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# Creeping Bentgrass Color and Quality, Chlorophyll Content, and Thatch–Mat Accumulation Responses to Summer Coring

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## ABSTRACT

Coring is a common cultural practice used on golf courses. The reported effects of coring alone on thatch–mat accumulation have been mixed. The objectives of this field study were to examine the effects of spring and summer coring on thatch–mat thickness and organic matter accumulation in creeping bentgrass (*Agrostis stolonifera* L.). Turfgrass color and quality and chlorophyll content were also monitored. The study site was 'Providence' creeping bentgrass grown on a sand-based rootzone maintained as a putting green. Three coring regimes were assessed as follows: spring-only coring (1.27-cm-diam. tines), spring plus three summer corings (0.64-cm-diam. tines), and a noncored control. At the end of the second year, spring-only and spring-plus-summer cored plots had developed a 66 and 89%, respectively, thicker thatch–mat layer compared with noncored bentgrass. The total organic matter content (weight loss-on-ignition) in thatch–mat layers, however, generally was similar among all three regimes in both years. This indicated that the organic matter was diluted by inclusion of sand from topdressing or reincorporation of cores. Thus, organic matter concentration (i.e., gravimetric organic: dry weight of the cores) in the thatch–mat layer was much lower in plots of both coring regimes vs. noncored plots. Both spring-only and especially spring-plus-summer coring caused substantial reductions in turf quality for a 2-wk period. Spring-plus-summer coring resulted in increased chlorophyll levels as well as improved turf color and quality in late summer.

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**Abbreviations:** LOI, loss-on-ignition.

Creeping bentgrass (*Agrostis stolonifera* L.) is aggressively stoloniferous and produces a well-defined organic layer at the soil surface. The surface organic layer in turfgrass is referred to as *thatch*, but on putting greens it is often mixed with sand topdressing and is referred to as *mat* (Turgeon, 2008). Hereafter, this organic layer will be referred to as *thatch–mat*. Excessive thatch–mat layers can have numerous negative effects on turfgrasses as outlined by McCarty et al. (2005, 2007). In addition, creeping bentgrass stems and roots become elevated in thick surface organic layers, and plants can be rendered more susceptible to injury from summer stresses and disease (Dernoeden, 2002; Turgeon, 2008).

Core cultivation is a common cultural practice routinely performed on golf course putting greens. In turfgrass management, the term *cultivation* refers to working the soil and/or thatch without destroying the turf (Turgeon, 2008). Coring is a cultivation technique (Beard, 1973), and the term *coring* will be used hereafter. There are numerous benefits associated with coring, but some of the primary purposes for coring include thatch–mat control, to improve air and water infiltration, and to promote rooting (Beard, 1973). Reports on the levels of thatch–mat control in response to coring, however, have been mixed (Murray and Juska, 1977;

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Eggens, 1980; White and Dickens, 1984; Murphy et al., 1993; McCarty et al., 2005, 2007). Murray and Juska (1977) observed that coring reduced total organic matter in the thatch of Kentucky bluegrass (*Poa pratensis* L.), but the effect was short-lived. Eggens (1980) reported that monthly coring was more effective than monthly vertical cutting in controlling the thatch depth of creeping bentgrass; however, this study focused on thatch and did not include the mat layer when measuring depth. White and Dickens (1984) found no differences in thatch–mat depth between monthly hollow-tine coring and twice-yearly hollow-tine coring in bermudagrasses [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* (Burtt Davy)]. The most extensive coring studies in creeping bentgrass were reported by McCarty et al. (2005, 2007) and Murphy et al. (1993). Murphy et al. (1993) investigated the effects of hollow- and solid-tine coring on thatch–mat in a 'Penneagle' creeping bentgrass green. They found that total organic matter content as well as the thickness of the thatch–mat layer increased with hollow-tine coring; however, the concentration of organic matter decreased with hollow-tine coring (Murphy et al., 1993). McCarty et al. (2005) evaluated coring, grooming, and vertical cutting regimes in immature creeping bentgrass grown on a sand-based rootzone and reported that none of the treatments prevented thatch–mat accumulation. Thatch–mat depth in plots subjected to only coring was slightly greater (i.e., 2.5 mm) than that found in untreated plots at the end of the 2-yr study. In a later study, McCarty et al. (2007) reported that coring four times annually in a 3-yr-old stand of creeping bentgrass had no effect on thatch–mat depth. Coring did maintain organic matter concentration in thatch–mat layer to prestudy levels, while organic matter concentration increased in the thatch–mat of untreated plots. Treatments combining coring, vertical mowing, and grooming were required to reduce organic matter concentration below prestudy levels (McCarty et al., 2007).

Coring is disruptive and causes mechanical injury to the turf surface. Wiecko et al. (1993) observed a slight reduction in visual quality of 'Tifway' bermudagrass grown on a sandy loam within a few days after hollow-tine coring. Murray and Juska (1977), however, reported that coring improved quality of common Kentucky bluegrass (*Poa pratensis* L.). McCarty et al. (2007) observed that coring four times annually reduced creeping bentgrass quality somewhat, but ratings were always in the acceptable range. Murphy et al. (1993) concluded that coring generally improved creeping bentgrass quality and that hollow-tine provided better quality than solid-tine coring.

