CHAPTER FOUR

BENTGRASS CULTIVAR AND ANNUAL NITROGEN REGIME AFFECTS SEASONAL SHOOT DENSITY

Abstract

Creeping bentgrass (*Agrostis stolonifera* var. *palustris* Huds. Farw.) is the preferred turfgrass species for golf greens. During summer months, however, shoot density (SD) often declines, resulting in poor stand quality. Turf managers utilize several management practices to maintain turf vigor. One practice is light, frequent, nitrogen (N) fertilization. However, annual N-rates vary widely. Recently, high shoot density (HSD) bentgrasses bred to provide superior appearance and stress tolerance compared to the industry standard, Penncross have been widely planted. The effect of variable N-rates on these cultivars is unclear. This field study measured seasonal SD changes of three contrasting cultivars maintained with low and high N-regimes, 112 and 196 kg N $ha^{-1}yr^{-1}$, respectively. Significant seasonal SD differences were measured and cultivars ranked A-4 (1400 - 2160 shoots dm^{-2}) > L-93 (1230-1780 shoots dm^{-2}) > Penncross (760-1470 shoots dm^{-2}). Generally, increasing N resulted in only slight differences in SD. In Aug., however, when N-regime was averaged across cultivars, higher N significantly increased SD in both study years. For the densest, most persistent turf during summer months, a HSD cultivar should be planted and moderate (146-196 kg N ha^{-1} yr^{-1}) N should be applied to sustain appearance and ensure adequate recovery should turf damage occur.

Introduction

Creeping bentgrass (*Agrostis stolonifera* var. *palustris* Huds. Farw.) is the most widely planted turfgrass species for golf course putting greens in the United States (Beard, 2002). Creeping bentgrass is a cool-season grass that forms an extremely dense, fine textured persistent turf which tolerates close (<3 mm), frequent mowing. The most commonly planted cultivar for putting greens since the 1950's has been Penncross (Beard et al., 2001). In recent decades new cultivars such as A-4 and L-93 have been developed and commercialized from existing cultivars, predominately Penncross, to improve playing conditions and meet golfer demands for more closely mowed putting greens. These cultivars posses a HSD and generally have better overall turfgrass quality (TQ) compared to Penncross. Some of the characteristics associated with the superior quality are: a more upright growth habit, higher SD, finer leaf texture, increased rooting depth, greater resistance to certain turf pathogens, better resist annual bluegrass (*Poa annua* L.) invasion, and improved heat and drought tolerance (Fraser, 1998; Beard et al., 2001; Bruneau et al., 2001; Morris, 2003; Stier and Hollman, 2003; Voigt et al., 2005).

Since bentgrass is a cool-season turf, a decline in density during the summer months is common throughout the lower cool-humid and transition zone regions (Carrow, 1996). Various cultural practices like mowing height, fertilization regime, and grooming can have an influence on SD, although little scientific data has reported the effects of these practices. The effect of mowing height (3.2 vs. 4 mm) on SD for twenty cultivars was evaluated in North Carolina but no correlation between mowing height and SD was observed (Bruneau et al., 2001). Research conducted in Texas found that five bentgrass cultivars irrigated every four days versus every one or two days increased SD (Jordan et al., 2003).

Contemporary golf course managers frequently apply N between 100 and 195 kg N $ha^{-1}yr^{-1}$ (USGA Green Section Staff, 2007). In recent years there has been a trend toward applying minimal ($\leq$ 100 kg N $ha^{-1}yr^{-1}$) N-amounts in an effort to produce consistently long ball roll distances. This practice of applying low annual N-amounts could result in substantial thinning because plants lack sufficient vigor needed to produce new shoots, especially during heat stress. In addition to regular mowing and fertilization, sand topdressing is commonly applied to golf greens for thatch management and to firm and smooth the surface. Sand particles are very abrasive to plant leaves and could severely reduce SD if intensive topdressing practices are conducted during summer stress (Carrow, 1996; Dernoeden, 2002). Anecdotal reports suggest that HSD cultivars require more intensive topdressing (Fraser, 1998) and thus more potential for leaf abrasion and thinning turf in golf greens with these cultivars, especially when grown with low N. Seasonal data regarding the changes in bentgrass SD when subjected to regular frequent topdressing does not exist. Additionally, the changes in putting green surface functional characteristics [i.e. surface hardness (SH), ball roll distance] as a result of seasonal SD declines are unclear but could be influenced by N-fertilization practices. Therefore, the objective of this field study was to measure seasonal changes in SD of three creeping bentgrass cultivars when maintained under two annual nitrogen regimes.

