CHAPTER THREE

EVALUATION OF PUTTING GREEN SURFACE ORGANIC MATTER MANAGEMENT PROGRAMS: Part II. Visual Turfgrass Responses

Abstract

Creeping bentgrass [*Agrostis stolonifera* L. var *palustris* (Huds.) Farw.] is the most widely planted turfgrass for putting greens. The objective of this three year field study was to assess seasonal visual changes of three creeping bentgrass cultivars ('A-4', 'L-93', and 'Penncross') maintained at 112 or 196 kg nitrogen (N) ha^{-1} annually when subjected to five organic matter (OM) management programs. The OM management programs were: twice annual core cultivation plus heavy topdressing using either a medium-coarse sand (HTSM) that matched the underlying rootzone or a medium-fine sand (HTSF), the aforementioned programs supplemented with frequent topdressing (HTFM and HTFF) throughout the growing season, no core cultivation but frequent topdressing throughout the growing season with the medium-coarse sand (TOP). Among management programs, TOP plots had the highest mean TQ, because the turf was never injured by core cultivation, although localized dry spot and disease (*Sclerotinia homoeocarpa* F.T. Bennett) were occasionally higher which reduced TQ. Among cultivars, A-4 and L-93 had superior mean TQ compared to Penncross (8.0 and 8.1 versus 7.5). Under a curative disease program (2006), A-4 was more susceptible to dollar spot, thus reducing TQ (7.8 versus 8.2). Moss (*Bryum agentium*) incidence was highest for Penncross at either N-regime compared to A-4 and L-93. The HTFF program also had elevated moss incidence among management programs but not consistent in 2007. Where the densest, most aesthetically pleasing and persistent turf is desired, modern bentgrass cultivars should be planted and maintained. Surface OM must be managed with sufficient sand topdressing and core cultivation to avoid stand failure.

Introduction

Creeping bentgrass [*Agrostis stolonifera* L. var *palustris* (Huds.) Farw.] is the most widely planted turfgrass for golf course putting greens in the United States (Beard, 2002). Creeping bentgrass is a cool-season perennial grass that forms an extremely dense, fine textured persistent turf which tolerates close (<3 mm), frequent mowing. Since the mid-1950's Penncross has been the most widely planted creeping bentgrass cultivar on putting greens (Beard 2002). Over the past few decades, numerous clonal selections from Penncross that maintain an extremely high shoot density (HSD) at ultra-low modern cutting heights have been developed to meet elevated golfer demands for consistent, firm, fast putting surfaces.

These HSD cultivars generally have better overall appearance and seasonal persistance due to: a more upright growth habit, higher shoot density, finer leaf texture, increased rooting depth, greater resistance to certain turf pathogens, better ability to resist annual bluegrass (*Poa annua*) invasion, and improved heat and drought tolerance (Robinson et al., 1991; Skogely et al., 1991; Hurley et al., 1994; Engelke et al., 1995a; Engelke et al., 1995b; Bruneau et al., 2001; Stier and Hollman, 2003; Morris, 2003; Voight et al., 2005). Their aggressive upright growth habit, however, may demand more intensive surface organic matter (OM) management programs compared to Penncross (Stier and Hollman, 2003).

Nitrogen (N) applications of 122 - 244 kg N $ha^{-1}yr^{-1}$ have generally been recommended to produce dense, healthy bentgrass putting greens (Beard, 2002; McCarty, 2005). It has been theorized, however, that HSD cultivars will perform best through slightly lower annual N regimes because the need to sustain adequate shoot density (SD) for putting greens is slightly less demanding (Beard, 2002). Research on annual N-regimes for HSD cultivars has typically ranged between 170-390 kg N $ha^{-1}yr^{-1}$ (Beard et al., 2001; Landry and Schlossberg, 2001; Stier and Hollman, 2003; Kauffman, 2007; McCarty et al., 2007, Landreth et al., 2007). However, contemporary fertilization programs seem to be abandoning the traditional moderate (146-196 kg N ha^{-1} yr^{-1}) levels in favor of greater ball roll distances (Brame, 2007).

Most putting greens are constructed using a high sand content (> 85 %) mixture to resist compaction and drain rapidly (Taylor and Blake, 1979). However, HSD bentgrasses have been shown to accumulate OM more rapidly than older cultivars (Ervin et al., 2000; Landry and Schlossberg, 2000; Stier and Hollman, 2003). Regardless of the creeping bentgrass cultivar, excess OM accumulation in the rootzone can degrade the optimum soil physical properties that sand-based rootzones posses, and if preventative management is not performed, it can result in deleterious effects to the rootzone functionality. Core cultivation (Engel and Alderfer, 1967; Engel, 1970; Eggens, 1980; Murphy et al., 1993; Kauffman, 2007) and sand topdressing (Engel and Alderfer, 1967; Eggens, 1980; Cooper and Skogley, 1981; Fermanian et al., 1985; Callahan et al., 1998; Stier and Hollman, 2003; McCarty et al., 2007) have been shown to be primary tools for OM management.

The effects of contemporary aggressive OM management programs which include regular light sand topdressing have not been well studied. The visual responses of HSD cultivars compared to older bentgrass cultivars maintained under varying annual N-regimes and management techniques have not been well documented. Therefore, the objective of this study was to assess seasonal visual changes of three contrasting bentgrass cultivars maintained under two annual nitrogen regimes when subjected to five OM management programs.

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 (≥ 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.

Core Cultivation

Core cultivation (1.6 cm diam. x 8 cm depth x 5 cm spacing) (Toro Greens 09120 Aerator, The Toro Company, Bloomington, MN) was performed in mid-Apr. and mid-Sept. from 2005 to 2007. Cores were removed following cultivation and channels back-filled with the appropriate sand size. One OM management program did not receive any core cultivation at any time during the study, and was included as the control treatment to compare frequent topdressing in place of core cultivation.

Visual Ratings

Plots were visually assessed every 7-10 days from 2006-2007 for visual appearance or turfgrass quality (TQ) on a 0-10 scale with 0=brown dead turf, 10=optimum greenness, density and uniformity, ratings >7.5 = acceptable putting green turf. Core cultivation recovery time was measured in the spring and late-summer of 2007. Plots were visually assessed every 7-10 days for the percent recovery of core cultivation holes. Initial ratings were made 7-10 days after core cultivation. Dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) infection centers were counted when disease outbreaks occurred in 2005 and 2006. In 2007, dollar spot was readily controlled with preventative fungicides except in Oct. when disease was allowed to develop. Moss (*Bryum agentium*) incidence was observed in 2005 and 2006 and quantified using a linear 0-to-100 % scale, where 0 % = no moss and 100 %= entire plot area with moss cover. Localized dry spot (LDS) was assessed on a linear 0-to-100 % scale, where 0 % = no LDS and 100 % = entire plot area of LDS. Canopy greenness was quantified using a handheld reflectance meter regularly from 2006-2007 (Field Scout CM-1000, Spectrum Technologies, Inc., East - Plainfield, IL). Five measurements were taken per plot using a systematic grid pattern, which measured the four corners and the center portion. These five measurements were averaged to produce a single plot measurement for statistical analysis and are reported as a color index.

Ball roll distance

Ball roll distance (BRD) 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.

Summer Canopy Temperature

Bentgrass canopy temperature (BCT) was measured using an infared thermometer (Raytek ST 20 Pro, Raytek, Santa Cruz, CA). Readings were taken in late-afternoon on 23 August with the daily high temperature of 30 degrees Celsius (° C) (Figure 3-1). Five readings were taken per plot using the aforementioned systematic grid pattern and pooled together and averaged to one number for statistical analysis to account for spatial variability.

Environmental Conditions

Weather data was collected from the Purdue University Airport, West Lafayette, IN from 1 Apr. to 31 Oct. for each study year (Figure 3-1). Environmental conditions, precipitation measured as rainfall, and air temperature varied between the three study years (Figure 3-1). Rainfall totaled 480 mm, 763 mm, and 415 mm yr^{-1} for 2005, 2006, and 2007 respectively. Rainfall was highest during the summer (June-Aug.) of each year (224 mm, 372 mm, and 156 mm respectively) compared to the spring (Apr.-May) and autumn (Sept.-Oct.). Air temperatures were slightly higher in 2005 (26 °C) and 2007 (26 °C) than 2006 (23 °C). Furthermore, the higher air temperatures persisted longer into the autumn in 2005 (28 °C) and 2007 (28 °C) than 2006 (24 °C).

Experimental Design and Statistical Analysis

The statistical design separated OM management programs in a randomized complete block with four replications (Figures A-9 and A-10). Main plots were separated in a two by two plus one factorial with two sand sizes and two application frequencies plus an non-cored topdressed only control. Five main plots (4.5 m x 3.0 m) determine management program (sand topdressing and core cultivation treatments) and were separated with 0.6 m borders. Management programs were:

1. Hollow tine aerification plus seasonal topdressing with a medium-coarse sand (HTSM)
2. Hollow tine aerification plus frequent topdressing with a medium-coarse sand (HTFM)
3. Hollow tine aerification plus seasonal topdressing with a medium-fine sand (HTSF)
4. Hollow tine aerification plus frequent topdressing with a medium-fine sand (HTFF)
5. Frequent topdressing only with a medium-coarse sand (TOP)

Subplots (1.5 m x 1.5 m) were separated in a three by two factorial containing cultivar and N treatments and were arranged in a completely randomized design within each main plot. All data was subjected to analysis of variance (ANOVA) using the general linear models procedure in SAS (SAS Institute, Cary, NC) and treatment means for management program, cultivar, and annual N-regime separated using Fisher's protected least significant difference (P=0.05). For each ANOVA table, a two by two plus one factorial was used which excluded the TOP (control) program.