Previously reported coring studies generally indicated that mixed results were achieved by this practice in terms of controlling thatch–mat accumulation. Interpretation of these mixed results is complicated by the fact that turfgrass species and cultivars as well as methodology to assess thatch–mat accumulation often varied among these studies. Moreover, different coring methods and timings were employed in the aforementioned studies. Spring coring with wide-diameter tines followed by filling holes to the surface combined with summer coring with narrow-diameter tines is commonly recommended (O'Brien and Hartwiger, 2003). No studies, however, have assessed summer coring and reincorporation of sand from plugs and their role in thatch–mat accumulation. Furthermore, the potential importance of organic matter concentration in the thatch–mat layer has received little study or interpretation. Chlorophyll is essential for carbohydrate production in plants and provides for the green color of turf. Leaf chlorophyll levels would be expected to impact the overall health of turf since carbohydrate production is essential for growth. There have been no studies, however, that have attempted to describe the effects of summer coring on chlorophyll production or its impact on summer turf color or quality. Therefore, the objectives of this study were to determine the influence of spring-only vs. spring-plus-summer coring on organic matter accumulation in the thatch–mat layer of creeping bentgrass. In addition, creeping bentgrass color and quality as well as leaf chlorophyll content were monitored.

## MATERIALS AND METHODS

The study was conducted on a research green built to United States Golf Association specifications (Green Section Staff, 1993) at the University of Maryland Turfgrass Research Facility in College Park in 2006 and 2007. Soil was a modified sand mix (97% sand, 1% silt, and 2% clay) with a pH of 6.5 and 10 g $kg^{-1}$ of organic matter. In September 2005, the study site was treated with glyphosate [*N*-(phosphonomethyl)glycine] and the sod was removed to expose bare ground. The area was seeded (50 kg seed $ha^{-1}$) with 'Providence' creeping bentgrass in September 2005. The turf was fertilized (25 kg N $ha^{-1}$ + 11 kg P $ha^{-1}$ + 20 kg K $ha^{-1}$) eight times (20, 23, 28, and 30 September, 18 and 20 October, and 1 and 3 November) in 2005 with a 20N–9P–16K fertilizer. A 19N–1P–15K fertilizer was applied on 11 November to provide 50 kg N $ha^{-1}$, 2.3 kg P $ha^{-1}$, and 40 kg K $ha^{-1}$. A total of 250 kg N $ha^{-1}$ were applied between 20 Sept. and 11 Nov. 2005. The bentgrass was fertilized biweekly with 4.9 kg N $ha^{-1}$ from urea between 1 May and 7 June and then weekly through 24 August for a total of 78.4 kg N $ha^{-1}$ during the experimental period in 2006. In the autumn of 2006, 71 kg N $ha^{-1}$ was applied between September and November. In 2007, the bentgrass was fertilized weekly at a rate of 4.9 kg N $ha^{-1}$ with urea between 30 April and 27 August to provide a total of 88.2 kg N $ha^{-1}$ during the experimental period.

Iprodione [3-(3,5-dichlorophenyl)-*N*-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide; 14.7 kg a.i. $ha^{-1}$] was applied biweekly in 2006 and 2007 to control dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) and brown patch (*Rhizoctonia solani* Kuhn). Iprodione was chosen because it has no known plant growth regulator effects. Deltamethrin ([(*S*)-cyano-(3-phenoxyphenyl)methyl] (1*R*,3*R*)-3-(2,2-dibromoethenyl)-2,2-

dimethyl-cyclopropane-1-carboxylate; 2.2 kg a.i. $ha^{-1}$) was applied on 26 July and 24 Aug. 2006 and 18 July 2007 to control sod webworm (*Crambus* spp.). Turf was mowed three times weekly to a height of 6 mm in the spring of 2006. Mowing height was reduced to 4 mm on 3 July 2006, and the green was mowed at that height four or five times weekly and clippings were removed throughout the remainder of the study. The turf was irrigated to prevent wilt and was syringed frequently during dry, windy weather to maintain growth and density.

Three coring regimes were assessed as follows: spring-only with cores removed followed by topdressing to fill holes; spring coring as previously described plus three summer corings followed by reincorporation of the cores; and a noncored control. Hereafter, these treatments will be referred to as *spring-only coring*, *spring-plus-summer coring*, and a *noncored control*. Spring coring was performed once annually on 27 Apr. 2006 and 29 Apr. 2007 using a Miltona Handi Aerifer (Miltona Turf Products, Miltona, MN). This handheld, manual aerifier had seven 1.27-cm-diam. hollow tines, which penetrated to a depth of 9.0 cm. Cores were removed on 5.0-cm spacings and there were about 400 holes $m^{-2}$. Spring-plus-summer coring included coring in April as previously described as well as three times during the summer. Summer coring was performed using one leg taken from a Core Master ★12 Aerator (GreenCare, Sydney, Australia) equipped with a quadra-tine holder on 6 and 28 June, and 25 July 2006; and on 6 June, and 3 and 31 July 2007. The quadra-tine holder had four 0.64-cm-diam. hollow tines and was manually forced into the turf to a depth of 5.5 cm, creating a right-angle hole spacing of 3.8 cm and a diagonal hole spacing of 5.0 cm (about 690 holes $m^{-2}$). Quadra-tine coring pattern was uniform and visually determined. Topdressing, using the previously described construction mix, was applied after spring coring to fill holes to the surface. Plots were brushed to incorporate sand from cores brought to the surface by summer coring, but no additional topdressing sand was applied. Non-cored plots were not topdressed.