Materials and Methods

A field experiment was conducted from Aug. 2004 through Nov. of 2007 on a sand-based (80 sand: 20 peat mixture) research green built to United States Golf Association (USGA) construction specifications with > 90 % of the sand particles between 0.1 - 1.0 mm size (USGA Green Section Staff, 1993) at the Purdue University, W.H. Daniel Turfgrass Research and Diagnostic Center, West Lafayette, Indiana. The rootzone was an 80:20 (v:v) sand and sphagnum peat mixture, which has a pH of 7.5 and a CEC of < 2 $cmol_c$ kg^{-1}. All construction materials were tested by an accredited lab (Hummel & Co, Inc., Trumansburg, NY) and met USGA specifications for putting green construction (Table A-9) (USGA Green Section Staff, 1993). The base sand was a locally available and widely used calcareous sand (Shelby Materials, Shelbyville, IN).

General Plot Maintenance

Three widely planted creeping bentgrass cultivars, A-4, L-93, and Penncross, were seeded on 5 August 2003 in 1.5 x 1.5 m plots at a rate of 73 kg seed ha^{-1}. A seeding box (1.5 x 1.5 m) was used to prevent cultivar seed contamination. A granular starter fertilizer (0-46-0) was applied at 73 kg P_2O_5 ha^{-1} to the rootzone prior to seeding and other nutrients were applied according to soil test recommendations. The study site was located in full-sun with no surrounding obstructions, which was conducive to rapid drying of the canopy in the early morning hours. Irrigation was used to supplement rainfall and promote plant growth during the growing months (Apr. - Nov.). In the absence of a significant ($\geq$ 13 mm) rainfall event, overhead irrigation was applied approximately 5 mm nightly to achieve 35 mm wk^{-1}. Irrigation was reduced to once per week (5 mm wk^{-1}) from 21 July to 15 Aug. 2006 and from 9 Aug. to 30 Aug. 2007. Plots were mowed (3.6 mm) six days per week using a triplex reel mower (Toro Greensmaster 3100, The Toro Company, Bloomington, MN) with clippings removed. Fungicides (chlorothanonil, propiconazole, thiophanate-methyl, and flutolonil) were applied curatively 2004 - 2006 and preventatively in 2007 during periods of active disease pressure, primarily for dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) and brown patch (*Rhizoctonia solani* Kuhn.) control.

Nitrogen Applications

Two fertility regimes designated as "low" and "high" were used to assess the varying range of N applied to golf course putting greens. Initially in 2004 and 2005 N regimes were 146 vs. 293 kg N $ha^{-1}yr^{-1}$ for the low and high N-levels respectively. Slightly higher N-levels were used during "grow-in" to ensure maximum turf coverage. In 2006, fertility was lowered (112 vs. 196 kg N $ha^{-1}yr^{-1}$) to adjust N-rates to those commonly applied by golf course managers in the cool-humid region. Nitrogen was applied either as liquid or granular formulations depending on application rates and dates (Table A-9). Granular applications for the "low" treatment were applied with a broadcast rotary spreader. "High" treatment plots receiving additional granular N-applications were applied evenly over individual plots using a hand shaker with a pre-weighed amount of fertilizer. Granular applications were made in mid-Apr., mid-Sept., and Oct. (depending upon annual N-regime) at 24 kg N ha^{-1}. Liquid applications were applied using a 2 m wide hand held boom sprayer with an 8010E TeeJet XR nozzle attached to an 11.4 L hand-pump back-pack container for "low" treatments. Additional liquid N-applications for "high" treatments were applied using a pressurized (242 kPa) CO_2 back-pack sprayer equipped with an 8010E TeeJet XR nozzle with 820 L ha^{-1} spray volume. Liquid applications of 10 kg N ha^{-1} were made every 14 days for the "high" treatment monthly for the "low" treatment (excluding Aug.) from May to Oct.

Topdressing Sand

Two different sand sizes were applied as topdressing: a predominantly medium-coarse (0.25-1 mm) sand that matched the underlying rootzone and a predominantly medium-fine (0.15-0.5 mm) sand. The medium-fine sand was selected because it is typical of sands chosen to easily filter into dense turf canopies. Particle size analysis was conducted (Table A-2) to determine sand sizes in relation to USGA specifications. The medium-coarse sand, which matched the underlying rootzone, fell within USGA specifications for rootzone construction while the medium-fine sand did not meet USGA specifications (USGA Green Section Staff, 2004). The medium-fine sand had approximately 650 g kg^{-1} in the fine sand category. Both sands were stored indoors to keep them dry and weed free.