Results and Discussion

Visual turfgrass appearance or TQ, canopy greenness measured as reflectance, disease and weed incidence and severity, and core cultivation recovery time were all influenced by management program, cultivar, and annual N-regime while LDS was influenced by management program only. Ball roll distance was affected by cultivar and annual N-regime and BTC was affected by management program and cultivar.

Visual Turfgrass Quality

Management program, cultivar, and annual N-regime all had strong effects on TQ (Table 3-1 and 3-2) with values ranging from 6.9 to 8.9. Among management programs, TOP plots (8.2) had the highest study mean TQ while HTSM (7.6), HTSF (7.7), and HTFF (7.7) were in the lowest statistical category and HTFM (8.0) was intermediate. For cultivar study means, TQ was highest for A-4 (8.0) and L-93 (8.1) which were both better than Penncross (7.5). As N increased from 112 to 196 kg N $ha^{-1}yr^{-1}$, TQ increased for the study mean, 7.5 and 8.2 respectively.

No substantial differences in TQ among management programs were observed from 2006 to 2007. In 2006, L-93 (8.1) had the highest TQ and Penncross (7.6) had the lowest TQ, while A-4 was intermediate (7.8). In 2007, however, A-4 (8.2) TQ was superior to both L-93 (8.0) and Penncross (7.4). During Sept., at the conclusion of a dry-down cycle with supplemental irrigation reduced to once per week (5 mm wk^{-1}), Penncross (6.9) became unacceptable, with ratings < 7.0.

By contrast, compared to all other management programs, the TOP program had the most consistent TQ throughout the study. This is most likely because the surface disruption all other management programs experienced from seasonal core cultivation resulted in a decline in TQ. Reductions in TQ from core cultivation practices typically lasted 14-28 days, and usually resulted in unacceptable (< 7.0) TQ for at least the first 7 days after the cultivation. Core cultivation has been reported to improve TQ in several studies (Carrow et al., 1987; Murphy et al., 1993). Serious injury, however, can result from core cultivation to turf depending on overall plant vigor and environmental conditions at the time of cultivation. Numerous researchers have reported reductions in TQ from core cultivation (Engel, 1951; Cooper and Skogley, 1981; Weston and Dunn, 1985; Carrow et al., 1987; Bunnell et al., 2001; Karcher et al., 2001). The primary benefit of not performing core cultivation is avoiding surface disruption associated with this practice (Karcher et al., 2001). As a result, TOP plots had more consistent TQ throughout the season than all other management programs. The absence of any surface disruption from core cultivation in TOP plots improved overall TQ in these plots because there was no recovery time. When evaluating TQ after all plots were fully recovered

(June to Aug.), HTFM plots were in the highest statistical category equal to TOP plots in 2006 (Table 3-1). In 2007, from June to July, HTFM plots were equal in TQ with TOP plots while in August, however, HTFM plots (8.3) had better TQ than TOP plots (7.9) (Table 3-2). This trend seems to support the previous statement suggesting that the superior overall TQ in TOP plots for the study mean is primarily a result of the absence of a recovery time associated with core cultivation (Table 3-3).

In addition to recovery from cultivation, other factors like moss, dollar spot incidence and LDS also affected overall TQ. In TOP plots the biggest factors were dollar spot and LDS which periodically affected TQ in both 2006 and 2007 but was not significant enough to be reflected in mean TQ values. Slight reductions in TQ were observed in HTFF plots as a result of moss incidence in 2006, but improved cool-season turf growing conditions in early 2007 allowed for bentgrass to out compete the existing moss. Even though TOP plots had the highest TQ, all management programs had acceptable putting green turf for each month of 2006 and 2007.

The study mean cultivar TQ results were somewhat expected and consistent with previous research (Bruneau et al., 2001; Morris, 2003; Voigt et al., 2005). A-4 and L-93 generally have better overall appearance due to a more upright growth habit, higher SD, and finer leaf texture than Penncross (Robinson et al., 1991; Skogely et al., 1991; Hurley et al., 1994; Engelke et al., 1995a; Engelke et al., 1995b; Bruneau et al., 2001; Stier and Hollman, 2003; Morris, 2003; Voight et al., 2005). The poorer TQ of A-4 in 2006, however, was due to significant dollar spot outbreaks, particularly early during the growing season, which subsequently affected TQ for the remainder of the growing season when a curative fungicide program was employed. A preventative fungicide program was implemented in 2007 which controlled disease, and improved A-4 TQ.

Fertilization applications of 122-244 kg N $ha^{-1}yr^{-1}$ have generally produced dense, healthy bentgrass putting greens (Beard, 2002). Therefore, it is not surprising that plots maintained at low N-regime had lower TQ. When averaged across all cultivars and management programs, plots maintained at 112 kg N $ha^{-1}yr^{-1}$ never reached a TQ value > 8.0. Conversely, plots maintained at 196 kg N $ha^{-1}yr^{-1}$ only had values < 8.0 in Sept. and Oct. 2006 and Sept. 2007, likely a product of the surface disruption caused by core cultivation. During the onset of summer stress, liquid N applied every 14 days at 10 kg N ha^{-1} to the 196 kg N $ha^{-1}yr^{-1}$ plots improved TQ while plots maintained at 112 kg N ha^{-1} yr^{-1} received 10 kg N ha^{-1} monthly (excluding Aug.).

Core Cultivation Recovery

Recovery time from core cultivation was affected by management program, cultivar, and annual N-regime during the spring and late-summer in 2007 (Tables 3-4 and 3-5). In the spring, 13 days after core cultivation (DAC), percent recovery was highest in HTFM plots (43 % recovery) compared to all other management programs ranging 29 to 34 % recovery $plot^{-1}$. On 20 DAC, HTFM plots had significantly higher (62 %) recovery than all other management programs (44 to 51 % recovery). At 27 DAC, HTSF plots (70 % recovery) had the lowest recovery while all other management programs were > 80 % plot recovery. All management programs were equal by 34 DAC (89-94 % recovery). Among cultivars, Penncross had a higher percent recovery compared to A-4 and L-93 until 34 DAC when all were equal. On 13 DAC, Penncross had 50 % recovery while A-4 and L-93 had 20 and 33 % recovery, respectively. On 20 DAC, Penncross had 75 % recovery $plot^{-1}$ while A-4 and L-93 were 30 and 50 % recovered respectively. At 27 DAC, Penncross was 94 % recovered while A-4 and L-93 were 64 and 80 % recovered respectively.

When averaged across all cultivars, plots maintained at 112 kg N ha^{-1} yr^{-1} had lower numerical percent recovery on all spring and autumn dates than those plots maintained at 196 kg N ha^{-1} yr^{-1}, although not statistically different on all dates. Similar results were observed in the autumn of 2007.

The slightly enhanced recovery following core cultivation in HTFM plots is not completely understood. Penncross tends to grow more laterally than A-4 and L-93, which may partially explain the enhanced recovery at least initially (Beard, 1973).

Dollar Spot

Dollar spot incidence and severity was affected by management program, cultivar, and annual N-regime with values ranging from 0.9 to 42.3 infection centers $plot^{-1}$ (Table

3-6). Among management programs, dollar spot was most severe in the TOP plots on all seven rating dates. The HTFF program was also in the highest statistical category on six of the seven rating dates. Conversely, the HTSM program had the least dollar spot infections centers on all seven rating dates.

The HTFF plots may have been more prone to dollar spot incidence because of the slightly elevated VWC commonly measured in these plots (Table 2-5). The higher VWC could produce a moist environment in the turf canopy favorable to fungal development. It is not well understood why the TOP plots had more dollar spot than other management programs, however, one reason could be a result of less phytoalexin production in the plant. Phytoalexins are antimicrobial secondary metabolites that are synthesized and accumulate within the plant as a defense response to wounding and other detriments (Marschner, 1995; Hammerschmidt, 1999). Without core cultivation, which wounds the plant, phytoalexin accumulation may have been lower in TOP plots, possibly making them more susceptible to disease outbreaks.

Among cultivars, A-4 had the most dollar spot on all rating dates compared to L-93 and Penncross. These data disagree with Bruneau et al (2001), which reported that A-4 had relatively good dollar spot resistance. However, a similar increase in susceptibility among cultivars in our data have been reported (Bigelow, 2008), who found A-4 to be more susceptible to dollar spot outbreaks than both L-93 and Penncross. Additionally, Stier and Hollman (2003) and several research trials throughout the U.S. (NTEP, 1998) have also reported A-4 to be more susceptible to Penncross. The HSD of A-4 may be a reason for its lack of disease resistance. Dollar spot is a foliar blight and disease development and spread may be enhanced in A-4 because of the ease of fungal movement from one leaf blade to another due to its HSD. Additionally, this HSD may also produce a slightly higher canopy humidity conducive to pathogen activity. Dollar spot infection centers may also be more visible on HSD turf.

Generally, turfgrasses grown under low N are more susceptible to dollar spot (Couch and Bloom, 1960; Smiley et al., 2005). However, no consistent differences were observed between annual N-regime in this study. A general seasonal pattern of early small disease outbreaks followed by larger, more pronounced outbreaks was observed in

2005 and 2006. A curative fungicide program was used during these years, and it seems that the initial pathogen outbreaks were simply suppressed but did not completely control the disease. This resulted in more disease later in the growing season.

