Seasonal Changes and Cultivar Difference in Turf Quality, Photosynthesis, and Respiration of Creeping Bentgrass

Xiaozhong Liu
Department of Botany and Microbiology, University of Oklahoma, Norman, OK 73019

Bingru Huang
Department of Plant Science, Rutgers University, New Brunswick, NJ 08901

Abstract. Summer decline in turf quality of creeping bentgrass (Agrostis palustris Hudson) is a major problem in golf course green management. The objective of this study was to examine whether seasonal changes and cultivar variations in turf performance are associated with changes in photosynthesis and respiration rates for creeping bentgrass. The study was conducted on a USGA specification putting green in Manhattan, Kans., during 1997 and 1998. Four creeping bentgrass cultivars, ‘L-93’, ‘Crenshaw’, ‘Penncross’, and ‘Providence’, were examined. Grasses were mowed daily at 4 mm and irrigated on alternate days to replace 100% of daily water loss. In both years, turf quality, canopy net photosynthetic rate (Pn), and leaf photochemical efficiency (Fv/Fm) were high in May and June and decreased to the lowest levels in July through September. Whole-plant respiration rate (R) and canopy minus air temperature (ΔT) increased during summer months. In October, turf quality and Pn increased, whereas R and ΔT decreased. During summer months, turf quality was highest for ‘L-93’, lowest for ‘Penncross’, and intermediate for ‘Providence’ and ‘Crenshaw’. Seasonal changes and cultivar variations in turf quality were associated with the decreasing photosynthetic rate and increasing respiration rate.

Materials and Methods

Plant materials and growing conditions. Four creeping bentgrass cultivars, ‘L-93’, ‘Providence’, ‘Crenshaw’, and ‘Penncross’, were examined. ‘Crenshaw’ and ‘Penncross’ are grown widely on golf greens, whereas ‘L-93’ and ‘Providence’ are relatively new cultivars. Each cultivar was seeded in 20.5 cm-wide × 73.5 cm-long plots at a rate of 76 kg ha⁻¹ in late Sept. 1996 on a USGA specification putting green at the Rocky Ford Turfgrass Research Center, Kansas State Univ., Manhattan. The green was covered with a fabric tarp from Dec. 1996 to Mar. 1997 to allow better canopy establishment. By June 1997, the canopy was completely closed. During the growing season from mid-June to mid-Oct. 1997 and from early May to late Oct. 1998, grasses were mowed daily, except Sundays, at 4 mm. During this period, the green was irrigated on alternate days to replace 100% of the evapotranspiration (ET) rate on the previous 2 days. The ET rate was estimated using an alimeter as described in Qian et al. (1996). Turf received four applications of total N of 216 kg ha⁻¹ in 1997 and 238 kg ha⁻¹ in 1998 to maintain adequate soil nutrients. In both years, lprodione [(3-(3,5-dichlorophenyl)-N-(1-methyl-ethyl)-2,4-dioxo-1-imidazolidine-carboxamide] at 3 kg ha⁻¹ was applied to control dollar spot and brown patch as a curative treatment as soon as initial symptoms were detected.

Measurements. All measurements were made nondestructively every 2 weeks on four samples randomly selected in each plot from mid-June to mid-Oct. 1997 or from late May to late Oct. 1998. Air temperatures were monitored with thermocouples, and data were collected with a CR-10 datalogger (Campbell Scientific, Logan, Utah). Canopy minus air temperature was determined with an infrared thermometer (Everest Intercensc, Tustin, Calif.) that was positioned at 45° and ± 30 cm from the canopy surface on clear sunny days from 1000 to 1200 hr. Turf quality was rated visually as a combination of density, uniformity, and color on a scale of 0 (lowest) to 9 (best).

Canopy net photosynthetic rate (Pn) and whole-plant (shoots and roots) dark respiration (R) rates were measured at various times in 1997 and 1998 by enclosing the turf canopy in a transparent cubic Plexiglas chamber (15 cm wide × 15 cm long × 12 cm deep) attached to the LI-COR 6400 gas exchange system (LI-COR, Lincoln, Nebr.). The Pn and R values were expressed as rates of CO₂ uptake and evolution per unit turf area, respectively. Canopy photosynthetic rate was measured once daily between 10:00 and 16:00 hr on sunny days. Dark respiration rate of whole plants with soil and that of bare soil without grass was measured 2 h after sunset. Respiration rate of plants was determined by subtracting soil respiration rate from that of whole plants with soil (Huang et al., 1998). Leaf photochemical efficiency was estimated by measuring chlorophyll fluorescence (Fv/Fm) (Krause and Weis, 1991) after leaves were exposed to the dark for...
20 min using the Plant Efficiency Analyzer (Hansatech Instrument, Kings Lynn, England).