Topdressing Applications

Topdressing applications began in May of 2004 and were applied using a 1 m wide drop-spreader (LESCO Drop Spreader, Cleveland, OH). Light applications consisted of 0.03 m^3 sand 100 m^2 applied every 7-10 days during periods of active growth. During periods of severe high temperature stress light topdressing was applied every 10-14 days. Heavy sand topdressing (0.13 m^3 100 m^2) was applied twice annually to back-fill aerification channels. Additionally, moderate (0.06 m^3 100 m^2) applications were made during periods of optimum growing conditions (Tables A-3, A-4, A-5, and A-6). Following all topdressing applications, sand was brushed into the turf canopy using a stiff bristle push broom in perpendicular directions.

Shoot Density

Seasonal SD was measured by removing two intact cores (1.9 cm diam., 2.84 cm^2) per plot with a soil probe and counting individual shoots which were then averaged and used for data analysis. A shoot was defined as a fully expanded leaf. Four (June, July, Aug., Oct.) SD measurements were taken in 2006 and six times (May - Oct.) in 2007.

Surface Hardness

A Clegg Impact Soil Tester (0.5 kg model, Lafayette Instrument Co., Lafayette, IN) was used to measure surface hardness (SH). The Clegg impact hammer is a commonly accepted method of measuring SH (Lush, 1985; Linde, 2005). Readings were taken nine times throughout 2006 and 2007. The hammer was dropped from 0.46 m three times per location and the third value was recorded. Two locations were measured per sub-plot and averaged to one value. Units were recorded in Clegg Impact Values (CIV's) which were converted to g_{max} (peak deceleration) using the following equation, (Bregar and Moyer, 1990).

Accerlation Due to Gravity

$$g_{max} = 10(CIV)$$

Ball Roll Distance

Ball roll distance is a key characteristic that identifies putting green smoothness and playability (Salaiz et al., 1995). Ball roll distance was measured using a modified USGA stimpmeter with the ball release notch half (38 cm) the distance compared to the conventional stimpmeter (Gaussoin et al., 1995). The average distance for three golf balls rolled in one direction and then re-rolled in the opposite direction was determined for each plot.

Visual Ratings

Plots were visually assessed every 7-10 days throughout the study for TQ on a 0-10 scale with 0=brown dead turf, 10=optimum greenness, density and uniformity, ratings ≥ 7 = acceptable putting green turf.

Experimental Design and Statistical Analysis

The study design was a 3 x 2 (cultivar x N regime) factorial with each treatment replicated four times and arranged in randomized complete block design. Due to the large number of TQ ratings, data were pooled into two-month periods and then used for statistical analysis. All data was subjected to analysis of variance using the SAS system (Statistical Analysis Systems Institute Inc., Cary, N.C.) general linear models procedure and treatment means separated using Fisher's protected least significant difference (LSD) test at the $p=0.05$ level.

Results and Discussion

Seasonal Variations in Bentgrass Shoot Density

Seasonal SD counts ranged from 760 to 2160 shoots dm^{-2} throughout the study (Tables 4-1 and 4-2). The temporal changes in SD followed the cool-season growth pattern with the highest values measured during spring and autumn and a decline during the summer months. Spring density was determined using the time period from May-June, summer was from July-Aug., and autumn was from Sept.-Oct. Cultivar had a significant effect on SD in both study years. Among cultivars, A-4 generally possessed the highest SD (1400-2160 shoots dm^{-2}) compared to Penncross (760-1470 shoots dm^{-2}) which had the least, while L-93 was intermediate (1230-1780 shoots dm^{-2}). While each cultivar experienced reduced SD during the summer, the magnitude of the decline varied with cultivar and to a lesser extent, N-regime. When comparing the cultivars on a percentage basis, the spring density of Penncross in both years was on average 37 % less than A-4 at 196 kg N ha^{-1} yr^{-1}. By comparison, summer density of Penncross averaged over both years was 44 % less than A-4 under 196 kg N ha^{-1} yr^{-1}. The higher SD of L-93 and A-4 is consistent with reports that have demonstrated the enhanced ability of HSD cultivars to provide superior turf conditions during the summer when compared to Penncross and many other earlier bentgrass generations (Landry and Schlossberg, 2001).

The SD values for HSD cultivars in this study were generally similar to some previously reported values (Ervin et al., 2000; Bruneau et al., 2001) but lower than others (Beard et al., 2001; Sifers et al., 2001; Jordan et al., 2003). Sweeney et al. (2001)

reported a similar number of shoots dm^{-2} for A-4 compared to our data. They did not, however, report significant density reductions and in some instances measured an increase in SD from spring through summer. Some possible reasons for our lower values may be the slightly higher cutting height and the more intensive light frequent sand topdressing program we employed to reflect contemporary management practices.