Localized Dry Spot

Management program was influenced by LDS in both years with values ranging from 0.1 to 49.7 % plot area affected (Table 3-7). Formation of LDS was more severe in 2007 as a result of hot and dry weather patterns (Figure 3-1). The HTFM and HTFF programs had the lowest LDS among management programs. By contrast, TOP plots had the most LDS of all management programs. Cultivar had no effect on LDS. Increasing annual N from 112 to 196 kg N $ha^{-1}yr^{-1}$ resulted in a small decline (1.6 % in 2006) in LDS although these results would not be deemed agronomically important.

No correlation (Figure 3-3: $R^2 = 0.223$) between LDS and VWC was measured among management programs. Formation of LDS may have been more prone to develop in TOP plots as a result of the rapid drying potential of thatch/mat layers, which due to the absence of core cultivation resulted in the highest OM of all management programs (Table 2-1). However, there was no correlation (Figure 3-2: $R^2 = 0.002$) between OM and LDS severity. Consistent with our observations, core cultivation has been reported to be a helpful management practice for LDS formation (Engel and Alderfer, 1967; Rieke and Beard, 1973; Wilkinson and Miller, 1978).

Moss Incidence

Moss was measurable in 2005 and 2006 only, with values ranging from 0 to 2.6 % moss $plot^{-1}$ (Table 3-8). Among cultivars, Penncross plots at either 112 or 196 kg N $ha^{-1}yr^{-1}$ had significantly more (2.4 and 1.1 % moss $plot^{-1}$ respectively) moss than A-4 and L-93 at either N-regime. Like many weeds, moss is an opportunistic plant and will rapidly occupy voids in the turf canopy. In late-summer, Penncross also suffered the most severe decline in SD (Table 4-1), and had voids in the turf canopy for moss to develop. When comparing moss incidence and SD, a mild correlation was measured (Figure 3-4: $R^2 = 0.533$). By contrast, the dense canopy of A-4 has been reported to resist

Poa annua invasion extremely well compared to Penncross (Voigt et al., 2005). This may explain the lower moss incidence for A-4. Additionally, L-93 SD did not decline as much as Penncross, likely enhancing its capability to resist moss encroachment. A topdressing frequency by cultivar interaction was measured in 2005 and 2006, which suggests that frequent topdressing may also have lead to more moss, specifically in Penncross. The hot and dry weather patterns in 2005 and the younger turf may also have contributed to the loss in SD (Figure 3-1). These data suggest that frequent and intensive topdressing practices can exacerbate Penncross SD decline and should be avoided during summer stress. A cultivar by N interaction was also measured in 2005 and 2006, suggesting that Penncross was particularly vulnerable to moss when maintained at 112 versus 196 kg N ha^{-1} yr^{-1}.

Among management programs, HTFF plots had the highest moss incidence in 2005 and 2006 (1.8 and 2 % moss $plot^{-1}$ respectively) while all other management programs were intermediate. The HTFF program likely had more moss incidence than all other management programs because the combination of frequent topdressing caused substantial thinning and the slightly higher VWC was conducive to moss encroachment and growth.

Canopy Greenness

Considerable differences in canopy greenness were measured among management program, cultivar, and annual N-regime with color indices ranging from 184 to 322 (Tables 3-9 and 3-10). When averaged over the entire study, HTFF plots had the darkest (257) green canopy whereas TOP plots had the least (237) canopy greenness. Among cultivars averaged across annual N-regimes and management programs, A-4 (255) and L-93 (252) had superior canopy greenness to Penncross (231). As expected, as N increased from 112 to 196 kg N $ha^{-1}yr^{-1}$, canopy greenness significantly increased, 228 versus 264, respectively.

Canopy greenness measurements were extremely consistent for management program, cultivar, and annual N-regime in both study years. It is not completely understood why HTFF plots had better greenness compared to all other management programs. One possible explanation for the darker green color could be the slightly higher rootzone volumetric water content (VWC) measured in these plots (Table 2-5), which may have resulted in increased nutrient availability due to more soil solution. By contrast, LDS was observed in TOP plots in Sept. of 2007, and less soil solution is possibly the reason for lower greenness values compared to all other management programs. The lower greenness values in TOP plots was observed in Aug. of each year during dry-down cycles where supplemental irrigation was reduced to once per week (5 mm wk^{-1}), which is also when LDS formation was prominent. The improved canopy greenness of A-4 and L-93 compared to Penncross is likely attributed to their genetic color and is consistent with other reports (NTEP, 1998; Stier and Hollman 2003).

Ball Roll Distance

Ball roll distance was measured only on 13 Sept., 2007 on a firm dry surface, and management program was not significant while cultivar and annual N-regime were significant (Table 3-11). Ball roll distance is related to the speed the ball is traveling and the friction between the turf and the ball (Gaussoin, et al., 1995). Throssell (1981) reported (0.13 m^3 100 m^2) topdressing initially slowed BRD for the initial eight days following application because particles remaining on the surface created resistance to the rolling golf ball. Eight days after topdressing, however, he reported an increase in BRD because the subsequent particles were no longer present (i.e. became integrated into the soil surface or removed by mowing) and a smoother, firmer surface was created. Among management programs, the lack of difference in BRD could be a result of insufficient time between topdressing practices for increases in BRD to be realized. Our BRD measurement was taken seven days after topdressing. Ball roll ranged from 148 to 157 cm and there was a significant difference between A-4 and L-93 with BRDs of 154 and 150 cm, respectively. A-4 has an upright growth habit, which may reduce friction between a golf ball and the grass blade, yielding longer BRD. By 13 Sept., Penncross had suffered a significant decline in SD, and had significantly firmer surfaces than A-4 and L-93, likely explaining the longer BRD. However, no correlation was measured in this study between surface hardness and BRD (Figure 3-5: $R^2 = 0.001$). As expected, annual N-regime affected BRD with shorter distances in plots receiving more annual N, with values of 148 and 157 cm for plots receiving 112 and 196 kg N ha^{-1} yr^{-1} respectively. Golf course managers routinely limit N when managing for longer BRD (Throssell, 1981; Zontek, 1997; Sweeney et al., 2000; Nikolai, 2005).

Summer Canopy Temperatures

For BCT, measured on 23 Aug., 2006, management program and cultivar were significant while annual N-regime was not significant (Table 3-12). Values ranged from 38.5° to 40.2 °C. Among management programs, HTSM, HTFM, and TOP plots had the highest BCTs (40.2 °, 40 °, and 40 °C, respectively). The HTSF and HTFF programs had significantly lower (38.7 ° and 38.5 °C respectively) BCTs. The slightly lower BCT could be a result of the slightly higher VWC commonly measured in plots topdressed with the medium-fine sand (Table 2-5). Cultivar had a small effect on BCT, with A-4 (39.8 °C) having slightly higher BCT compared to Penncross (39.1 °C). Differences among management programs and cultivar were relatively small and not practically important because all BCTs were well above the range of optimal growth for cool-season grasses, 16-24 °C.

Summary

These data suggest that there were significant differences in above-ground seasonal visual characteristics among bentgrass cultivar, annual N-regime, and OM management program. Consistent with other reports, A-4 and L-93 provided better overall TQ and canopy greenness compared to Penncross. The more vertically oriented dense leaf architecture combined with finer texture was the main explanation for superior TQ. A-4, however, was more susceptible to dollar spot, and a substantial decline in TQ was measured when maintained under a curative fungicide program. Unless sufficient disease prevention strategies are employed, A-4 may not provide acceptable putting green quality during periods of high disease pressure. Visual TQ increased ss N increased from 112 to 196 kg N ha^{-1} yr^{-1}. Higher annual N produced a more vigorous turf better able to persist during the high temperatures associated with the summer months. Moss incidence also caused periodic reductions in TQ. Penncross maintained at either annual N-regime, however, was more susceptible to moss invasion than A-4 and L-93. A substantial decline of SD in Penncross likely enhanced moss encroachment. The medium-fine sand used in the HTFF plots may have contributed to the decline in SD from leave abrasion and increased VWC, thus providing a suitable growing environment for moss. Core cultivation recovery was influenced by management program and cultivar at least initially. The more laterally spreading growth habit of Penncross was advantageous for initial recovery time. The non-cored plots experienced a decline in TQ, primarily from LDS formation and dollar spot outbreak. With the exception of greater moss incidence in plots topdressing frequently with the medium-fine sand, OM management programs did not have substantial impacts on the majority of visual measurements.

During stressful conditions, enhanced deleterious visual effects will likely be observed if excessive OM accumulation is not mitigated through regular core cultivation and sand topdressing. Initially, visual responses from a lack of OM management techniques may be small and unsubstantial. Over time, however, these effects will likely increase dramatically and result in poor quality putting surfaces. For a high quality golf green, where the densest, most aesthetically pleasing and persistent turf is desired, modern bentgrass cultivars should be planted and OM must be properly managed. Additionally, moderate (146 to 196 kg N ha^{-1} yr^{-1}) annual N should be applied and small (5 kg N ha-1 wk^{-1}) amounts should be applied particularly during the summer months.

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Table 3-1. Turf quality as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes in 2006.