Turf color and quality were assessed visually on a weekly basis using a scale of 0 to 10, where 0 = brown or dead turf; 7 = minimum acceptable color or quality; 8 = very good summer color or quality; and 10 = optimum greenness, uniformity, and cover. Clippings were collected every 4 wk from late May until late August and analyzed for chlorophyll *a* and *b*. Clippings consisted mostly of leaf and some sheath tissue, which hereafter will be referred to as *leaves* or *leaf tissue*. Leaves were placed immediately in liquid nitrogen and stored in a freezer at −80°C until analyzed. Chlorophyll was extracted by soaking about 0.05 g of leaf tissue in dimethyl sulfoxide for 48 h as described by Fu and Huang (2001). Absorbance of the extract was measured at 663.2 nm ($OD_{663.2}$) and 646.8 nm ($OD_{646.8}$) with a spectrophotometer (Beckman Coulter, Inc., Fullerton, CA). Chlorophyll *a* and *b* were quantified using the equations described by Fu and Huang (2001):

$$\text{Chlorophyll } a = (12.25 \times OD_{663.2} - 2.79 \times OD_{646.8})/\text{Fresh weight}$$

$$\text{Chlorophyll } b = (21.50 \times OD_{646.8} - 5.10 \times OD_{663.2})/\text{Fresh weight}$$

For thatch–mat depth and organic matter measurements, two cores (2.5 cm diam. by 8.0 cm deep) were taken from each plot on 11 June, 21 July, and 18 Aug. 2006 and five cores were removed from each plot on 28 Sept. 2006 and 22 May, 18 July, and 5 Sept. 2007. Only intact cores without coring holes were selected for study. The uncompressed thatch–mat depth of each core was measured with a ruler. Green leaf and sheath tissue and soil below the thatch–mat layer of each core were removed with scissors. Thatch–mat samples were dried for 1 h at 125°C, weighed, combusted for 2 h at 550°C, and reweighed to determine weight loss-on-ignition (LOI) (Nelson and Sommers, 1996). Total organic matter content was calculated as LOI divided by the surface area of core samples. The organic matter concentration was calculated as the ratio of the organic matter (weight LOI) to the dry weight of cores, which also contained topdressing. The average thatch–mat depth, total organic matter, and organic matter concentration for each plot was used in the statistical analyses.

The experiment was arranged in a completely randomized block design with four replications. Each plot measured 1.8 by 2.4 m and individual plots were separated by a 60-cm perimeter border of creeping bentgrass. Correlation coefficients were determined for total chlorophyll (i.e., *a* + *b*) and visual color ratings. Tissue for chlorophyll analyses was collected within 72 h of obtaining color ratings. Treatment effects were determined by the analysis of variance using the general linear model procedure of the Statistical Analysis System (SAS Institute, Cary, NC). Means were separated by Fisher's protected least significant difference test ($P \leq 0.05$). The analysis of variance revealed significant differences among most treatments in both years, and therefore data are shown for each year.

# RESULTS

## Turf Color

It should be noted that the creeping bentgrass was seeded in September 2005 and had not reached a year of maturity

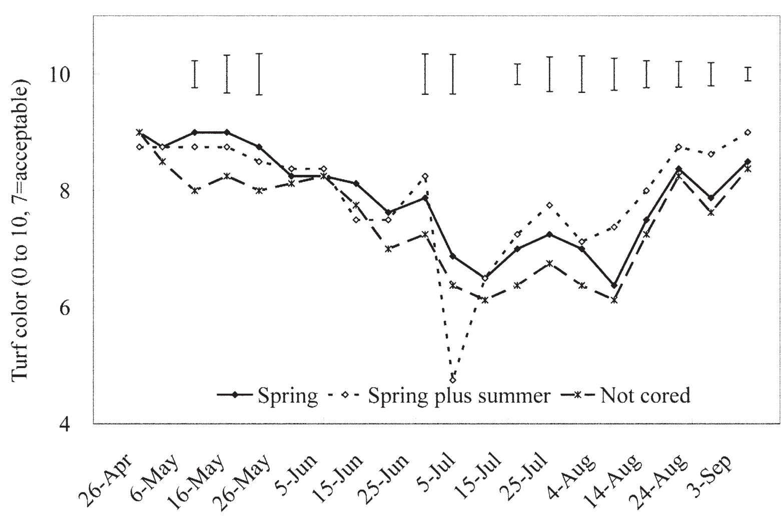


Figure 1. 'Providence' creeping bentgrass color in response to spring-only coring, spring-plus-summer coring, and noncored regimes in 2006. Spring-only coring was performed on 27 April and spring-plus-summer corings were performed on 27 April, 6 and 28 June, and 25 July 2006. Bars indicate significantly different means based on Fisher's protected LSD test ($P \leq 0.05$).

at the time treatments were imposed in 2006. In 2006, spring-plus-summer cored bentgrass had similar (nine out of 20 rating dates) or better green color (10 out of 20 rating dates) than noncored bentgrass (Fig. 1). Bentgrass subjected to spring-only coring had similar color ratings on 16 out of 20 dates vs. noncored bentgrass. Lowest turf color ratings were recorded on 3 July in spring-plus-summer cored bentgrass; however, color ratings improved and exceeded noncored bentgrass by 17 July. This was the only time there was a large reduction (≤7) in color ratings following a summer coring in 2006. Between 3 July and 7 August, color ratings were near or below 7 (i.e., minimum acceptable) for all regimes. After 7 August, color ratings among all regimes increased and exceeded 8 (i.e., very good summer color) on 21 August. On the final two rating dates (28 August and 5 September), color ratings were highest in spring-plus-summer cored bentgrass.

Spring green-up ratings were higher in spring-only and spring-plus-summer cored plots than in noncored plots in April and May 2007 (Fig. 2). Turf color ratings generally were higher in 2007, especially after late May when they exceeded 7 on all rating dates and in all regimes. Turf color ratings were similar ($n = 6$) or better ($n = 11$) for spring-plus-summer cored bentgrass vs. noncored bentgrass on 17 out of 18 dates (Fig. 2). Noncored plots generally had lower color ratings from late April to late June vs. cored plots, but ratings were ≥8 by late July and thereafter. Spring-only cored plots generally had similar or higher color ratings vs. the other regimes on most rating dates between late April and mid-August. Spring-plus-summer cored plots exhibited a reduction in color after coring on 6 June and 3 and 31 July 2007, but ratings increased within 2 wk to levels similar to spring-only cored plots throughout the summer. By early September and thereafter, spring-plus-summer cored plots exhibited higher color ratings than the other two regimes.