In general, annual N-regime did not significantly affect SD (Tables 4-1 and 4-2). In Aug. of each year, however, when overall SD was lowest, the high N-regime resulted in significantly more shoots than low N plots when averaged across cultivars, 1170 versus 1330 and 1220 shoots dm^{-2} versus 1310 shoots dm^{-2} for the low and high N-regimes in the 2006 and 2007 study years, respectively. For example, SD reductions for A-4, L-93, and Penncross from June to Aug. of each year averaged 23, 23, and 37% at 112 kg N $ha^{-1}yr^{-1}$, respectively. By comparison, at the 196 kg N $ha^{-1}yr^{-1}$ N-rate, reductions were 17, 15, and 23 %, respectively. Among cultivars, L-93 SD was least affected by N-regime. These cultivar results are also consistent with previous research (Schlossberg and Karnok, 2001). Higher annual N-fertility has also been associated with greater root length and density, and this may help avoid summer decline and allow the plant to explore a greater soil volume for nutrients (Kohlmeier and Eggens, 1983; Schlossberg and Karnok, 2001). Based on these data and the recommendations of other agronomists (Beard, 2002; Dernoeden, 2002), it is suggested that golf course managers should continue to fertilize greens moderately during the summer months. When cool-season turfgrasses experience stand loss, it is imperative to have a sufficient nutrient supply to promote rapid recovery when favorable growing conditions return to promote shoot growth. This is especially important for recreational areas to contest some of the stresses associated with heavy use and moderate-intensive contemporary topdressing programs.

Cultivar and N-Regime Affect Appearance

Both cultivar and N-regime had strong effects TQ (Table 4-3 and 4-4). The TQ values ranged from 7.4 to 8.7 and increased for HSD cultivars and N-regime within each cultivar. Among cultivars, Penncross at 112 kg N $ha^{-1}yr^{-1}$, provided the poorest TQ, while A-4 and L-93 both had superior TQ compared to Penncross during both study years. These results were expected and consistent with previous research (Bruneau et al., 2001; Schlossberg and Karnok, 2001; Stier and Hollman, 2003). When averaged across both study years, the highest mean TQ was associated with L-93 and A-4 at 196 kg N $ha^{-1}yr^{-1}$. When evaluating each individual study year, the mean annual TQ for L-93 was superior to A-4 at both N-regimes in 2006. The poorer TQ of A-4 in 2006 was due to significant dollar spot outbreaks, particularly early during the growing season, which negatively affected TQ when a curative fungicide program was implemented (Table 3-6). The high susceptibility of A-4 to dollar spot is consistent with previous reports (NTEP, 1998, Stier and Hollman, 2003, Bigelow, 2008). In 2007, however, when a preventative fungicide program was used, A-4 TQ was equivalent to that of L-93 at the 112 kg N $ha^{-1}yr^{-1}$ N-regime and superior to L-93 TQ at the 196 kg N $ha^{-1}yr^{-1}$ N-regime. Ball roll distance was not significantly influenced by cultivar.

During the onset of summer heat stress, both A-4 and L-93 at either N-regime maintained an acceptable quality putting green while Penncross under the low N-regime resulted in unacceptable TQ, with values < 7.0, TQ. As expected, increasing N from 112 to 196 kg N $ha^{-1}yr^{-1}$, significantly increased TQ values by 0.4-1.1 points, when averaged across cultivars. Lower annual N however, did slightly increase ball roll distances from 145 to 158 cm using a modified stimpmeter (38 cm) across all cultivars (Table 4-5).

In general, the superior TQ of HSD bentgrasses is often attributed to their increased SD relative to earlier bentgrass generations which has been demonstrated in this study. Although N-regime effects on SD were minor, N-regime significantly affected cultivar visual characteristics such as leaf texture, architecture and an overall greener color (Tables 3-1, 3-2, 3-4, and 3-5).

Bentgrass Shoot Density Affects Surface Firmness

One of the characteristics most important to golf course managers is SH, which can be affected by soil organic matter content (Carrow, 2003), SD (Sherratt et al., 2005), and rootzone water content (McNitt and Landshoot, 2000). Values for SH ranged from 125 - 167 g_{max}, and were variable depending upon measurement date (Table 4-5). Since both A-4 and L-93 had higher SD values than Penncross these cultivars generally yielded lower g_{max} values and softer surfaces, especially during the spring. Additionally, both A-4 and L-93 maintained at 196 kg N $ha^{-1}yr^{-1}$ yielded the softest surfaces on the majority of the measurement dates. In July, as SD declined for all cultivars, Penncross at both annual N-regimes yielded the firmest surfaces. Averaged across all cultivars, plots fertilized with 112 kg N $ha^{-1}yr^{-1}$ resulted in firmer surfaces in May and June, however, as SD declined and slowly recovered, N-regime was less influential on SH. In July of 2007, however, SD was negatively correlated with SH (Figure 4-1: R^2 =0.616) demonstrating that as bentgrass SD declines during the summer a turf manager can naturally expect an overall increase in SH. Therefore, aggressive management practices to promote SH on older bentgrass cultivars may be unnecessary and in fact negatively affect overall putting green health.