		Turf quality †						
Management program ‡	Sand particle size	May	June	July	Aug	Sept	Oct	Mean
		(0-10)						
HT + Seas. Top.	Medium-coarse	8.3 a§	7.9 a	7.7 b	7.7 b	7.2 c	7.0 c	7.7 c
HT + Freq. Top.	Medium-coarse	8.4 a	7.8 ab	7.9 ab	7.9 a	7.7 b	7.6 b	7.9 b
HT + Seas. Top.	Medium-fine	8.1 b	7.6 bc	7.9 ab	7.7 b	7.7 b	7.5 b	7.7 bc
HT + Freq. Top.	Medium-fine	7.9 b	7.4 c	7.7 b	7.7 b	7.6 b	7.6 b	7.6 c
Freq. Top. Only	Medium-coarse	8.6 a	7.9 ab	8.1 a	7.9 a	8.6 a	8.9 a	8.2 a
Cultivar								
A-4		7.7 c	7.4 b	8.2 a	8.2 a	7.4 b	7.3 c	7.8 b
L-93		8.6 a	8.4 a	8.2 a	8.1 a	7.9 a	7.8 b	8.1 a
Penncross		8.3 b	7.5 b	7.3 b	7.2 b	7.9 a	8.0 a	7.6 c
Annual N regime								
112 kg N ha^{-1} yr^{-1}		7.9 b	7.4 b	7.3 b	7.2 b	7.6 b	7.6 b	7.5 b
196 kg N ha^{-1} yr^{-1}		8.6 a	8.1 a	8.4 a	8.4 a	7.9 a	7.9 a	8.2 a

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

‡ Hollow tine core cultivation occurred on 14 Apr. and 14 Sept.

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

Table 3-1a. ANOVA table of turf quality as affected by various factors, 2006.

ANOVA	Turf quality †						
	May	June	July	Aug	Sept	Oct	Mean
Sand Size (S)	***	**	NS	NS	*	**	NS
Application frequency (F)	NS	NS	NS	*	*	***	NS
S x F	NS	NS	NS	NS	**	**	*
Cultivar (C)	***	***	***	***	***	***	***
F x C	NS	NS	NS	NS	NS	***	NS
S x C	*	*	NS	NS	NS	NS	NS
S x F x C	NS	NS	NS	NS	NS	NS	NS
Nitrogen (N)	***	***	***	***	***	***	***
F x N	NS	NS	NS	NS	NS	NS	NS
S x N	NS	NS	NS	NS	NS	NS	NS
S x F x N	NS	NS	NS	**	NS	NS	NS
C x N	*	NS	NS	*	NS	NS	NS
F x C x N	NS	NS	NS	NS	NS	NS	NS
S x C x N	NS	NS	NS	NS	NS	NS	NS
S x F x C x N	NS	NS	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 ≥ 7 acceptable.
‡ Hollow tine core cultivation occurred on 14 Apr. and 14 Sept.
*, **, ***, and NS refer to significant at the 0.05, 0.01, 0.001, and non-significant respectively.

Table 3-2. Turf quality as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes in 2007.

		Turf quality †							
Management program ‡	Sand particle size	May	June	July	Aug	Sept	Oct	Mean	Study Mean
		(0-10)							
HT + Seas. Top.	Medium-coarse	7.4 c§	7.8 c	7.7 b	7.8 bc	7.1 c	7.5 c	7.6 b	7.6 c
HT + Freq. Top.	Medium-coarse	7.9 b	8.5 a	8.3 a	8.3 a	7.7 a	8.0 b	8.1 a	8.0 b
HT + Seas. Top.	Medium-fine	7.5 c	8.1 b	7.8 b	7.8 bc	7.2 bc	7.5 c	7.7 b	7.7 c
HT + Freq. Top.	Medium-fine	7.7 bc	8.0 bc	7.8 b	7.7 c	7.2 bc	7.6 c	7.7 b	7.7 c
Freq. Top. Only	Medium-coarse	8.6 a	8.5 a	8.2 a	7.9 b	7.4 ab	8.4 a	8.2 a	8.2 a
Cultivar									
A-4		7.4 a	8.7 a	8.6 a	8.7 a	7.7 a	8.2 a	8.2 a	8.0 a
L-93		8.2 a	8.4 b	8.0 b	7.9 b	7.4 b	7.8 b	8.0 b	8.1 a
Penncross		7.9 b	7.6 c	7.2 c	7.1 c	6.9 c	7.4 c	7.4 c	7.5 b
Annual N regime									
112 kg N ha^{-1} yr^{-1}		7.5 b	8.0 b	7.6 b	7.4 b	7.1 b	7.6 b	7.5 b	7.5 b
196 kg N ha^{-1} yr^{-1}		8.2 a	8.6 a	8.4 a	8.4 a	7.5 a	8.0 a	8.2 a	8.2 a

† Turfgrass quality was visually rated on a 0-10 scale where 0 = brown, dead turf, 10 = optimum greenness and uniformity $\geq$ 7 acceptable.
‡ Hollow tine core cultivation occurred on 13 Apr. and 18 Sept.
§ Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD t-test (p=0.05).

Table 3-2a. ANOVA table of turf quality as affected by various factors, 2007.

ANOVA	Turf quality †							
	May	June	July	Aug	Sept	Oct	Mean	Study Mean
Sand Size (S)	NS	NS	NS	***	NS	NS	NS	*
Application frequency (F)	**	**	**	**	*	**	***	***
S x F	NS	***	NS	NS	*	*	**	***
Cultivar (C)	***	***	***	***	***	***	***	***
F x C	NS	NS	NS	NS	NS	NS	NS	NS
S x C	NS	NS	NS	NS	NS	NS	NS	NS
S x F x C	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen (N)	***	***	***	***	**	***	***	***
F x N	NS	NS	NS	NS	NS	NS	NS	NS
S x N	NS	NS	NS	NS	NS	NS	NS	NS
S x F x N	*	*	NS	NS	NS	NS	NS	*
C x N	NS	*	NS	NS	NS	NS	NS	NS
F x C x N	NS	NS	NS	NS	NS	NS	NS	NS
S x C x N	NS	NS	NS	NS	NS	NS	NS	NS
S x F x C x N	NS	NS	NS	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.

‡ Hollow tine core cultivation occurred on 13 Apr. and 18 Sept.

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

Table 3-3. Annual turf quality as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes from June to mid-Sept. in 2006-2007.

		Turf quality †			
		2006		2007	
Management program ‡	Sand particle size	4 June - 10 Sept	Annual mean	7 June - 17 Sept	Annual mean
		(0-10)			
HT + Seas. Top.	Medium-coarse	7.8 abc§	7.7 c	7.8 b	7.6 b
HT + Freq. Top.	Medium-coarse	7.9 ab	7.9 b	8.3 a	8.1 a
HT + Seas. Top.	Medium-fine	7.7 bc	7.7 bc	7.9 b	7.7 b
HT + Freq. Top.	Medium-fine	7.6 c	7.6 c	7.8 b	7.7 b
Freq. Top. Only	Medium-coarse	8.0 a	8.2 a	8.1 a	8.2 a
Cultivar					
A-4		8.0 b	7.8 b	8.6 a	8.2 a
L-93		8.2 a	8.1 a	8.1 b	8.0 b
Penncross		7.4 c	7.6 c	7.3 c	7.4 c
Annual N regime					
112 kg N ha^{-1} yr^{-1}		7.4 b	7.5 b	7.6 b	7.5 b
196 kg N ha^{-1} yr^{-1}		8.3 a	8.2 a	8.4 a	8.2 a

† Turfgrass quality was visually rated on a 0-10 scale where 0 = brown, dead turf, 10 = optimum greenness and uniformity ≥ 7 acceptable. Measurement periods were selected between complete core cultivation recovery from the initial and immediately prior to the second core cultivation event.

‡ Hollow tine core cultivation occurred on 14 Apr. and 14 Sept. and 13 Apr. and 18 Sept. in 2006 and 2007.

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

Table 3-4. Percent recovery from core cultivation as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes, spring 2007.

		Percent recovery †			
Management program ‡	Sand particle size	13 DAC	20 DAC	27 DAC	34 DAC
		% recovery			
HT + Seas. Top.	Medium-coarse	34 b§	51 b	81 ab	93 a
HT + Freq. Top.	Medium-coarse	43 a	62 a	81 ab	94 a
HT + Seas. Top.	Medium-fine	29 b	44 b	70 b	89 a
HT + Freq. Top.	Medium-fine	31 b	48 b	85 a	94 a
Freq. Top. Only	Medium-coarse	NM¶	NM	NM	NM
Cultivar					
A-4		20 c	30 c	64 c	83 b
L-93		33 b	50 b	80 b	95 a
Penncross		50 a	75 a	94 a	99 a
Annual N regime					
112 kg N ha^{-1} yr^{-1}		31 b	49 a	74 b	89 b
196 kg N ha^{-1} yr^{-1}		37 a	54 a	84 a	96 a

† Percent recovery measured by visually estimating the amount of area lacking turf cover each day after cultivation (DAC).
‡ Hollow tine core cultivation occurred on 13 Apr.
§ Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD t-test (p=0.05).
¶ NM designates to not measured.

Table 3-4a. ANOVA table of percent recovery as affected by various factors, spring 2007.