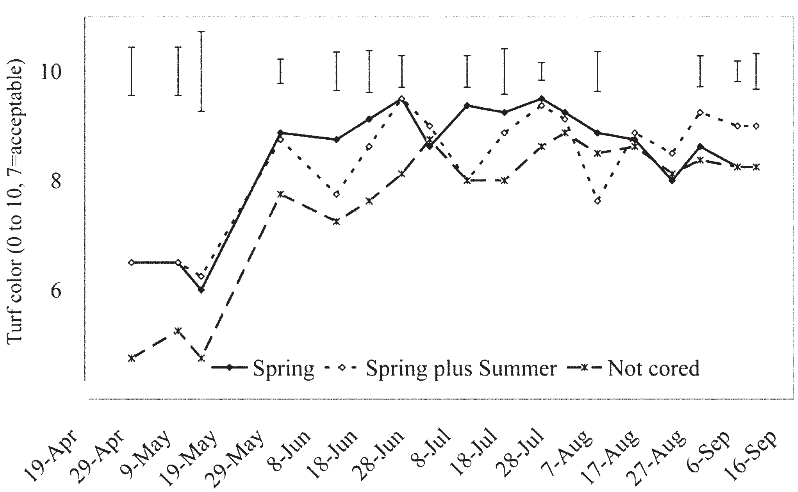


Figure 2. 'Providence' creeping bentgrass color in response to spring-only coring, spring-plus-summer coring, and noncored regimes in 2007. Spring-only coring was performed on 29 April and spring-plus-summer corings were performed on 29 April, 6 June, and 3 and 31 July 2007. Bars indicate significantly different means based on Fisher's protected LSD test ($P \leq 0.05$).

## Turf Quality

In 2006, turf quality generally was similar or better in spring-only coring vs. noncored bentgrass. Plots subjected to spring-plus-summer coring had a level of quality similar to noncored bentgrass on 12 out of 20 rating dates (Fig. 3). Turf quality was lower for spring-plus-summer cored vs. noncored bentgrass on 1 May, 12 June, and 3, 10, and 31 July, but better on 27 June, 24 July, and 5 Sept. 2006. Unacceptable quality (i.e., <7) was observed in spring-plus-summer cored plots following each coring (i.e., 27 April, 6 and 28 June, and 25 July) on 1 May, 12 June, and 3, 10, and 31 July. In general, however, turf quality was unacceptable (i.e., <7.0 rating) between late July and early August, regardless of coring regime. On the final rating date (i.e., 5 September), spring-plus-summer cored plots had the highest quality (rating = 9.4) compared with both spring-only (rating = 8.9) and noncored bentgrass (rating = 8.8).

Quality ratings generally were better in the more mature bentgrass in 2007. A similar or better level of quality was observed on all assessment dates in spring-only vs. spring-plus-summer and noncored bentgrass (Fig. 4). By 30 May and thereafter, spring-only cored plots generally had quality ratings ≥8.0 (i.e., very good summer quality). Bentgrass subjected to spring-plus-summer coring exhibited a similar quality level to noncored plots on 12 out of 18 rating dates. Quality was better on four (29 April, and 9, 14, and 31 May) and lower on two (7 and 15 August) out of 18 rating dates in spring-plus-summer vs. noncored bentgrass. There were no quality differences between 23 August and 10 September, but ratings were ≥8 in all regimes.

## Tissue Chlorophyll

In 2006, creeping bentgrass leaf tissue from plots subjected to spring-plus-summer coring had a greater level of chlorophyll *a* on 21 June, 21 July, and 7 September compared to either spring-only or noncored bentgrass (Table 1). No significant difference in chlorophyll *a* content was observed on 25 May and 4 Aug. 2006 between spring-plus-summer and noncored bentgrass. Chlorophyll *a* content was similar between spring-only and noncored bentgrass on all five measuring dates. Coring regimes had no effect on chlorophyll *b* levels on any date in 2006 (data not shown). Chlorophyll *a* + *b* levels were greater on 21 June and 21 July 2006 for spring-plus-summer vs. noncored bentgrass, but similar on 25 May, 4 August, and 7 September. Spring-plus-summer cored bentgrass tissues had higher levels of chlorophyll *a* + *b* between 21 June and 7 September compared to spring-only cored bentgrass. No differences in chlorophyll $a + b$ content were observed between spring-only and noncored bentgrass on all five measurement dates.

In 2007, spring-plus-summer cored creeping bentgrass tissue had a greater level of chlorophyll *a* on 28 June, 15 August, and 6 September but had similar chlorophyll *a* levels on 1 June and 17 July compared with noncored bentgrass (Table 2). Chlorophyll *a* level was similar on three (1 and 28 June and 17 July) out of five measuring dates for spring-only vs. noncored bentgrass. On 15 August and 6 September, spring-only cored bentgrass tissues contained a higher level of chlorophyll *a* than noncored bentgrass. No significant differences in chlorophyll *b* levels were observed among the three regimes (data not shown). Chlorophyll $a + b$ levels were greater in spring-plus-summer vs. noncored bentgrass on 28 June and 6 September. Chlorophyll $a + b$ levels were greater in spring-only vs. noncored bentgrass on 15 August and 6 September. On 1 June and 17 July, chlorophyll $a + b$ levels were similar among treatments.

## Thatch–Mat Depth and Organic Matter Content

On all four assessment dates in 2006, spring-only and spring-plus-summer cored bentgrass had a thicker thatch–mat layer than noncored bentgrass (Table 3). As early as 7 June, a less deep thatch–mat layer was observed in noncored bentgrass. The thatch–mat depth in spring-plus-summer exceeded spring-only cored plots on 31 August but were equivalent on 28 September. There was an increase in the thatch–mat depth in all plots between 31 August and 28 September, but the largest increase was observed in plots of both coring regimes. The thatch–mat layer increased substantially in cored plots over winter and was nearly twice as thick as noncored bentgrass on 25 Apr. 2007. The thatch–mat layer depth increased between 25 Apr. and 5 Sept. 2007 in all plots, but especially in spring-plus-summer cored plots. By 5 September (final measurement), the thatch–mat layer was deepest in spring-plus-summer followed by spring-only cored plots and was least in noncored bentgrass.

