hence, the aforementioned rainfall appeared to have had a more beneficial quality response in DI rather than LF plots in late summer of the second year. Regardless, by September 2007, DI plots continued to exhibit improved quality compared to LF plots. Other possible reasons for the improvement in DI bentgrass quality in 2007 are discussed below.

Since we are not aware of any investigations in which creeping bentgrass was irrigated at wilt stress, it is difficult to compare our results with other studies. Previous studies, however, have shown that turfgrass quality responds positively to deficit irrigation (3, 7, 16, 21). For example, Jordan et al. (2003) reported creeping bentgrass putting green quality was improved by irrigating every four days compared to irrigation every one or two days. In a study conducted by DaCosta and Huang (3), creeping bentgrass was maintained to a height of 9.5 mm and grown on a sandy loam, and plots were irrigated every 3 days to either 40, 60, 80, or 100% ET. They reported that creeping bentgrass irrigated at 80% ET maintained acceptable summer quality. Irrigating creeping bentgrass at 60% ET significantly reduced quality, and irrigating at 40% ET resulted in poor summer quality (3).

In our study, soil likely would have been much drier than the sandy loam irrigated at 40% ET by DaCosta and Huang (3). By continuously subjecting creeping bentgrass to wilt stress, leaves of some plants turned brown. Browning of tissue in response to wilt stress often reduced color and quality ratings, but drought-damaged plants invariably recovered. Additionally, the generally higher canopy temperatures in DI plots could have contributed to an increase in heat stress.

The improvement in color and quality in DI bentgrass throughout 2007, and in particular late summer, indicated that the turf may have adapted to wilt stress overtime. For example, turfgrasses subjected to deficit irrigation can develop a larger root system and store more carbohydrates than well-watered plants (2, 6, 8, 9, 16). Hence, the generally higher color and quality levels in DI plots in 2007 may be the result of a more expansive root system and improved carbohydrate status that develops when moisture stress is imposed on mature turf.

Chlorophyll content in living plants is an important factor in determining photosynthetic capacity as well as providing for visual green color. Moderate soil drying can increase leaf chlorophyll content. Jiang and Huang (15) reported that leaf chlorophyll a, b, and a + b content increased within 12 days after conditions of drought stress were imposed in tall fescue and within 6 days for Kentucky bluegrass grown in a greenhouse. Using a meter, DaCosta and Huang (3) observed higher chlorophyll index readings in bentgrass subjected to 60 and 80% ET compared to plots irrigated to 40 or 100% ET. Our results showed that DI irrigation reduced chlorophyll content in 2006, but resulted in an increase in chlorophyll by mid-July in 2007 compared to LF bentgrass. Higher chlorophyll levels in DI bentgrass were associated with improved visual color ratings after mid-July in 2007. The generally improved quality and increases in chlorophyll content in late summer of 2007 suggests that the creeping bentgrass was adapting to wilt stress and/or it was a function of maturity.

When measured in late summer in both years, thatch-mat thickness was about 32% less in DI versus LF plots. Similarly, total organic matter was about 23% less in late summer of both years in DI versus LF plots. Thatch decomposition by microorganisms would be expected to be impaired under dry conditions (1). Under conditions of restricted soil moisture and frequent wilt stress, however, there likely would be less stem and shoot growth, which could have resulted in less thatch-mat being produced. Regardless of the mechanism, thatch-mat accumulation was reduced when creeping bentgrass was routinely subjected to wilt stress in summer prior to being irrigated.

In practice, most golf course superintendents would not usually subject their putting greens to levels of wilt stress that would reduce quality to below acceptable levels. Obviously, a balance is necessary between maintaining soils as dry as possible, while avoiding LF irrigation. The restrictive irrigation employed in DI plots in this study probably should be avoided in the first summer following creeping bentgrass establishment in sand-based rootzones. By restricting irrigation, however, it appears that more mature plants adapt overtime to the stress by increasing chlorophyll levels and by eventually exhibiting improvements in color and quality. Substantial savings in water usage also are achieved by DI irrigation. Furthermore, restricting irrigation will limit thatch-mat accumulation, which is very important for numerous reasons as outlined by McCarty (17).