Experimental design and statistical analysis. The four bentgrass cultivars were arranged in a randomized complete-block design with three replicates. Effects of sampling time, cultivar, and the interaction were determined by analysis of variance according to the general linear model procedure of the Statistical Analysis System (SAS, Cary, N.C.). Differences between cultivar means at a given time or differences between sampling times were separated by the least significance difference (LSD) test at the 0.05 level.

Results

Air temperature. Air temperatures fluctuated in both 1997 and 1998 at the experimental site, as shown in Fig. 1. However, they generally increased as summer approached, reaching the highest levels in late July 1997 and mid-July 1998. On many days in both years, temperature exceeded the high end of the optimum temperature range (24 °C), particularly in 1998.

Canopy minus air temperature (ΔT). In 1997, ΔT fluctuated somewhat, but all four cultivars had the highest values during July and August (Fig. 2) and the lowest levels in September and October. In 1998, ΔT increased steadily from May to the highest levels in July and August and then decreased steadily to a lower level in October (Fig. 2). ‘Penncross’ had significantly higher ΔT than ‘L-93’ at most times of July and August in both years.

Turf quality. Turf quality in 1997 increased from June to the highest levels in July, declined in August, and remained at a low level until September (Fig. 3). In October, turf quality increased to levels similar to those in August. This seasonal pattern was true for all four cultivars.

In 1998, turf quality of all four cultivars was highest in late May (Fig. 3). Quality began to decline from late June and reached the lowest levels in late August and early September. Then it began to recover in late September, and by late October reached levels similar to those in June.

The decline in turf quality during summer months was more dramatic in 1998 than in 1997. ‘Penncross’ had significantly lower turf quality than the other three cultivars at most times from June to Sept. 1997 and from July to Sept. 1998. ‘L-93’, ‘Crenshaw’, and ‘Providence’ had similar quality during most months, but ‘Crenshaw’ had lower quality in September.

Canopy net photosynthesis (Pn) and whole-plant respiration rate (R). In 1997, Pn values for all four cultivars were highest in early July and then decreased to the lowest levels in August and early September (Fig. 4). In mid-September and October, Pn increased to higher levels than those in August and early September. In 1998, Pn for all cultivars was highest in mid-June and then decreased to the lowest levels in late July and early August (Fig. 4). Net photosynthesis increased somewhat in

Fig. 1. Seasonal changes in air temperatures in 1997 and 1998 at the Rocky Ford Turfgrass Research Center, Kansas State Univ., Manhattan. Tmax is the maximum daily temperature; Tmin is the minimum daily temperature.

Fig. 2. Seasonal changes in canopy minus air temperature (ΔT) of creeping bentgrass in 1997 and 1998. Vertical bars indicate LSD values (P = 0.05) for cultivar comparisons within a given day. LSD values (P = 0.05) for seasonal comparisons at 1997 and 1998 were 0.10 and 0.06 for ‘L-93’, 0.12 and 0.08 for ‘Providence’, 0.25 and 0.10 for ‘Penncross’, and 0.30 and 0.12 for ‘Crenshaw’.

Fig. 3. Seasonal changes in turf quality in 1997 and 1998.
late August but was still lower than that in early June. In October, \( P_n \) increased to levels similar to those in June.

During most of the growing season, ‘L-93’ had the highest \( P_n \), ‘Penncross’ had the lowest \( P_n \), and ‘Providence’ and ‘Crenshaw’ had intermediate \( P_n \).

The seasonal pattern in \( R \) (Fig. 5) contrasted to that of \( P_n \). Respiration rates in 1997 increased to the highest levels in late August and then decreased to the lowest levels in late October. In 1998, \( R \) increased to the highest levels in July and August and then decreased to lower levels in September and October.

During late Aug. 1997 and from July to early Oct. 1998, \( R \) was highest for ‘Penncross’, lowest for ‘L-93’, and intermediate for ‘Crenshaw’ and ‘Providence’.

**Leaf photochemical efficiency (Fv/Fm).** The Fv/Fm ratios for all cultivars were highest in May and June and declined rapidly to the lowest levels in July through early September in both 1997 and 1998 (Fig. 6). The ratio increased from September to October in 1997.

From July to September in both years, ‘Penncross’ had the lowest Fv/Fm ratio, ‘L-93’ had the highest, and ‘Providence’ and ‘Crenshaw’ were intermediate.