Total organic matter (LOI per unit area) in thatch–mat layers was similar among coring regimes on 28 Sept. 2006 (Table 4). Total organic matter in the thatch–mat layer doubled between 28 Sept. 2006 and 25 Apr. 2007. By 18 July 2007, total organic matter content in spring-only cored plots was greater than in noncored plots. Between 25 Apr. and 5 Sept. 2007, there was virtually no change in total organic matter in the thatch–mat layer of noncored bentgrass, while a small increase was observed in both coring regimes. On the final observation date of the study, total organic matter levels among the three regimes were statistically the same.

Noncored plots contained the greatest concentration of organic matter (i.e., the gravimetric ratio of organic to inorganic matter in the thatch–mat) on 28 Sept. 2006. Spring-plus-summer cored bentgrass had a greater organic matter concentration than spring-only cored bentgrass (Table 4). On all three measurement dates in 2007, spring-only and spring-plus-summer cored bentgrass had a lower organic matter concentration than noncored bentgrass. The organic matter concentration doubled between 28 Sept.

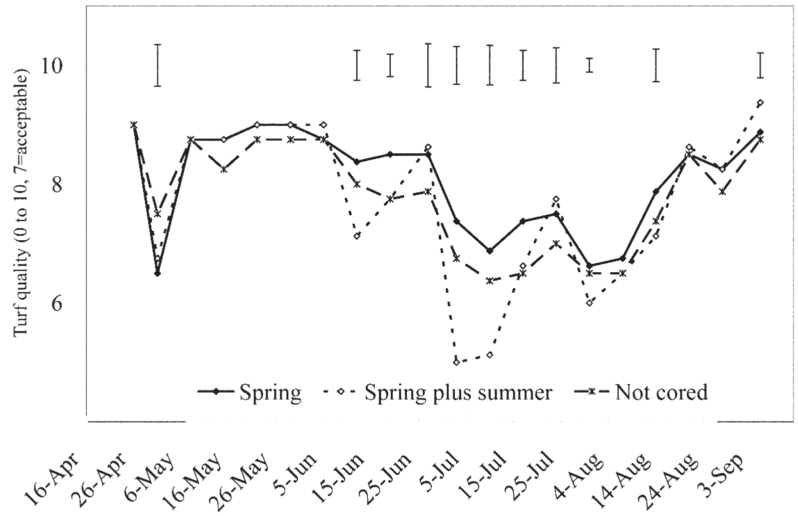


Figure 3. ‘Providence’ creeping bentgrass quality in response to spring-only coring, spring-plus-summer coring, and noncored regimes in 2006. Spring-only coring was performed on 27 Apr. and spring-plus-summer corings were performed on 27 April, 6 and 28 June, and 25 July 2006. Bars indicate significantly different means based on Fisher’s protected LSD test ($P \leq 0.05$).

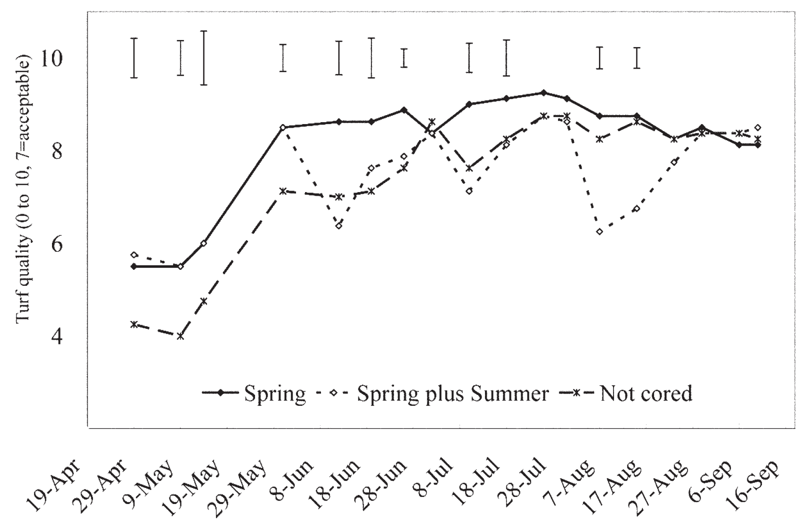


Figure 4. ‘Providence’ creeping bentgrass quality in response to spring-only coring, spring-plus-summer coring, and noncored regimes in 2007. Spring-only coring was performed on 29 Apr. and spring-plus-summer corings were performed on 29 April, 6 June, and 3 and 31 July 2007. Bars indicate significantly different means based on Fisher’s protected LSD test ($P \leq 0.05$).

Table 1. Chlorophyll *a* and *a* + *b* content in 'Providence' creeping bentgrass leaf and sheath tissue subjected to spring-only coring (SP), spring-plus-summer coring (SP + SU), or noncored (NC) regimes in 2006.

| Core timing | 25 May | 21 June | 21 July | 4 Aug. | 7 Sept. |
|---|---|---|---|---|---|
| | Chlorophyll *a* (μg $g^{-1}$ fresh wt.) | | | | |
| SP† | 77.8a‡ | 91.5b | 102.2b | 97.9a | 94.0b |
| SP + SU§ | 77.0a | 95.2a | 105.0a | 100.8a | 98.4a |
| NC | 76.9a | 90.5b | 102.5b | 99.1a | 95.6b |
| | Total chlorophyll *a* + *b* (μg $g^{-1}$ fresh wt.) | | | | |
| SP | 97.2a | 113.1b | 125.9b | 122.8b | 117.4b |
| SP + SU | 97.5a | 116.6a | 129.1a | 126.0a | 122.5a |
| NC | 96.2a | 112.1b | 126.5b | 124.3ab | 119.4ab |

†Spring-only (SP) coring was performed on 27 Apr. 2006.