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Literature Cited

1. Beard. J. B. 1973. Turfgrass: Science and culture. Prentice-Hall, Englewood Cliffs, NJ. (TGIF Record 294)

2. DaCosta, M., and B. Huang. 2006. Changes in carbon partitioning and accumulation patterns during drought and recovery for colonial bentgrass, creeping bentgrass, and velvet bentgrass. *J. Amer. Soc. Hort. Sci.* 131:484-490. (TGIF Record 113616)

3. DaCosta, M., and B. Huang. 2006. Minimum water requirements for creeping, colonial, and velvet bentgrasses under fairway conditions. *Crop Sci.* 46:81-89. (TGIF Record 109502)

4. Dernoeden, P. H. 2002. Creeping bentgrass management: Summer stresses, weeds, and selected maladies. John Wiley & Sons, Hoboken, NJ. (TGIF Record 64873)

5. Dernoeden, P. H., and J. Fu. 2008. Fungicides can mitigate injury and improve creeping bentgrass quality. *Golf Course Management* 76(4):102-106. (TGIF Record 134970)

6. Fry, J., and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Inc., Hoboken, NJ. (TGIF Record 93226)

7. Fry, J., and J. D. Butler. 1989. Evapotranspiration rate of turf weeds and ground covers. *HortScience* 24:73-75. (TGIF Record 14141)

8. Fu, J., and B. Huang. 2001. Involvement of antioxidants and lipid peroxidation in the adaptation of two cool-season grasses to localized drought. *Environ. Exp. Bot.* 45:105-114. (TGIF Record 81542)

9. Fu, J., and P. H. Dernoeden. 2009. Creeping bentgrass putting green turf responses to two summer irrigation practices: Rooting and soil temperature. *Crop Sci.* 49:1071-1078. (TGIF Record 152931)

10. Fu, J., and P. H. Dernoeden. 2008. Carbohydrate metabolism in creeping bentgrass as influenced by two summer irrigation practices. *J. Amer. Soc. Hort. Sci.* 133:678-683. (TGIF Record 141452)

11. Fu, J., J. Fry, and B. Huang. 2004. Minimum water requirements of four turfgrasses in the transition zone. *HortScience* 39:1740-1744. (TGIF Record 111102)

12. Gibeault, V.A., J. L. Meyer, V. B.Youngner,

and S. T. Cockerham. 1985. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation: Performance of commonly used turfgrasses. Pages 347-356. *In* F. Lennaire (ed). Proc. 5th Intl. Turfgrass Res. Conf. Avignon, France. 1-5 July. INRA Publ., Versailles, France. (TGIF Record 9027)

13. Hodges, C. F. 1992. Interaction of cyanobacteria and sulfate-reducing bacteria on subsurface black-layer formation in high-sand content golf greens. *Soil. Biol. Biochem.* 24:15-20. (TGIF Record 41196)

14. Huang, B., X. Liu, and J. Fry. 1998. Effect of high temperature and poor soil aeration on root growth and viability of creeping bentgrass. *Crop Sci.* 38:1618-1622. (TGIF Record 56305)

15. Jiang, Y., and B. Huang. 2001. Drought and heat stress injury to two cool-season turfgrasses in relation to antioxidant metabolism and lipid peroxidation. *Crop Sci.* 41:436-442. (TGIF Record 73364)

16. Jordan, J., R. White, D.Vietor, T. Hale, J. Thomas, and M. Engelke. 2003. Effect of irrigation frequency on turf quality, shoot density, and root length density of five bentgrass cultivars. *Crop Sci.* 43:282-287. (TGIF Record 84098)

17. McCarty, L. B. 2001. Best golf course management practices. Prentice Hall, Upper Saddle River, NJ. (TGIF Record 73109)

18. McCarty, L. B., M. F. Gregg, and J. E. Toler. 2007. Thatch and mat management in an established creeping bentgrass golf green. *Agron. J.* 99: 1530-1537. (TGIF Record 131334)

19. Murray, J. J., and F.V. Juska. 1977. Effect of management practices on thatch accumulation, turf quality, and leaf spot damage in common Kentucky bluegrass. *Agron. J.* 69:365-369. (TGIF Record 849)

20. Murphy, J.A., P. E. Rieke, and A.E. Erickson. 1993. Core cultivation of a putting green with hollow and solid tines. *Agron. J.* 85:1-9. (TGIF Record 26844)

21. Richie, W. E., R. L. Green, G. J. Klein, and S. Hartin. 2002. Tall fescue performance influenced by irrigation scheduling, cultivar, and mowing height. *Crop Sci.* 42:2011-2017. (TGIF Record 83706)

22. Turgeon, A.J. 2008. Turfgrass management. 8th edition. Pearson Prentice Hall, Upper Saddle River, NJ. (TGIF Record 127766)