Summary and Recommendations

As golf course managers continue to strive to produce smooth, firm, consistent, putting green conditions, it is clear that several important factors affect bentgrass appearance and overall health. Of utmost importance is cultivar selection and N-fertility level, particularly with respect to summer performance. This field study validates what has been frequently reported: HSD cultivars like A-4 and L-93 possess and maintain a substantially higher SD throughout the year and are, therefore, more reliable than Penncross, especially when subjected to contemporary putting green management practices. The HSD cultivars are more reliable than Penncross because they maintain a dense turf canopy even with SD losses during the summer. Although the SD of all cultivars declined from spring to late-summer, Penncross was most affected, often losing nearly 40 % of it's SD, compared to A-4 and L-93 which lost 25-30 %. Additionally, when Penncross was most dense, May or June, it's SD was nearly equivalent to A-4 and L-93 at their lowest SD.

The agronomic benefits of an adequately fertilized turf have been well documented, and include increased vigor, canopy greenness, rooting, and damage recovery. In response to golfer's desires for fast green speeds many golf course managers are applying less N than ever, often ≤ 112 kg N $ha^{-1}yr^{-1}$. This management approach is risky, and may compromise bentgrass health on heavily trafficked greens grown in stressful growing environments on sand-based rootzones that retain fewer nutrients. These ultra-low N-regimes result in malnourished turf which is more prone to environmental stress and pest damage. An alternative approach might be to apply 112-196 kg N $ha^{-1}yr^{-1}$ and manipulate other inputs such as applying plant growth regulators or using lightweight rollers to achieve green speed.

In this study, N-levels of 112 or 196 kg N $ha^{-1}yr^{-1}$ had very little effect on the SD for the three cultivars evaluated. The exception, however, occurred in August of both years when a beneficial response of the higher N-level for SD was observed for Penncross and A-4. Although increased N did not enhance SD, it dramatically improved bentgrass visual appearance. This data supports the recommendation that moderate summer N at 49 - 73 kg N ha^{-1} should be applied to minimize stand loss and ensure rapid recovery at the onset of favorable growing weather.

Due to the increased SD of newer bentgrass cultivars, many golf course managers are on an aggressive sand-topdressing program to maintain a firm, smooth surface. This normally involves the light application of sand every 7-10 days throughout the growing season. Although not directly evaluated in this study, we suggest that care should be exercised when attempting this management strategy for older bentgrass cultivars like Penncross, especially when maintained using a low-N fertility program. Sand topdressing is a mechanically abrasive practice (Carrow, 1996; Dernoeden, 2002), and if improperly timed, may cause deleterious effects, further reducing Penncross SD and negatively affecting overall putting green quality.

Where the densest, most aesthetically pleasing and persistent putting greens are desired, modern bentgrass cultivars should be planted and moderate (146-196 kg N ha^{-1} yr^{-1}) annual N should be regularly applied, particularly during the summer months. Future studies providing additional information regarding the affects of mowing frequency, frequent lightweight rolling, turf grooming and plant growth regulators on SD for HSD cultivars would be beneficial.

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Table 4-1. Creeping bentgrass shoot density as influenced by cultivar and annual N regime, 2006.

Cultivar	Annual N regime ‡	Shoot density †			
		28 June	27 July	24 Aug	13 Oct
	---- kg N ha^{-1} yr^{-1} ----	---- shoots dm^{-2} ----			
A-4	112	1950 a§	1550 ab	1400 b	1870 a
L-93	112	1620 b	1410 bc	1360 b	1680 b
Penncross	112	1290 cd	930 d	760 d	1330 c
A-4	196	2130 a	1590 a	1630 a	2030 a
L-93	196	1480 bc	1320 c	1340 b	1670 b
Penncross	196	1170 c	1020 d	1030 c	1400 c
Mean		1605 A	1304 B	1251 B	1664 A
Annual N regime					
112 kg N ha^{-1} yr^{-1}		1620 a	1300 a	1170 b	1630 a
196 kg N ha^{-1} yr^{-1}		1590 a	1310 a	1330 a	1700 a
ANOVA					
Cultivar (C)		***	***	***	***
N regime (N)		NS	NS	**	NS
C x N		NS	NS	*	NS

† Shoot density was determined by counting the number of shoots in two cores (2.84 cm^2) taken from the center portion of each plot.

‡ Nitrogen applied in liquid and granular formulations throughout the growing season to emulate contemporary putting green fertilization practices.

§ Means in the same column followed by the same lower case letter and means in the same row followed by the same upper case letter are not significantly different according to Fisher's protected LSD t-test ($p=0.05$).