‡Means in a column for each chlorophyll parameter followed by the same letter are not significantly different based on Fisher's protected LSD test ($P \leq 0.05$).

§Spring-plus-summer (SP + SU) corings were performed on 27 April, 6 and 28 June, and 25 July 2006.

Table 2. Chlorophyll *a* and *a* + *b* content in 'Providence' creeping bentgrass leaf and sheath tissue subjected to spring-only coring (SP), spring-plus-summer coring (SP + SU), or noncored (NC) regimes in 2007.

| Core timing | 1 June | 28 June | 17 July | 15 Aug. | 6 Sept. |
|---|---|---|---|---|---|
| | Chlorophyll *a* (μg $g^{-1}$ fresh wt.) | | | | |
| SP† | 51.8a‡ | 62.6b | 59.2a | 54.7a | 58.3a |
| SP + SU§ | 53.9a | 65.6a | 59.4a | 54.0a | 57.4a |
| NC | 52.3a | 62.7b | 58.0a | 52.2b | 55.0b |
| | Total chlorophyll *a* + *b* (μg $g^{-1}$ fresh wt.) | | | | |
| SP | 64.0a | 77.2b | 72.7a | 67.4a | 71.6a |
| SP + SU | 66.2a | 80.6a | 72.8a | 65.9ab | 70.2a |
| NC | 64.2a | 77.0b | 71.4a | 64.1b | 67.5b |

†Spring-only (SP) coring was performed on 29 Apr. 2007.

‡Means in a column for each chlorophyll parameter followed by the same letter are not significantly different based on Fisher's protected LSD test ($P \leq 0.05$).

§Spring-plus-summer (SP + SU) corings were performed on 29 Apr., 6 June, and 3 and 31 July 2007.

2006 and 25 Apr. 2007 in spring-only and noncored plots, while there was only a 44% increase in the organic matter concentration in spring-plus-summer cored plots. As was observed for total organic matter, organic matter fraction did not vary between spring-only and spring-plus-summer coring regimes between 25 Apr. and 5 Sept. 2007.

## DISCUSSION

This investigation was conducted on Providence creeping bentgrass <1 yr old at the time the study was initiated. Frequent, low-nutrient-rate fertilizer applications (i.e., spoon feeding) were routinely performed throughout the study period in both years. Data collected at the end of 2 yr showed that spring-only and spring-plus-summer cored plots had 66 and 89%, respectively, greater thatch–mat layer depth compared with noncored plots. Total organic matter, however, increased at a similar rate among all treatments from September 2006 to September 2007. By the end of the study, total organic matter in the thatch–mat layers was essentially the same among the three treatments. Conversely, the organic matter concentration of the thatch–mat layer in noncored bentgrass was 211 and 298% greater than observed in spring-only and spring-plus-summer cored bentgrass, respectively, by the end of the study. Thus, it would appear that the increased depth of the thatch–mat layer in cored plots was primarily due to additions of mineral matter rather than an accumulation of organic matter.

Three other coring studies evaluated the thatch–mat layer of creeping bentgrass maintained as putting green turf (Murphy et al., 1993; McCarty et al. 2005, 2007). McCarty et al. (2005, 2007) cored in March and September with 1.6-cm-diam. tines and in May and June with 0.64-cm-diam. tines in South Carolina. Coring alone had little or no effect on thatch–mat depth at the end of 2 yr in these South Carolina studies. McCarty et al. (2007) did not measure total organic matter but observed that coring alone did not change the organic matter concentration, while organic matter concentration increased in untreated (noncored and non-topdressed) plots compared to prestudy levels. Murphy et al. (1993) cored once in June, July, and August with 1.3-cm-diam. hollow or solid tines in compacted or noncompacted loamy sand in Michigan. Hollow-tine coring in both compacted and noncompacted soils increased total organic matter and thatch–mat thickness but reduced the organic matter concentration. Hence, the results of our study were different from those reported by McCarty et al. (2005, 2007), but were more similar to Murphy et al. (1993). We observed an increase in total organic matter in the thatch–mat layer over time, and increases were equal among cored and noncored plots. Conversely, Murphy et al. (1993) reported that coring increased total organic matter and attributed this increase to either the burying of leaf sheaths and crowns or stimulation of growth (crowns, stolons, and roots) within the thatch–mat layer with soil reincorporation after coring. Considering the pronounced dilution effect of mineral matter within the thatch–mat layer found in our study, it is plausible that other coring studies conducted under conditions of routine and uniform topdressing (another practice that dilutes organic matter) would have masked coring effects on organic matter concentration or thatch–mat depth.

Murphy et al. (1993) and our study applied no or less topdressing, respectively, than McCarty et al. (2005, 2007) and observed a reduction in organic matter concentration in cored vs. noncored plots. Organic matter concentration was less because coring combined with either soil reincorporation and/or topdressing dilutes the organic matter in the thatch–mat layer with mineral matter (Murphy et al., 1993; Couillard et al., 1997). Dilution of organic matter by topdressing could conceivably improve the growing

Table 3. Thatch–mat depth in spring-only coring (SP), spring-plus-summer coring (SP + SU), or noncored (NC) 'Providence' creeping bentgrass in 2006 and 2007.

| Core timing | Thatch–mat depth 2006 | | | |
|---|---|---|---|---|
| | 7 June | 24 July | 31 Aug. | 28 Sept. |
| | mm | | | |
| SP† | 4.5a‡ | 5.0a | 4.8b | 8.0a |
| SP + SU§ | 5.3a | 5.8a | 6.0a | 8.4a |
| NC | 2.5b | 3.0b | 3.0c | 4.7b |
| | | 2007 | | |
| | | 25 Apr. | 18 July | 5 Sept. |
| | | mm | | |
| SP | | 10.4a | 13.5b | 13.8b |
| SP + SU | | 10.3a | 15.5a | 15.7a |
| NC | | 5.3b | 7.9c | 8.3c |

†Spring-only (SP) coring was performed on 27 Apr. 2006 and 29 Apr. 2007.