**Discussion**

**Seasonal changes.** Turf quality of all four cultivars declined during summer months in both 1997 and 1998, but the decline was greater in 1998. Seasonal changes in turf performance rated as visual quality were related closely to changes in air temperature and \( \Delta T \); both were highest during the summer months. Air temperature reached a high level earlier and remained higher longer in 1998 than in 1997.

The \( \Delta T \) is determined by transpirational effect. Under optimum growth conditions, transpirational water loss from leaves results in a leaf temperature that is lower relative to air temperature. Therefore, a negative \( \Delta T \) indicates a healthy leaf. A high positive \( \Delta T \) usually is associated with heat stress injury in leaves (Nobel, 1991).

The decline in turf quality during summer months could be associated with the decrease in photosynthetic capacity and increase in respiration rate. Canopy \( P_n \) of cool-season plants decreases with increasing temperatures (Huang and Gao, 2000; Huang et al., 1998; Paulsen, 1994). In general, three major factors control canopy \( P_n \), including leaf area, color, and photochemical efficiency expressed as chlorophyll fluorescence (Fv/Fm).

The differences between \( P_n \) and \( R \) determine the availability of carbohydrates to support plant growth. Greater \( P_n \) than \( R \) and net carbon gain are important processes controlling shoot and root growth. However, \( P_n \) decreased while \( R \) increased during the summer in both years. The imbalance between \( P_n \) and \( R \) could cause carbohydrate depletion, leading to the decline in turf quality and growth. In earlier work with ‘Cohanesey’ creeping bentgrass, Schmidt and Blaser (1967) also reported carbohydrate depletion under high temperatures. The increase in whole-plant res-
piration could be caused largely by the increase in root respiration (Ruter and Ingram, 1991), because roots are more sensitive to temperature changes than shoots (Paulsen, 1994). Increasing mowing height could enhance \( P_r \) and carbohydrate accumulation, but this practice is not practical on golf courses. Turf quality and growth could be improved by reducing carbohydrate consumption through respiration. This could be achieved by reducing soil temperature by any means possible, such as syringing (Beard, 1997). Xu and Huang (2000) found that lowering soil temperature while exposing shoots to high air temperature reduced respiration rate and enhanced \( P_n \) and turf quality in creeping bentgrass.

**Cultivar variations.** The decline in turf quality during summer was least for ‘L-93’, greatest for ‘Penncross’, and intermediate for ‘Providence’ and ‘Crenshaw’, indicating that creeping bentgrass cultivars vary in heat tolerance, with ‘L-93’ being more tolerant to heat stress than ‘Penncross’, and ‘Crenshaw’ and ‘Providence’ being intermediate. This result was consistent with results of other researchers who examined the same four cultivars (Settle, personal communication). In growth chamber studies with high temperature treatment, ‘L-93’ and ‘Crenshaw’ maintained better quality than ‘Penncross’ (Huang and Gao, 2000; Huang et al., 1998).

The difference between canopy and air temperatures had been used widely to indicate turf performance. The increase in \( \Delta T \) was least in ‘L-93’, most in ‘Penncross’, and intermediate in ‘Crenshaw’ and ‘Providence’ during summer months. This suggested that ‘L-93’ maintained the highest transpirational ability to cool down the leaves and protect the photosynthetic metabolism from heat stress injury. ‘Penncross’ maintained poor transpirational cooling and was affected more by heat stress. The differences in \( \Delta T \) between ‘L-93’ and ‘Penncross’ could be related to differences in their leaf characteristics. Xu and Huang (2000) reported that compared to ‘Penncross’, ‘L-93’ had narrower leaves that have lower boundary resistance to water loss and are conducive to transpirational cooling.

In both years, ‘L-93’ maintained the highest \( P_n \) in the summer months. In a growth chamber study (Huang et al., 1998), ‘Crenshaw’ maintained higher \( P_r \) than ‘Penncross’ under heat stress. Watschke et al. (1972) also found that heat-tolerant genotypes of bermudagrass (*Cynodon dactylon* L.), Kentucky bluegrass (*Poa pratensis* L.), and creeping red fescue (*Festuca rubra* L.), had higher \( P_r \). In contrast to \( P_n \), whole-plant respiration was greatest for ‘Penncross’, least for ‘L-93’, and intermediate for ‘Providence’ and ‘Crenshaw’. This result indicated that ‘Penncross’ could have less carbohydrate availability in the summer months, which could contribute to the more severe declines in turf quality.