*, **, ***, and NS refer to significant at the 0.05, 0.01, 0.001, and non-significant respectively.

Table 4-2. Creeping bentgrass shoot density as influenced by cultivar and annual N regime, 2007.

Cultivar	Annual N regime ‡	Shoot density †					
		22 May	19 June	23 July	22 Aug	25 Sept	21 Oct
	---- kg N ha^{-1} yr^{-1} ----	shoots dm^{-2}					
A-4	112	2030 a§	1920 a	1760 a	1580 b	1940 a	1940 b
L-93	112	1830 b	1590 b	1500 b	1230 c	1490 b	1560 d
Penncross	112	1470 c	1260 c	1190 c	850 d	1160 c	1360 e
A-4	196	2020 a	1970 a	1830 a	1730 a	1990 a	2160 a
L-93	196	1780 b	1650 b	1480 b	1290 c	1540 b	1700 c
Penncross	196	1450 c	1320 c	1210 c	890 d	1040 d	1430 e
Mean		1763 A	1618 C	1496 D	1262 E	1524 D	1689 B
Annual N regime							
112 kg N ha^{-1} yr^{-1}		1780 a	1590 a	1480 a	1220 b	1530 a	1620 b
196 kg N ha^{-1} yr^{-1}		1750 a	1640 a	1510 a	1310 a	1520 a	1760 a
ANOVA							
Cultivar (C)		***	***	***	***	***	***
N regime (N)		NS	NS	NS	**	NS	***
C x N		NS	NS	NS	NS	NS	NS

† Shoot density was determined by counting the number of shoots in two cores (2.84 cm^2) taken from the center portion of each plot.

‡ Nitrogen applied in liquid and granular formulations throughout the growing season to emulate contemporary putting green fertilization practices.

§ Means in the same column followed by the same lower case letter and means in the same row followed by the same upper case letter are not significantly different according to Fisher's protected LSD t-test (p=0.05).

, *, and NS refer to significant at the 0.01, 0.001, and non-significant respectively

Table 4-3. Creeping bentgrass visual quality as influenced by cultivar and annual N regime, 2006.

Cultivar	Annual N regime ‡	Turf quality †			
		May-June	July-Aug	Sept-Oct	Mean
	---- kg N ha^{-1} yr^{-1} ----	(0-10)			
A-4	112	7.2 c§	7.8 b	8.4 c	7.7 c
L-93	112	8.9 ab	8.2 b	8.9 ab	8.5 b
Penncross	112	7.8 c	6.5 c	8.7 bc	7.5 c
A-4	196	7.1 c	8.7 a	8.6 c	8.3 b
L-93	196	9.3 a	8.8 a	9.1 a	9.0 a
Penncross	196	8.4 b	8.2 b	8.9 ab	8.4 b
Mean		8.2 BC	8.0 C	8.8 A	
Annual N regime					
112 kg N ha^{-1} yr^{-1}		8.0 b	7.5 b	8.7 b	7.9 b
196 kg N ha^{-1} yr^{-1}		8.5 a	8.6 a	8.9 a	8.6 a
ANOVA					
Cultivar		***	***	***	***
N regime		**	***	*	***
C x N		NS	*	NS	NS

† Turfgrass quality was visually rated on a 0-10 scale where 0 = brown, dead turf, 10 = optimum greenness and uniformity ≥ 7 acceptable.

‡ Nitrogen applied in liquid and granular formulations throughout the growing season to emulate contemporary putting green fertilization practices.

§ Means in the same column followed by the same lower case letter and means in the same row followed by the same upper case letter are not significantly different according to Fisher's protected LSD t-test (p=0.05).

*, **, ***, and NS refer to significant at the 0.05, 0.01, 0.001, and non-significant respectively.

Table 4-4. Creeping bentgrass visual quality as influenced by cultivar and annual N regime, 2007.

Cultivar	Annual N regime ‡	Turf quality †				
		May-June	July-Aug	Sept-Oct	Mean	Study Mean
	---- kg N ha^{-1} yr^{-1} ----	---------- (0-10) ----------				
A-4	112	8.3 bc	8.3 b	8.3 b	8.3 b	8.0 c
L-93	112	8.8 a	7.9 bc	7.9 c	8.3 b	8.4 b
Penncross	112	7.9 c	6.9 d	7.1 d	7.4 d	7.4 d
A-4	196	8.9 a	9.3 a	8.6 a	9.0 a	8.6 ab
L-93	196	9.0 a	8.3 b	8.0 bc	8.5 b	8.7 a
Penncross	196	8.4 b	7.5 c	7.5 d	7.8 d	8.1 c
Mean		8.6 A	8.0 C	7.9 C		
Annual N regime						
112 kg N ha^{-1} yr^{-1}		8.3 b	7.7 b	7.6 b	8.0 b	7.9 b
196 kg N ha^{-1} yr^{-1}		8.8 a	8.3 a	8.1 a	8.4 a	8.5 a
ANOVA						
Cultivar		***	***	***	***	***
N regime		***	***	**	***	***
C x N		NS	NS	NS	NS	NS

† Turfgrass quality was visually rated on a 0-10 scale where 0 = brown, dead turf, 10 = optimum greenness and uniformity $\geq$ 7 acceptable.