‡Means in a column for each year followed by the same letter are not significantly different based on Fisher's protected LSD test ($P \leq 0.05$).

§Spring-plus-summer (SP + SU) corings were performed on 27 April, 6 and 28 June, and 25 July 2006; and on 29 April, 6 June, and 3 and 31 July 2007.

Table 4. Total organic matter (loss on ignition) and organic matter concentration in the thatch–mat layer in response to spring-only coring (SP), spring-plus-summer coring (SP + SU), and noncored (NC) 'Providence' creeping bentgrass in 2006 and 2007.

| Core timing | 2006 | 2007 | | |
|---|---|---|---|---|
| | 28 Sept. | 25 Apr. | 18 July | 5 Sept. |
| | Organic matter | | | |
| | $g\ m^{-2}$ | | | |
| SP† | 47a‡ | 97a | 109a | 105a |
| SP + SU§ | 48a | 96a | 107ab | 101a |
| NC | 45a | 96a | 96b | 96a |
| | Organic matter concentration | | | |
| | $mg\ g^{-1}$ soil | | | |
| SP | 48.5c | 110.2b | 93.1b | 78.5b |
| SP + SU | 61.1b | 87.8b | 74.8b | 61.5b |
| NC | 120.0a | 239.0a | 205.4a | 244.5a |

†Spring-only (SP) coring was performed on 27 Apr. 2006 and 29 Apr. 2007.

‡Means in a column followed by the same letter are not significantly different based on Fisher's protected LSD test ($P \leq 0.05$).

§Spring-plus-summer (SP + SU) corings were performed on 27 April, 6 and 28 June, and 25 July 2006; and on 29 April, 6 June, and 3 and 31 July 2007.

environment for stems and roots in the thatch–mat layer. The agronomic importance of organic matter concentration has been debated and a number of critical threshold values (Carrow, 2004; Hartwiger, 2004) have been proposed using various measurement techniques (Vermeulen and Hartwiger, 2005). Data from our study, in which only the thatch–mat layer was being measured, indicated that organic matter concentration <110 g $kg^{-1}$ were associated with better turf performance. Similarly, Murphy et al. (1993) reported turf quality often was better on plots having organic matter concentration <95 g $kg^{-1}$. The organic matter concentration of the thatch–mat layer in the studies reported by McCarty et al. (2005, 2007) were considerably lower (16–25 g $kg^{-1}$) and turf quality generally was very good across treatments.

The thatch–mat layer developed slowly during summer months in both years compared with the change over autumn and winter of 2006 and 2007, regardless of coring regime. The greatest increase in total organic matter and organic matter concentration occurred between September 2006 and April 2007. Thatch increases when organic matter production exceeds decomposition (Beard, 1973). Hence, the increases in organic matter observed between September and April were attributed in part to N (71 kg N $ha^{-1}$) applications during autumn 2006. The autumn-applied N stimulated tissue production at a time when environmental conditions were optimum for growth and temperatures would be less than optimum for organic matter decomposition. Furthermore, plots were not cored or otherwise managed to control thatch–mat between autumn and spring. Hence, all three of the aforementioned studies as well as the current study indicate that coring alone does not reduce thatch–mat depth on creeping bentgrass putting green turf. Rather, the thatch–mat layer probably will increase in depth because of the reincorporation of soil and/or the inclusion of topdressing after coring along with the accumulation of plant organic matter. Total organic matter in the thatch–mat layer was not reduced by coring in the current study or in the study reported by Murphy et al. (1993). Thus, the primary effect of coring as used in these studies appears to be a dilution of organic matter as it accumulates, which reduces its concentration.

Turf color is an important aspect of turfgrass quality. Color ratings were highest in April and September and generally were better in spring-only cored vs. noncored bentgrass. Creeping bentgrass subjected to spring-plus-summer coring in 2006 also exhibited an improved level of spring green-up in 2007 and exhibited a higher level of quality until 31 May vs. noncored bentgrass. Color ratings in either spring-only or noncored plots did not fluctuate as greatly as in plots subjected to spring-plus-summer coring. Spring-plus-summer cored bentgrass exhibited reductions in color ratings just following coring, but ratings invariably improved within 2 wk. Chlorophyll *a* and *a* + *b* levels generally were higher in plots subject to spring-plus-summer vs. spring-only coring in 2006 and noncored plots in both years. Chlorophyll content in plants determines photosynthetic capacity and also provides for the visual green color of foliage. The improved visual color ratings associated with spring-plus-summer coring may have been due in part to the higher chlorophyll *a* and *a* + *b* levels found. The mechanism of increased chlorophyll production as a result of summer coring may be due to improved nutrient (e.g., N) uptake resulting from better root to soil contact enhanced by soil reincorporation and topdressing after coring. Improvement in soil oxygen levels and/or other factors that promote healthy root function may also play a role in the increases in chlorophyll production observed. We are not aware of other studies that have measured chlorophyll levels in response to coring. Carrow et al. (1987) observed that 'Tifway' bermudagrass subjected to coring twice per year exhibited improved spring color compared with noncored bermudagrass.