ANOVA	Percent recovery †			
	13 DAC	20 DAC	27 DAC	34 DAC
Sand Size (S)	**	**	NS	NS
Application frequency (F)	NS	*	NS	NS
S x F	NS	NS	NS	NS
Cultivar (C)	***	***	***	***
F x C	NS	NS	NS	NS
S x C	NS	NS	NS	NS
S x F x C	NS	NS	NS	NS
Nitrogen (N)	*	NS	*	*
F x N	NS	NS	NS	NS
S x N	NS	NS	NS	NS
S x F x N	NS	NS	NS	NS
C x N	NS	NS	NS	NS
F x C x N	NS	NS	NS	NS
S x C x N	NS	NS	NS	NS
S x F x C x N	NS	NS	NS	NS

† Percent recovery measured by visually estimating the amount of area lacking turf cover each day after cultivation (DAC).
‡ Hollow tine core cultivation occurred on 13 Apr.
*, **, ***, and NS refer to significant at 0.05, 0.01, 0.001, and non-significant respectively.

Table 3-5. Percent recovery from core cultivation as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes, late-summer 2007.

Management program ‡	Sand particle size	Percent recovery †			
		8 DAC	15 DAC	24 DAC	35 DAC
		% recovery			
HT + Seas. Top.	Medium-coarse	26 b§	51 b	80 c	100 a
HT + Freq. Top.	Medium-coarse	51 a	76 a	97 a	97 a
HT + Seas. Top.	Medium-fine	30 b	44 b	82 c	98 a
HT + Freq. Top.	Medium-fine	29 b	48 b	91 b	100 a
Freq. Top. Only	Medium-coarse	NM¶	NM	NM	NM
Cultivar					
A-4		20 b	35 c	75 c	85 b
L-93		31 b	55 b	90 b	96 a
Penncross		50 a	78 a	98 a	100 a
Annual N regime					
112 kg N ha^{-1} yr^{-1}		32 a	51 a	81 b	99 a
196 kg N ha^{-1} yr^{-1}		35 a	58 a	93 a	100 a

† Percent recovery measured by visually estimating the amount of area lacking turf cover each day after cultivation (DAC).
‡ Hollow tine core cultivation occurred on 18 Sept.
§ Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD t-test (p=0.05).
¶ NM designates to not measured.

Table 3-5a. ANOVA table of percent recovery as affected by various factors, late-summer 2007.

ANOVA	Percent recovery †			
	8 DAC	15 DAC	24 DAC	35 DAC
Sand Size (S)	*	***	NS	NS
Application frequency (F)	**	***	***	NS
S x F	**	*	NS	NS
Cultivar (C)	***	***	***	NS
F x C	NS	NS	NS	NS
S x C	NS	NS	NS	NS
S x F x C	NS	NS	NS	NS
Nitrogen (N)	NS	NS	***	NS
F x N	NS	NS	NS	NS
S x N	NS	NS	NS	NS
S x F x N	NS	NS	NS	NS
C x N	NS	NS	NS	NS
F x C x N	NS	NS	NS	NS
S x C x N	NS	NS	NS	NS
S x F x C x N	NS	NS	NS	NS

† Percent recovery measured by visually estimating the amount of area lacking turf cover each day after cultivation (DAC).
‡ Hollow tine core cultivation occurred on 18 Sept.
*, **, ***, and NS refer to significant at 0.05, 0.01, 0.001, and non-significant respectively.

Table 3-6. Dollar spot severity as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes, 2005-2007.

		Dollar spot infection centers †						
		2005			2006			2007
Management program ‡	Sand particle size	24 July	16 Sept	16 Oct	22 May	1 Aug	19 Aug	21 Oct
		No. of *S. homoeocarpa* infection centers plot $^{-1}$						
HT + Seas. Top.	Medium-coarse	2.3 b§	10.0 d	10.8 c	1.9 c	3.2 c	13.2 d	5.2 d
HT + Freq. Top.	Medium-coarse	2.4 b	20.3 bc	20.5 b	4.8 bc	10.9 b	19.8 cd	9.9 c
HT + Seas. Top.	Medium-fine	1.6 b	18.3 c	25.0 ab	9.8 ab	12.1 ab	22.1 bc	11.3 bc
HT + Freq. Top.	Medium-fine	1.8 b	24.8 ab	27.6 a	12.8 a	12.6 ab	29.0 ab	14.0 ab
Freq. Top. Only	Medium-coarse	4.1 a	28.6 a	29.3 a	10.8 a	18.9 a	32.8 a	16.5 a
Cultivar								
A-4		5.5 a	31.3 a	42.1 a	20.9 a	28.0 a	42.3 a	22.1 a
L-93		1.0 b	16.9 b	12.6 b	1.5 b	3.9 b	14.1 b	6.3 b
Penncross		0.9 b	13.1 b	13.2 b	1.7 b	2.8 b	13.7 b	5.8 b
Annual N regime								
112 kg N ha^{-1} yr^{-1}		2.5 a	20.5 a	22.8 a	8.5 a	9.2 a	18.9 b	10.7 a
196 kg N ha^{-1} yr^{-1}		2.4 a	20.4 a	22.5 a	7.5 a	13.9 a	27.8 a	12.1 a

† Individual dollar spot infection centers were counted during periods of disease activity.
‡ Hollow tine core cultivation on 14 Apr. and 8 Sept. in 2005, 14 Apr. and 14 Sept. in 2006, and 13 Apr. and 18 Sept. in 2007.
§ Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD t-test ($p=0.05$).

Table 3-6a. ANOVA table of dollar spot infection centers as affected by various factors, 2005-2007.

	Dollar spot infection centers †						
	2005			2006			2007
ANOVA	24 July	16 Sept	16 Oct	22 May	1 Aug	19 Aug	21 Oct
Sand Size (S)	NS	**	***	***	*	**	NS
Application frequency (F)	NS	***	*	NS	NS	*	NS
S x F	NS	NS	NS	NS	NS	NS	NS
Cultivar (C)	***	***	***	***	***	***	***
F x C	NS	NS	NS	NS	NS	NS	NS
S x C	NS	NS	**	***	*	*	NS
S x F x C	NS	NS	NS	NS	NS	NS	NS
Nitrogen (N)	NS	NS	NS	NS	*	***	NS
F x N	NS	NS	NS	NS	NS	NS	NS
S x N	NS	NS	NS	NS	NS	NS	NS
S x F x N	NS	NS	NS	NS	NS	NS	NS
C x N	NS	NS	NS	NS	NS	NS	NS
F x C x N	NS	NS	NS	NS	NS	NS	NS
S x C x N	NS	NS	NS	NS	NS	NS	NS
S x F x C x N	NS	NS	NS	NS	NS	NS	NS

† Individual dollar spot infection centers were counted during periods of disease activity.
*, **, ***, and NS refer to significant at the 0.05, 0.01, 0.001, and non-significant respectively.

Table 3-7. Localized dry spot as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes, 2005-2006.

Management program §	Sand particle size	Localized dry spot †		Volumetric water content ‡
		28 Aug 2006	5 Sept 2007	2 Sept
		% plot area affected		$m^3\ m^{-3}$
HT + Seas. Top.	Medium-coarse	2.5 a¶	32.2 b	0.104 b
HT + Freq. Top.	Medium-coarse	0.5 ab	18.0 c	0.121 a
HT + Seas. Top.	Medium-fine	1.4 ab	36.0 ab	0.097 b
HT + Freq. Top.	Medium-fine	0.1 b	32.0 bc	0.122 a
Freq. Top. Only	Medium-coarse	2.0 ab	49.7 a	0.096 b
Cultivar				
A-4		2.0 a	32.1 a	0.107 a
L-93		0.7 a	29.7 a	0.110 a
Penncross		1.2 a	38.8 a	0.106 a
Annual N regime				
112 kg N $ha^{-1}\ yr^{-1}$		2.2 a	37.5 a	0.109 a
196 kg N $ha^{-1}\ yr^{-1}$		0.4 b	29.6 a	0.107 a

† Localized dry spot measured by estimating the percent of surface area discolored from wilt.
‡ Volumetric water content was measured (0-2.25 cm depth) using time domain reflectometry.
§ Hollow tine core cultivation occurred on 14 Apr. and 14 Sept. in 2006, and 13 Apr. and 18 Sept. in 2007.
¶ Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD t-test ($p=0.05$).

Table 3-7a. ANOVA table of localized dry spot as affected by various factors, 2006-2007.

ANOVA	Localized dry spot †	
	28 Aug 2006	5 Sept 2007
Sand Size (S)	NS	NS
Application frequency (F)	*	NS
S x F	NS	NS
Cultivar (C)	NS	NS
F x C	NS	NS
S x C	NS	NS
S x F x C	NS	NS
Nitrogen (N)	NS	*
F x N	NS	NS
S x N	NS	NS
S x F x N	NS	NS
C x N	NS	NS
F x C x N	NS	NS
S x C x N	NS	NS
S x F x C x N	NS	NS

† Localized dry spot measured by estimating the percent of surface area discolored from wilt.
* and NS refer to significant at the 0.05 and non-significant respectively.

Table 3-8. Percent moss, shoot density, and volumetric water content as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes, 2005-2006.