‡ Nitrogen applied in liquid and granular formulations throughout the growing season to emulate contemporary putting green fertilization practices.

§ Means in the same column followed by the same lower case letter and means in the same row followed by the same upper case letter are not significantly different according to Fisher's protected LSD t-test (p=0.05).

*, **, ***, and NS refer to significant at the 0.05, 0.01, 0.001, and non-significant respectively.

Table 4-5. Creeping bentgrass surface hardness and ball roll distance as influenced by cultivar and annual N regime, 2007.

Cultivar	Annual N regime ‡	Surface hardness †						Ball roll distance ‡
		24 May	21 June	23 July	22 Aug	27 Sept	25 Oct	13 Sept
	---- kg N ha^{-1} yr^{-1} ----	---- g_{max} ----						---- cm ----
A-4	112	134 bc¶	137 a	136 abc	141 a	151 bc	152 a	163 a
L-93	112	131 bcd	129 bc	131 cd	137 a	141 c	150 a	155 ab
Penncross	112	145 a	139 a	142 a	142 a	167 a	156 a	157 ab
A-4	196	127 d	125 c	125 d	136 a	147 bc	150 a	147 bc
L-93	196	131 cd	127 c	133 bcd	136 a	159 ab	152 a	141 c
Penncross	196	137 b	135 ab	139 ab	140 a	157 abc	151 a	146 bc
Mean		134 C	132 C	134 C	139 B	154 A	152 A	
Annual N regime								
112 kg N ha^{-1} yr^{-1}		137 a	135 a	136 a	140 a	153 a	152 a	158 a
196 kg N ha^{-1} yr^{-1}		132 b	129 b	132 a	137 a	155 a	152 a	145 b
ANOVA								
Cultivar		***	**	**	NS	*	NS	NS
N regime		*	**	NS	NS	NS	NS	**
C x N		NS	*	NS	NS	NS	NS	NS

† Surface hardness values are the means of two measurements from each plot determined using a Clegg Impact Soil Tester (0.5 kg hammer).

‡ Ball roll distance measured using a modified stimpmeter with the ball release notch half (38 cm) the distance compared to the conventional stimpmeter.

§ Nitrogen applied in liquid and granular formulations throughout the growing season to emulate contemporary putting green fertilization practices.

¶ Means in the same column followed by the same lower case letter and means in the same row followed by the same upper case letter are not significantly different according to Fisher's protected LSD t-test (p=0.05).

*, **, ***, and NS refer to significant at the 0.05, 0.01, 0.001, and non-significant respectively.