Fry and Huang (2004) stated that coring with hollow tines may cause a short-term decline in quality because a portion of the turf canopy is removed. The decline in quality in response to summer coring also can be associated with mechanical damage exacerbated by high temperature stress and decreased leaf growth rate in the summer. We observed significant reductions in quality as a result of coring, which generally required a 2-wk period for recovery. Spring-only and spring-plus-summer cored plots averaged 15% lower creeping bentgrass quality over both years 2 wk after coring. Quality was diminished more in 2006 than in 2007, indicating that caution needs to be exercised in coring the summer following establishment. The greatest decline in bentgrass quality (38% decline) occurred 5 d after coring on 3 July 2006. The precipitous drop in quality on this one date was due to a combination of mechanical injury from reducing the mowing height, coring, sod webworm damage, and probably heat stress. A 1-yr study, in which creeping bentgrass was cored once in July with 1.6-cm-diam. hollow tines, found that quality generally was unaffected, but solid tines reduced quality below the acceptable level for about 2 wk (Bunnell et al., 2001). McCarty et al. (2005) observed only slight injury following coring in immature creeping bentgrass; however, they did not core in July. Murphy et al. (1993) reported that hollow-tine cultivation over three seasons improved creeping bentgrass quality, especially in the autumn. Improved aeration and other soil and thatch physical properties accorded by coring probably were responsible for the improvement in color and quality in spring-plus-summer cored bentgrass by late summer in each year.

## CONCLUSIONS

Coring substantially increased thatch–mat depth, but total organic matter was unaffected, regardless of coring or not coring. Organic matter concentration in the thatch–mat layer was much lower in plots subjected to coring than in noncored plots, and a concentration <110 g $ha^{-1}$ was associated with better turf quality. Thus, it appears that coring, when combined with topdressing or reincorporation of cores, functions to dilute organic matter and reduce its concentration within the thatch–mat layer. Our findings also indicate that a relatively large increase in organic matter (total and concentration) can occur between late summer and spring when late-season N fertilization is employed during cooler temperatures. During the second year in more mature bentgrass, spring green-up and quality were improved by coring in 2006, and late-summer 2006 visual turf color was enhanced in spring-plus-summer cored bentgrass. It also was revealed that summer coring causes much more injury than previously reported and that coring during the first summer of creeping bentgrass establishment should be avoided or at least cautiously used. Future research efforts should assess the effects of summer coring immature creeping bentgrass to the depth of the thatch–mat layer without substantially penetrating soil. Summer coring of mature creeping bentgrass greens is recommended; however, it should be combined with other cultural and mechanical practices to reduce or otherwise manage organic matter in thatch–mat layers as demonstrated by McCarty et al. (2007).

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### References

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

Bunnell, B.T., L.B. McCarty, and H.S. Hill. 2001. Summer cultivation effects on a sand based creeping bentgrass golf green. Int. Turfgrass Soc. Res. J. 9:843–849.

Carrow, R.N. 2004. Surface organic matter in bentgrass greens. U.S. Golf Assoc. Green Sect. Rec. 42(1):11–15.

Carrow, R.N., B.J. Johnson, and R.E. Burns. 1987. Thatch and quality of Tifway bermudagrass turf in relation to fertility and cultivation. Agron. J. 79:524–530.

Couillard, A., A.J. Turgeon, and P.E. Rieke. 1997. New insights into thatch biodegradation. Int. Turfgrass Soc. Res. J. 8:427–435.

Dernoeden, P.H. 2002. Creeping bentgrass management: Summer stresses, weeds, and selected maladies. John Wiley & Sons, Hoboken, NJ.

Eggens, J.L. 1980. Thatch control on creeping bentgrass turf. Can. J. Plant Sci. 60:1209–1213.

Fry, J., and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Hoboken, NJ.

Fu, J., and B. Huang. 2001. Involvement of antioxidants and lipid peroxidation in the adaptation of two cool-season grasses to localized drought. Environ. Exp. Bot. 45:105–114.

Green Section Staff. 1993. USGA recommendations for a method of putting green construction. USGA Green Sect. Rec. 31(2):1–3.

Hartwiger, C. 2004. The importance of organic matter dynamics. U.S. Golf Assoc. Green Sect. Rec. 42(3):9–11.

McCarty, L.B., M.F. Gregg, J.J. Camberato, and H.S. Hill. 2005. Minimizing thatch and mat development in a newly seeded creeping bentgrass golf green. Crop Sci. 45:1529–1535.

McCarty, L.B., M.F. Gregg, and J.E. Toler. 2007. Thatch and mat management in an established creeping bentgrass golf green. Agron. J. 99:1530–1537.

Murphy, J.A., P.E. Rieke, and A.E. Erickson. 1993. Coring cultivation of a putting green with hollow and solid tines. Agron. J. 85:1–9.

Murray, J.J., and F.V. Juska. 1977. Effect of management practices on thatch accumulation, turf quality, and leaf spot damage in common Kentucky bluegrass. Agron. J. 69:365–369.

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. p. 961–1010. *In* D.L. Sparks (ed.) Methods of soil analysis. Part 3. Chemical methods. SSSA Series 5. SSSA, Madison, WI.

O'Brien, P., and C. Hartwiger. 2003. Aeration and topdressing for the 21st century. U.S. Golf Assoc. Green Sect. Rec. 41(2):1–7.

Turgeon, A.J. 2008. Turfgrass management. 8th ed. Pearson Prentice Hall, Upper Saddle River, NJ.

Vermeulen, P., and C. Hartwiger. 2005. Strategies for organic matter control: Using scientific and empirical approaches for managing organic matter accumulation can be frustrating. U.S. Golf Assoc. Green Sect. Rec. 43(3):18–19.

White, R.H., and R. Dickens. 1984. Thatch accumulation in bermudagrass as influenced by cultural practices. Agron. J. 70:299–304.

Wiecko, G., R.N. Carrow, and K.J. Karnok. 1993. Turfgrass cultivation methods: Influence on soil physical, root/shoot, and water relationships. Int. Turfgrass Soc. Res. J. 7:451–457.