		Moss incidence †		Shoot density ‡	Volumetric water content §
Management program ‡	Sand particle size	24 July 2005	1 Aug 2006	27 July 2006	13 Aug 2006
		--------- % moss $plot^{-1}$ ---------		--- shoots dm^{-2} ---	----------- m^3 m^{-3} -----------
HT + Seas. Top.	Medium-coarse	0.1 c#	0.4 bc	NM††	0.168 b
HT + Freq. Top.	Medium-coarse	0.5 bc	0.4 bc	NM	0.170 b
HT + Seas. Top.	Medium-fine	0.9 b	0.9 b	NM	0.173 b
HT + Freq. Top.	Medium-fine	1.8 a	2.0 a	NM	0.190 a
Freq. Top. Only	Medium-coarse	0.1 c	0.3 c	NM	0.166 b
Cultivar	Annual N regime				
A-4	112 kg N ha^{-1} yr^{-1}	0.1 c	0.1 c	1554 ab	0.168 a
L-93	112 kg N ha^{-1} yr^{-1}	0.3 c	0.3 c	1413 bc	0.176 a
Penncross	112 kg N ha^{-1} yr^{-1}	2.4 a	2.6 a	929 d	0.172 a
A-4	196 kg N ha^{-1} yr^{-1}	0.1 c	0.1 c	1593 a	0.171 a
L-93	196 kg N ha^{-1} yr^{-1}	0.1 c	0.1 c	1320 c	0.176 a
Penncross	196 kg N ha^{-1} yr^{-1}	1.1 b	1.8 b	1016 d	0.180 a

† Moss incidence quantified by estimated the percent of the surface infested with moss.

‡ 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.

§ Volumetric water content measured (0-2.25 cm depth) using time domain reflectometry.

¶ Hollow tine core cultivation on 14 Apr. and 8 Sept. in 2005, 14 Apr. and 14 Sept. in 2006.

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

†† NM designates to not measured.

Table 3-8a. ANOVA table of moss incidence as affected by various factors, 2005-2006.

	Moss incidence †	
ANOVA	24 July 2005	1 Aug 2006
Sand Size (S)	***	***
Application frequency (F)	*	*
S x F	NS	*
Cultivar (C)	***	***
F x C	**	*
S x C	***	***
S x F x C	NS	NS
Nitrogen (N)	*	NS
F x N	NS	NS
S x N	NS	NS
S x F x N	NS	NS
C x N	*	NS
F x C x N	NS	NS
S x C x N	NS	NS
S x F x C x N	NS	NS

† Moss incidence quantified by estimated the percent of the surface infested with moss.
*, **, ***, and NS refer to significant at the 0.05, 0.01, 0.001, and non-significant respectively.

Table 3-9. Canopy greenness as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes in 2006.

		Greenness †						
Management program ‡	Sand particle size	May	June	July	Aug	Sept	Oct	Mean
		color index (spectrum units)						
HT + Seas. Top.	Medium-coarse	228 ab§	218 b	246 b	250 b	212 b	189 b	223 b
HT + Freq. Top.	Medium-coarse	223 b	217 b	246 b	250 b	218 b	191 b	223 b
HT + Seas. Top.	Medium-fine	228 ab	222 b	248 b	251 b	218 b	192 ab	225 b
HT + Freq. Top.	Medium-fine	235 ab	231 a	259 a	262 a	229 a	198 a	234 a
Freq. Top. Only	Medium-coarse	238 a	221 b	242 b	243 c	213 b	188 b	223 b
Cultivar								
A-4		239 a	232 a	260 a	264 a	220 a	194 a	234 a
L-93		246 a	232 a	254 b	255 b	223 a	197 a	233 a
Penncross		207 b	201 b	231 c	236 c	211 b	184 b	209 b
Annual N regime								
112 kg N ha^{-1} yr^{-1}		212 b	205 b	232 b	235 b	208 b	177 b	209 b
196 kg N ha^{-1} yr^{-1}		249 a	238 a	264 a	268 a	228 a	206 a	242 a

† Greenness was measured using a hand-held reflectance meter (CM1000) with five measurements per plot recorded in a systematic grid pattern.

‡ Hollow tine core cultivation occurred on 14 Apr. and 14 Sept.

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

Table 3-9a. ANOVA table of canopy greenness as affected by various factors, 2006.

ANOVA	Greenness †						
	May	June	July	Aug	Sept	Oct	Mean
Sand Size (S)	NS	**	***	**	**	*	**
Application frequency (F)	NS	NS	*	**	**	NS	*
S x F	NS	NS	**	*	NS	NS	NS
Cultivar (C)	***	***	***	***	*	***	***
F x C	NS	NS	NS	NS	NS	NS	NS
S x C	NS	NS	NS	NS	NS	NS	NS
S x F x C	NS	NS	NS	NS	NS	NS	NS
Nitrogen (N)	***	***	***	***	***	***	***
F x N	NS	NS	NS	NS	NS	NS	NS
S x N	NS	NS	NS	NS	NS	NS	NS
S x F x N	NS	NS	NS	NS	NS	NS	NS
C x N	NS	NS	NS	NS	NS	NS	NS
F x C x N	NS	NS	NS	NS	NS	NS	NS
S x C x N	NS	NS	NS	NS	NS	NS	NS
S x F x C x N	NS	NS	NS	NS	NS	NS	NS

† Greenness was measured using a hand-held reflectance meter (CM1000) with five measurements per plot recorded in a systematic grid pattern.

‡ Hollow tine core cultivation occurred on 14 Apr. and 14 Sept.

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

Table 3-10. Canopy greenness as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes in 2007.

		Greenness †							
Management program ‡	Sand particle size	May	June	July	Aug	Sept	Oct	Mean	Study Mean
		color index (spectrum units)							
HT + Seas. Top.	Medium-coarse	218 b§	262 b	302 b	307 b	285 a	284 a	273 b	247 b
HT + Freq. Top.	Medium-coarse	218 b	260 b	298 bc	286 c	273 ab	269 b	264 c	242 bc
HT + Seas. Top.	Medium-fine	218 b	262 b	299 bc	300 b	269 b	280 a	268 bc	246 b
HT + Freq. Top.	Medium-fine	233 a	277 a	313 a	322 a	287 a	288 a	284 a	257 a
Freq. Top. Only	Medium-coarse	215 b	252 b	293 c	272 d	238 c	268 b	253 d	237 c
Cultivar									
A-4		225 a	272 a	317 a	312 a	275 a	290 a	278 a	255 a
L-93		225 a	267 a	303 b	299 b	276 a	283 b	272 a	252 a
Penncross		212 b	248 b	283 c	281 c	260 b	261 c	254 b	231 b
Annual N regime									
112 kg N ha^{-1} yr^{-1}		198 b	235 b	274 b	282 b	261 b	256 b	248 b	228 b
196 kg N ha^{-1} yr^{-1}		243 a	290 a	328 a	313 a	280 a	300 a	289 a	264 a

† Greenness was measured using a hand-held reflectance meter (CM1000) with five measurements per plot recorded in a systematic grid pattern.

‡ Hollow tine core cultivation occurred on 13 Apr. and 18 Sept.

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

Table 3-10a. ANOVA table of canopy greenness as affected by various factors, 2007.

ANOVA	Greenness †							
	May	June	July	Aug	Sept	Oct	Mean	Study Mean
Sand Size (S)	*	*	*	***	NS	*	*	**
Application frequency (F)	*	NS	NS	NS	NS	NS	NS	NS
S x F	*	**	**	***	**	***	***	***
Cultivar (C)	**	***	***	***	*	***	***	***
F x C	NS	NS	NS	NS	NS	NS	NS	NS
S x C	NS	NS	NS	NS	NS	NS	NS	NS
S x F x C	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen (N)	***	***	***	***	***	***	***	***
F x N	NS	NS	NS	NS	NS	NS	NS	NS
S x N	NS	NS	NS	NS	NS	NS	NS	NS
S x F x N	NS	NS	NS	NS	NS	NS	NS	NS
C x N	NS	NS	NS	NS	NS	NS	NS	NS
F x C x N	NS	NS	NS	NS	NS	NS	NS	NS
S x C x N	NS	NS	NS	NS	NS	NS	NS	NS
S x F x C x N	NS	NS	NS	NS	NS	NS	NS	NS

† Greenness was measured using a hand-held reflectance meter (CM1000) with five measurements per plot recorded in a systematic grid pattern.

‡ Hollow tine core cultivation occurred on 13 Apr. and 18 Sept.

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

Table 3-11. Ball roll distance, shoot density, and volumetric water content as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes in 2007.

Management program ‡	Sand particle size	Ball roll distance † 13 Sept	Shoot density ‡ 25 Sept	Volumetric water content § 2 Sept	Volumetric water content § 17 Sept
		------------- cm -------------	----- shoots / dm^2 ------	------------ m^3 m^{-3}	-------------
HT + Seas. Top.	Medium-coarse	152 a[#]	NM[††]	0.104 b	0.129 bc
HT + Freq. Top.	Medium-coarse	154 a	NM	0.121 a	0.133 b
HT + Seas. Top.	Medium-fine	152 a	NM	0.097 b	0.129 bc
HT + Freq. Top.	Medium-fine	154 a	NM	0.122 a	0.165 a
Freq. Top. Only	Medium-coarse	151 a	NM	0.096 b	0.109 c
Cultivar					
A-4		154 a	1963 a	0.107 a	0.128 a
L-93		150 b	1512 b	0.110 a	0.135 a
Penncross		153 ab	1100 c	0.106 a	0.136 a
Annual N regime					
112 kg N ha^{-1} yr^{-1}		157 a	1530 a	0.109 a	0.139 a
196 kg N ha^{-1} yr^{-1}		148 b	1520 a	0.107 a	0.127 a

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

‡ 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.