In summary, decline in turf quality occurred in the summers of 1997 and 1998. The declines in turf quality and growth could be associated with decreasing photosynthesis and increasing respiration, leading to carbohydrate depletion. Use of heat-tolerant cultivars such
as ‘L-93’ could help maintain quality turf and reduce management costs during summer months. Any cultural practices that could promote carbon production through photosynthesis or reduce carbon consumption through respiration would be beneficial for maintaining the quality of creeping bentgrass during summer.

**Literature Cited**

Beard, J.B. 1973. Turfgrass: Science and culture. Prentice-Hall, Englewood Cliffs, N.J.

Carrow, R.N. 1996. Summer decline of bentgrass greens. Golf Course Mgt. 64:51–56.

DiPaola, J.M. and J.B. Beard. 1992. Physiological effects of temperature stress, p. 231–262. In: D.V. Waddington, R.N. Carrow, and R.C. Shearman (eds.). Turfgrass Agron. Soc. Amer. Publ., Madison, Wis.

Huang, B. and W. Gao. 2000. Growth and carbohydrate metabolism of creeping bentgrass cultivar in response to increasing temperature. Crop Sci. 40:1115–1120.

Huang, B., X. Liu, and J.D. Fry. 1998. Shoot physiological responses of two bentgrass cultivars to high temperature and poor soil aeration. Crop Sci. 38:1219–1244.

Kobza, J. and G.E. Edwards. 1987. Influences of leaf temperature on photosynthetic carbon metabolism in wheat. Plant Physiol. 83:69–74.

Krans, J.V. and G.V. Johnson. 1974. Some effects of subirrigation on bentgrass during heat stress in the field. Agron. J. 66:526–530.

Krause, G.H. and E. Weis. 1991. Chlorophyll fluorescence and photosynthesis: The basics. Annu. Rev. Plant Physiol. Plant Mol. Biol. 42:313–349.

Lopez, R.R., A.G. Matche, and J.D. Baldridge. 1967. Vegetative development and organic reserve of tall fescue under conditions of accumulated growth. Crop Sci. 7:409–412.

Nobel, P.S. 1991. Physicochemical and environmental plant physiology. Academic, London.

Paulsen, G.M. 1967. Effect of temperature, light, and nitrogen on growth and metabolism of ‘Cohansey’ bentgrass (Agrostis palustris Huds.). Crop Sci. 7:372–376.

Paulsen, G.M. 1994. High temperature responses of crop plants, p. 365–389. In: K.J. Boote, J.M. Bennett, T.R. Sinclair, and G.M. Paulsen (eds.). Physiology and determination of crop yield. ASA, CSSA, and SSSA, Madison, Wis.

Qian, Y.L., J.D. Fry, S.C. Wiest, and W.S. Upham. 1996. Estimating turfgrass evapotranspiration using atmometers and the Penman–Monteith model. Crop Sci. 36:699–704.

Robson, M.J. 1968. Changing tillering population of spaced plants of S.170 tall fescue (Festuca arundinacea), J. Appl. Ecol. 5:575–590.

Ruter, J.M. and D.L. Ingram. 1991. Root respiratory characteristics of ‘Rotundifolia’ holly under supraoptimal temperatures. J. Amer. Soc. Hort. Sci. 116:560–564.

Sanftier, K.A. 1975. Sites of heat sensitivity in chloroplasts and differential inactivation of cyclic and noncyclic photophosphorylation by heating. J. Therm. Biol. 1:101–107.

Schmidt, R.E. and R.E. Blaser. 1967. Effect of temperature, light, and nitrogen on growth and metabolism of ‘Cohansey’ bentgrass (Agrostis palustris Huds.). Crop Sci. 7:447–451.

Schreiber, U. and W. Bilger. 1987. Rapid assessment of stress effects on plant leaves by chlorophyll fluorescence measurements, p. 27–53. In: J.D. Tenhunen (ed.). Plant response to stress. Springer-Verlag, Heidelberg, Germany.

Spak, D.R., J.M. DiPaola, and C.E. Anderson. 1993. Tall fescue sward dynamics: I. Seasonal patterns of turf shoot development. Crop Sci. 33:300–304.

Watschke, T.L., R.R. Schmidt, and R.E. Blaser. 1970. Responses of some Kentucky bluegrass cultivars to high temperature and nitrogen fertility. Crop Sci. 10:372–376.

Xu, Q. and B. Huang. 2000. Effects of differential air and soil temperatures on carbohydrate metabolism in creeping bentgrass. Crop Sci. 40:1368–1374.

Zarrough, K.M., C.J. Nelson, and J.H. Coutts. 1983. Relationship between tillering and forage yield of tall fescue: II. Pattern of tillering. Crop Sci. 23:338–342.