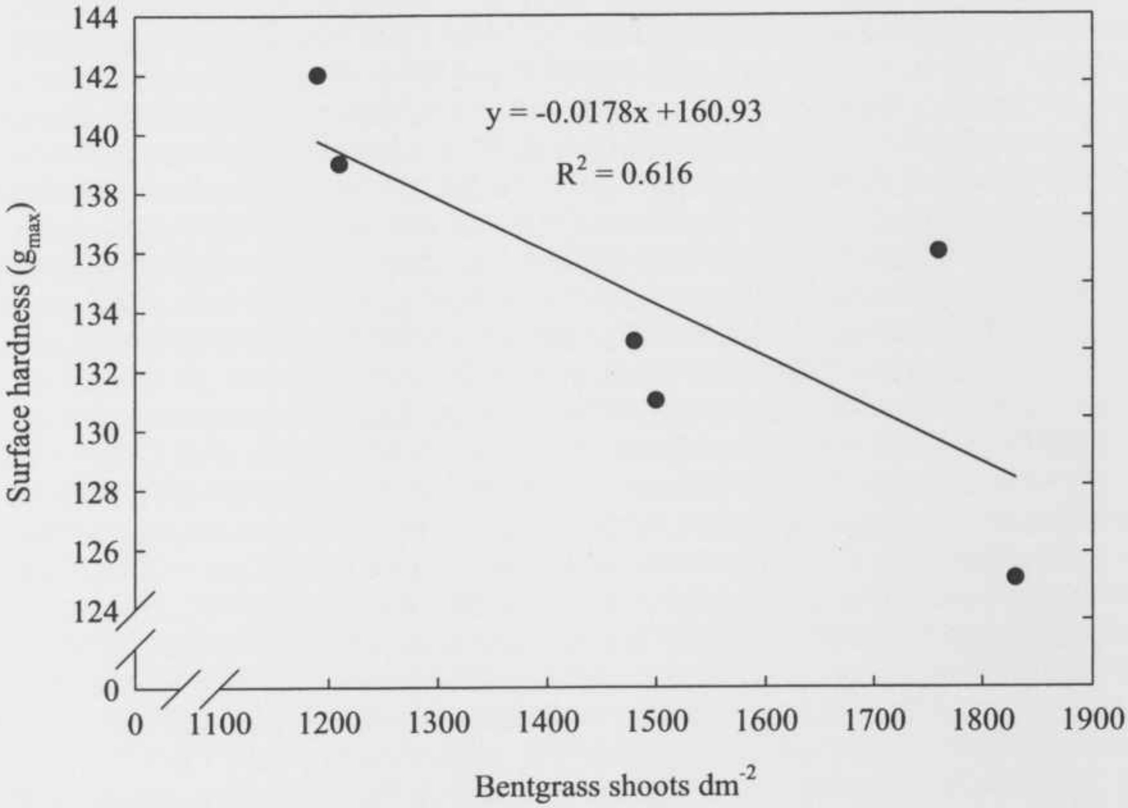

Figure 4-1. Surface hardness as affected by shoot density 23 July, 2007 (Data are mean values averaged across all cultivars and N-regimes. Eight data points within each replication are averaged per value).

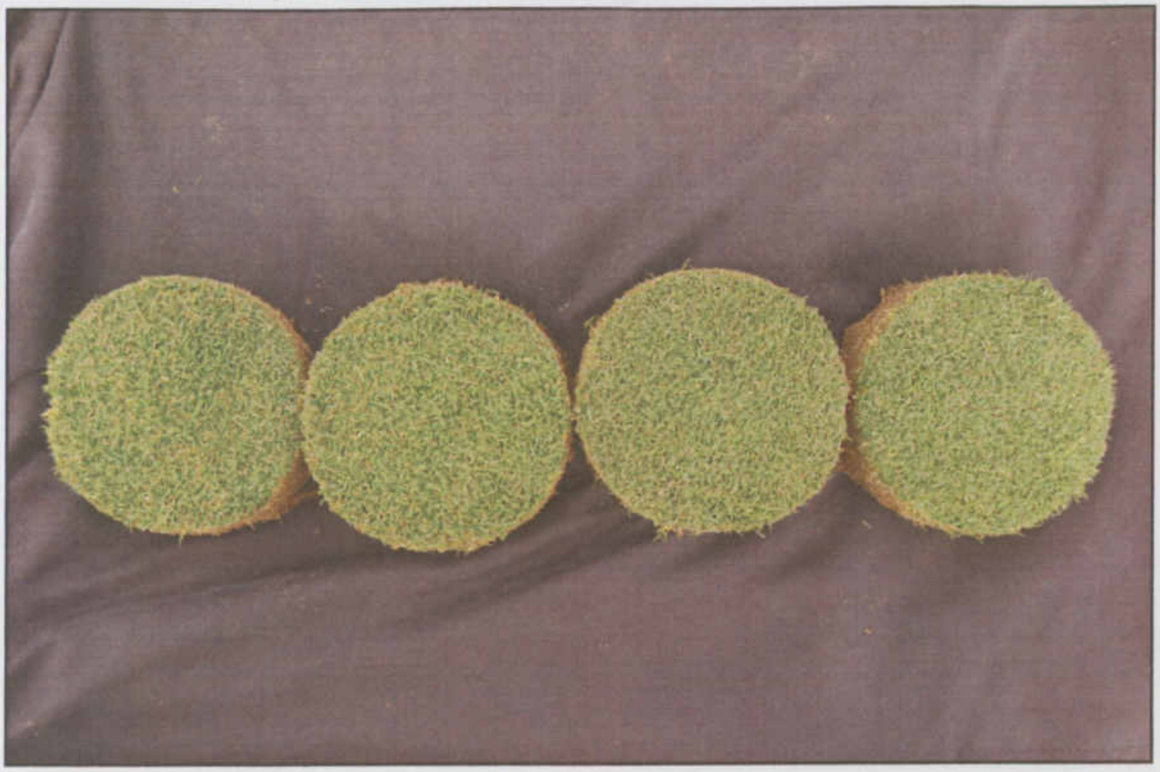

Figure 4-2. In recent decades turfgrass breeders have bred higher shoot density bentgrasses to meet golfer demands for more closely mowed putting greens. Shown here are four generations of bentgrass cultivars planted on putting greens from left to right, Penncross, 'Pennlinks', A-4, 'A-1' (photo 24 Nov., 2007).