§ Volumetric water content measured (0-2.25 cm depth) using time domain reflectometry.

¶ Hollow tine core cultivation occurred on 13 Apr. and 18 Sept.

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

†† NM designates to not applicable.

Table 3-11a. ANOVA table of ball roll distance as affected by various factors, 2007.

	Ball roll distance †
ANOVA	13 Sept
Sand Size (S)	NS
Application frequency (F)	NS
S x F	NS
Cultivar (C)	NS
F x C	NS
S x C	NS
S x F x C	NS
Nitrogen (N)	***
F x N	NS
S x N	NS
S x F x N	NS
C x N	NS
F x C x N	NS
S x C x N	NS
S x F x C x N	NS

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

*** and NS refer to significant at 0.001 and non-significant respectively.

Table 3-12. Canopy temperature and volumetric water content as affected by five organic matter management programs, three creeping bentgrass cultivars, and two annual N regimes in 2006.

		Canopy temperature †	Volumetric water content ‡
Management program ‡	Sand particle size	23 Aug	13 Aug
		°C	m^3 m^{-3}
HT + Seas. Top.	Medium-coarse	40.2 a¶	0.168 b
HT + Freq. Top.	Medium-coarse	40.0 a	0.170 b
HT + Seas. Top.	Medium-fine	38.7 b	0.173 b
HT + Freq. Top.	Medium-fine	38.5 b	0.190 a
Freq. Top. Only	Medium-coarse	40.0 a	0.166 b
Cultivar			
A-4		39.8 a	0.170 a
L-93		39.3 ab	0.174 a
Penncross		39.1 b	0.176 a
Annual N regime			
112 kg N ha^{-1} yr^{-1}		39.6 a	0.171 a
196 kg N ha^{-1} yr^{-1}		39.2 a	0.176 a

† Canopy temperature was measured using a hand-held infared (Raytek ST 20 Pro, Raytek, Santa Cruz, CA) thermometer during late afternoon in a systematic grid pattern for five locations per plot and averaged into one value for statistical analysis.

‡ Volumetric water content measured (0-2.25 cm depth) using time domain reflectometry.

§ Hollow tine core cultivation occurred on 14 Apr. and 14 Sept.

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

Table 3-12a. ANOVA table of bentgrass canopy temperature as affected by various factors, 2006.

ANOVA	Canopy temperature †
	23 Aug
Sand Size (S)	*
Application frequency (F)	NS
S x F	NS
Cultivar (C)	NS
F x C	NS
S x C	NS
S x F x C	NS
Nitrogen (N)	NS
F x N	NS
S x N	NS
S x F x N	NS
C x N	NS
F x C x N	NS
S x C x N	NS
S x F x C x N	NS

† Canopy temperature was measured using a hand-held infared (Raytek ST 20 Pro, Raytek, Santa Cruz, CA) thermometer during late afternoon in a systematic grid pattern for five locations per plot and averaged into one value for statistical analysis.

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

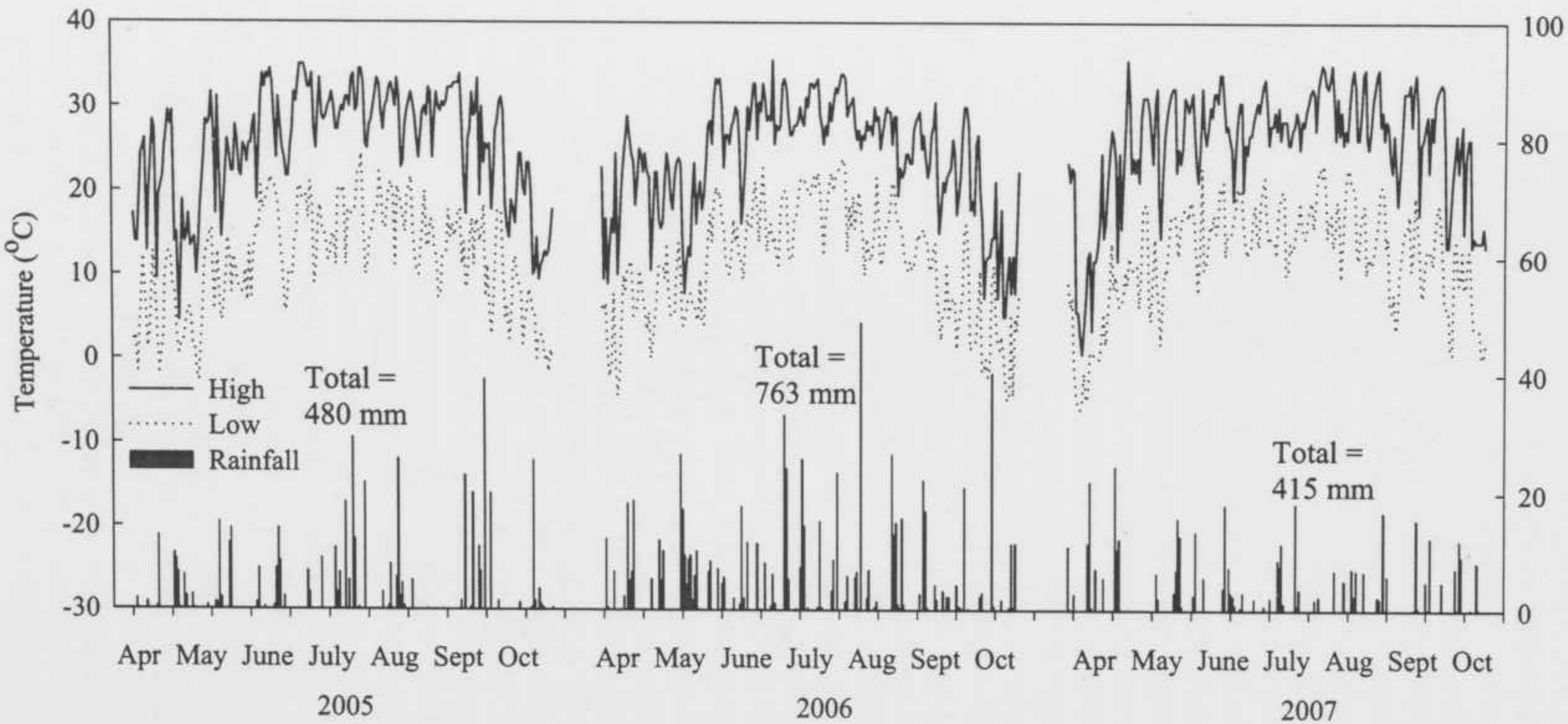

Figure 3-1. Daily temperature and rainfall during the growing season (1 Apr. to 31 Oct.) for 2005, 2006, and 2007 in West Lafayette, IN.

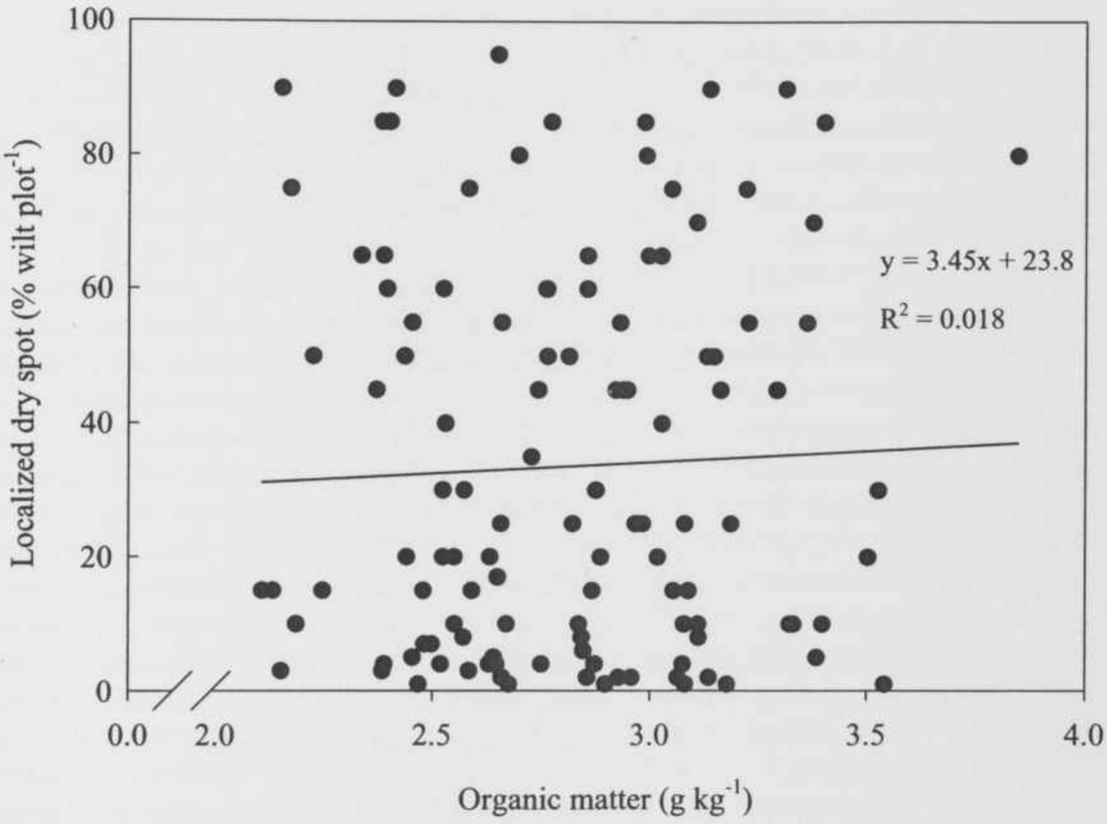

Figure 3-2. Localized dry spot (5 Sept 2007) and organic matter (2007).

