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

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Abstract. Summer decline in turf quality of creeping bentgrass (*Agrostis palustris* Hud.) 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', 'Pennncross', 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 (P_n), 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 P_n increased, whereas R and T decreased. During summer months, turf quality was highest for 'L-93', lowest for 'Pennncross', 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.

Creeping bentgrass is a cool-season grass commonly used on golf course greens in the transition zone and northern United States. The optimum temperatures for shoot growth of cool-season grasses are 15 to 24 °C, and maximum growth occurs during spring and fall when these temperatures are common (Beard, 1973). Temperatures often exceed the optimum range during summer. Decline in growth and quality of creeping bentgrass during summer months is common on many golf courses when greens are receiving maximum use (Beard, 1973).

High temperature generally reduces shoot growth and density in cool-season turf (Beard, 1973; Carrow, 1996; DiPaola and Beard, 1992; Krans and Johnson, 1974). However, growth responses to high temperature can vary among cool-season turfgrass cultivars. Zarroug et al. (1983) and Spak et al. (1993) reported that under hot summer conditions shoot mortality increased and shoot initiation decreased in

several cultivars of tall fescue (*Festuca arundinacea* Schreb.), leading to reduction in stand density. However, Lopez et al. (1967) and Robson (1968) reported that other tall fescue cultivars maintained high tiller density during summer months.

Sustaining turf quality and growth may depend on the balance between photosynthesis and respiration. This may be especially true for creeping bentgrass, which is mowed closely and has little leaf area remaining to capture light energy. High temperature stress can damage a plant's photosynthetic system (Carrow, 1996; Paulsen, 1994; Santarius, 1975; Schreiber and Bilger, 1987), but may increase dark respiration (Carrow, 1996; Paulsen, 1994) and photorespiration (Kobza and Edwards, 1987). Earlier growth chamber studies with creeping bentgrass showed that photosynthesis rate decreased but respiration rate increased with increasing temperature (Huang and Gao, 2000; Huang et al., 1998). Whether seasonal changes in creeping bentgrass growth are related to changes in photosynthesis and respiration is not clear. Furthermore, variations in physiological responses to summer stress among creeping bentgrass cultivars are poorly understood.

The objectives of this study were to: 1) investigate genetic variations in seasonal shoot growth patterns and summer decline of creeping bentgrass and 2) examine the physiological factors that influence summer decline.

Plant materials and growing conditions. Four creeping bentgrass cultivars, 'L-93', 'Providence', 'Crenshaw', and 'Pennncross', were examined. 'Crenshaw' and 'Pennncross' are grown widely on golf greens, whereas 'L-93' and 'Providence' are relatively new cultivars. Each cultivar was seeded in 20.5-cm-wide $\times$ 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 altimeter 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, Iprodione [(3-(3,5-dichlorophenyl)-N-(1-methylethyl)-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 (Everst Interscience, Tustin, Calif.) that was positioned at 45° and $\approx$ 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 (P_n) 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 $\times$ 15 cm long $\times$ 12 cm deep) attached to the LI-COR 6400 gas exchange system (LI-COR, Lincoln, Nebr.). The P_n 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

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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). 'Pennncross' 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. 'Pennncross' 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 (P_n) and whole-plant respiration rate (R). In 1997, P_n 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, P_n increased to higher levels than those in August and early September. In 1998, P_n 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. T_{max} is the maximum daily temperature; T_{min} 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 in 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 'Pennncross', and 0.30 and 0.12 for 'Crenshaw'.

Fig. 3. Seasonal changes in turf visual quality 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 0.32 and 0.20 for 'L-93', 0.21 and 0.18 for 'Providence', 0.60 and 0.23 for 'Pennncross', and 0.60 and 0.31 for 'Crenshaw'.

Fig. 4. Seasonal changes in canopy net photosynthetic rate (P_n) 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 0.31 and 0.22 for 'L-93', 0.12 and 0.72 for 'Providence', 0.22 and 0.52 for 'Pennncross', and 0.22 and 0.32 for 'Crenshaw'.

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 , 'Pennncross' 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 'Pennncross', 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, 'Pennncross' 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 ΔT ; both were highest during the summer months. Air temperature reached a high level earlier and remained higher longer in 1998 than in 1997. The ΔT 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 ΔT indicates a healthy leaf. A high positive ΔT 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 'Cohansey' creeping bentgrass, Schmidt and Blaser (1967) also reported carbohydrate depletion under high temperatures. The increase in whole-plant res-

Fig. 5. Seasonal changes in whole-plant respiration rate (R) 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 0.65 and 0.22 for 'L-93', 1.00 and 0.28 for 'Providence', 0.48 and 0.45 for 'Pennncross', and 0.52 and 0.55 for 'Crenshaw'.

Fig. 6. Seasonal changes in canopy photochemical efficiency (F_v/F_m) 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 were 0.01 for 'L-93', 0.008 for 'Providence', 0.03 for 'Crenshaw', and 0.005 for 'Pennncross' in 1997, and 0.008 for 'L-93', 0.008 for 'Providence', 0.012 for 'Pennncross', and 0.020 for 'Crenshaw' in 1998.

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_n 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 'Pennncross', 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 'Pennncross', 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 'Pennncross' (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 ΔT was least in 'L-93', most in 'Pennncross', 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. 'Pennncross' maintained poor transpirational cooling and was affected more by heat stress. The differences in ΔT between 'L-93' and 'Pennncross' could be related to differences in their leaf characteristics. Xu and Huang (2000) reported that compared to 'Pennncross', '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_n than 'Pennncross' 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_n . In contrast to P_n , whole-plant respiration was greatest for 'Pennncross', least for 'L-93', and intermediate for 'Providence' and 'Crenshaw'. This result indicated that 'Pennncross' 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.

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