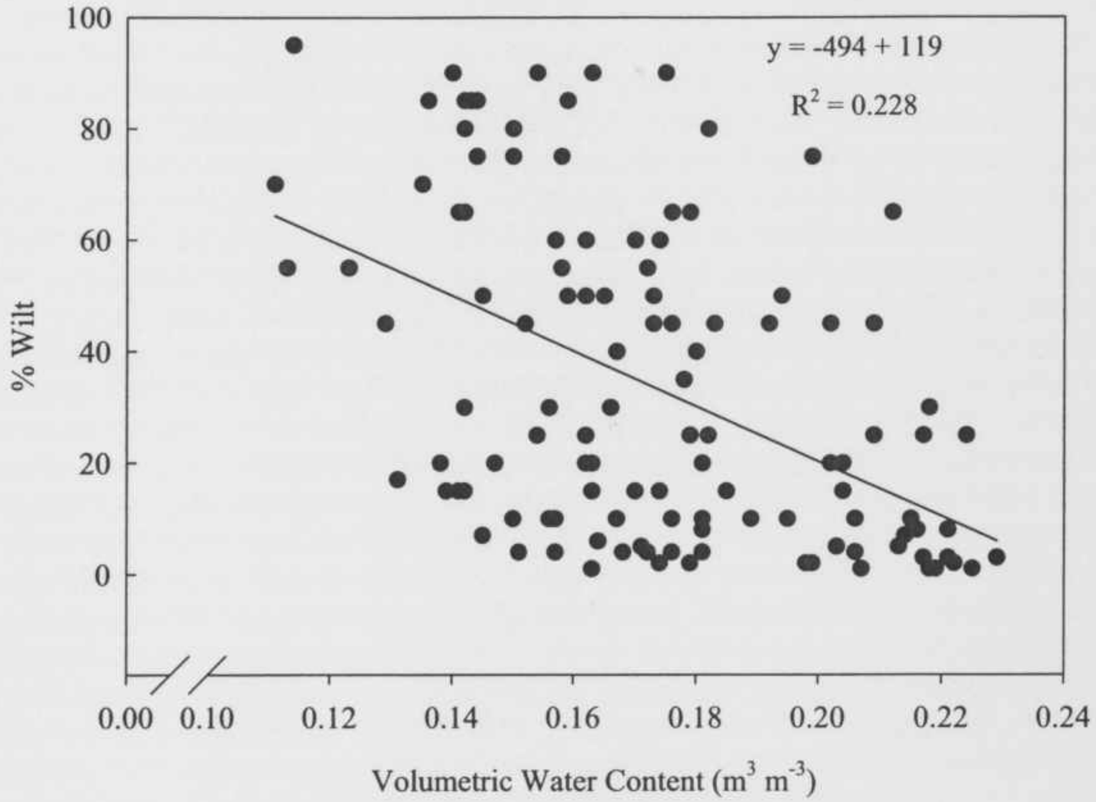

Figure 3-3. Localized dry spot (5 Sept. 2007) and volumetric water content

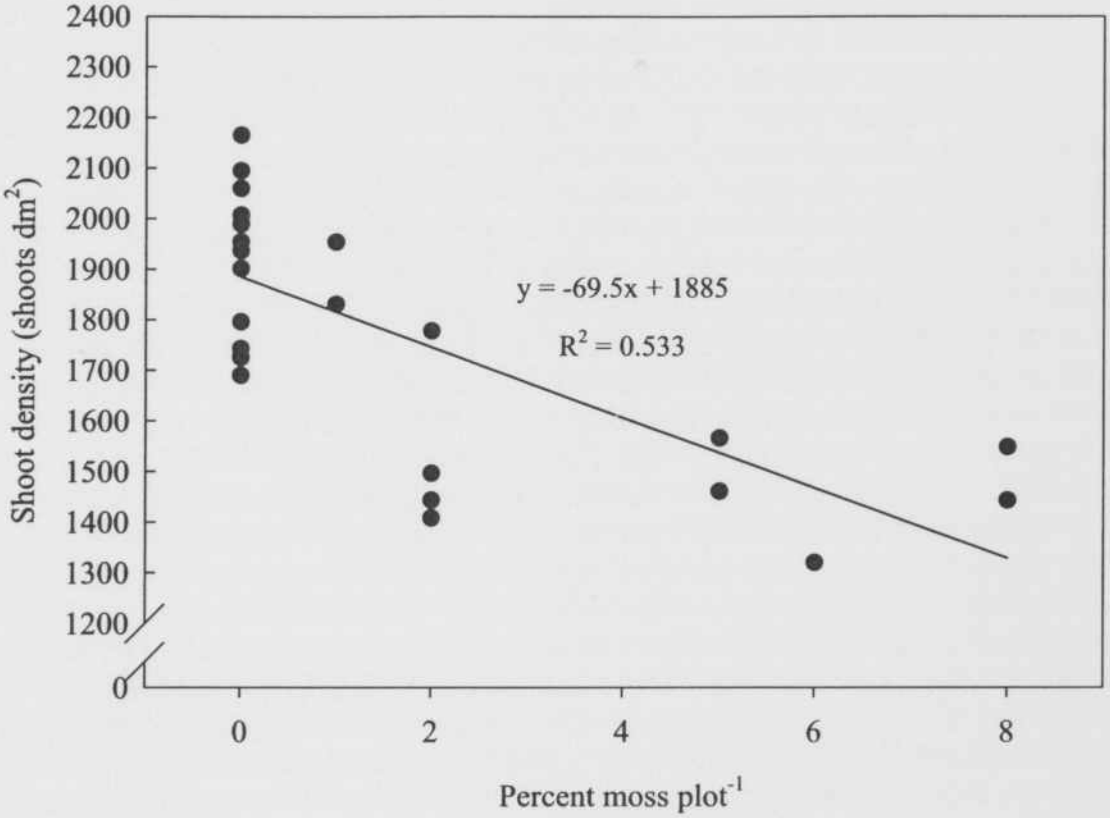

Figure 3-4. Shoot density (27 July 2006) and moss incidence (1 Aug 2006).

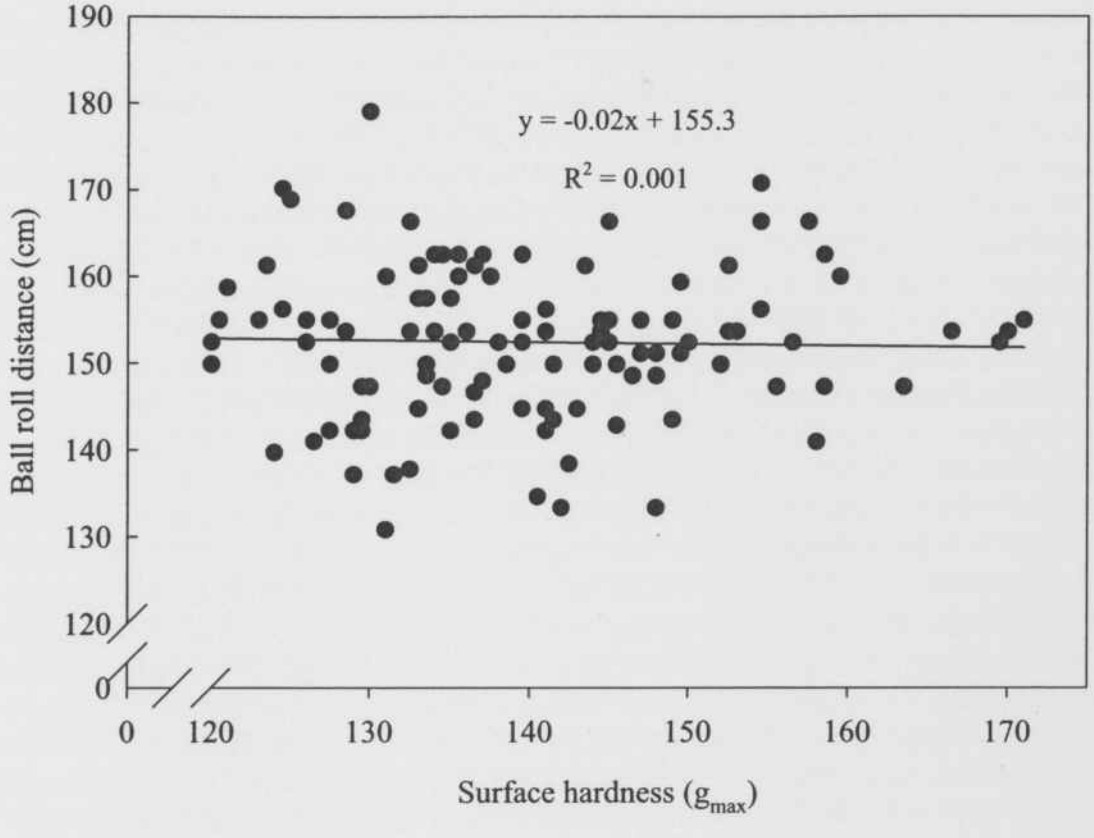

Figure 3-5. Surface hardness (27 Aug 2007) and ball roll distance (13 Sept 2007).