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Rooting in a Creeping Bentgrass Putting Green in Response to Spring and Summer Coring

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ABSTRACT

Understanding root growth response of creeping bentgrass (*Agrostis stolonifera* L.) to coring will help golf course superintendents maintain high quality putting green turf. The objective of this field study was to examine the effects of coring on summer rooting in young creeping bentgrass grown on a sand-based root zone and maintained as a putting green. The study was initiated on 7-mo-old 'Providence' creeping bentgrass in 2006 and compared spring (SP) only coring, spring plus three summer (SU) corings (SP + SU) and a noncored control through 2007. The minirhizotron imagining technique was used to measure total root count (TRC) and total root length (TRL) from late spring to late summer. The percentage of the TRC in the surface 0- to 6-cm root zone depth averaged over measurement dates was 48 to 53% and 33 to 44% among all treatments in 2006 and 2007, respectively. Greater TRC were observed in 2006 with 28, 51, and 50% lower TRC's found in SP + SU, SP only, and noncored plots in 2007, respectively. Spring + SU coring generally reduced TRC and TRL at various root zone depths and dates during the first year of establishment. In 2007, greater TRC and TRL were observed throughout the 0- to 24-cm root zone in SP + SU cored compared to SP only and noncored plots. Thus, SP + SU coring in the second study year promoted creeping bentgrass root growth and/or longevity, but coring during the first summer of establishment reduced rooting.

Creeping bentgrass is the most widely used cool-season turfgrass on golf greens. Creeping bentgrass is aggressively stoloniferous and produces a well-defined surface organic layer, which hereafter will be referred to as the thatch-mat layer (McCarty et al., 2007). Excessive thatch-mat layers commonly are associated with negative effects on biological and soil properties as summarized by McCarty et al. (2005). Managing thatch-mat layers on putting greens is difficult and involves numerous cultural practices, including core cultivation (McCarty et al., 2007). In turfgrass management the term cultivation refers to working the soil and/or thatch-mat layer without destroying the turf (Turgeon, 2008). Coring (i.e., hollow or solid tines are used) is a cultivation technique (Beard, 1973) and the term coring will be used hereafter. Coring is used to manage thatch-mat layers and improve turf quality by promoting water infiltration, reducing soil surface wetness, and improving aeration and rooting (Beard, 1973; Fry and Huang, 2004).

Some research efforts involving coring have examined rooting by destructive sampling methods (Harper, 1953; Murphy et al., 1993; Wiecko et al., 1993). Reports on turf rooting in response to coring, however, have not been consistent. In a fairway coring study, Harper (1953) reported that a single spring coring did not affect bentgrass root mass compared to noncored bentgrass. In a Georgia study, Tifway bermudagrass [*Cynodon transvaalensis* Burtt-Davy × *C. dactylon* (L.) Pers] was cored to a 7.6-cm soil depth using hollow tines between late April and early August (Wiecko et al., 1993). Data from 1 yr of that study indicated that coring resulted in an increase in root length, but had no effect on root length in the second year (Wiecko et al., 1993). Murphy et al. (1993) sampled roots in a Penneagle creeping bentgrass green grown on a modified loamy sand. In compacted and noncompacted soil, coring reduced both total root weight and root density (Murphy et al., 1993). Furthermore, summer coring did not enhance surface root development of creeping bentgrass.

Root production, growth, longevity, and mortality are critical components contributing to plant adaptation to environmental stresses. Most turfgrass root studies were conducted using destructive soil sampling techniques, which typically quantify living and dead root biomass at a singular time of the growing season. Destructive sampling techniques are not able to detect root initiation or root death. The minirhizotron imaging technique, however, allows for nondestructive monitoring of root production and growth (Murphy et al., 1994; Liu and Huang 2002). The minirhizotron allows for the quantification of various living root parameters throughout a 0 to 24-cm deep root zone. Its greatest advantage is that it provides information on seasonal changes of the same roots, which eliminates confounding spatial variation and permits a high frequency of visual root observations (Murphy et al., 1994).

Coring generally is performed in the spring and autumn. Little information is available on summer coring effects on seasonal and vertical changes in a creeping bentgrass root system grown on a sand-based root zone. Previous studies were conducted on modified or native soil research putting greens. Most putting greens today are constructed with a high sand content to reduce

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Abbreviations: SP, spring only coring; SP + SU, spring plus summer coring; TRC, total root count; TRL, total root length.

problems associated with compaction; that is, to maintain air-filled porosity and drainage. Furthermore, we are not aware of any studies in which coring was assessed in the first and second summer following establishment. It was our hypothesis that summer coring would be more injurious to creeping bentgrass grown in the first summer following establishment than in the second summer after establishment. Thus, the objective of this study was to quantify summer rooting in response to spring and summer coring in putting green height creeping bentgrass grown on a sand-based root zone during the first two summers following establishment.

MATERIALS AND METHODS

This field study was conducted on a sand-based root zone built using USGA recommendations (Green Section Staff, 1993) at the University of Maryland Turfgrass Research Facility in College Park. The research green was built in 1999 and the root zone mixture consisted of 80:20 (v/v) sand and sphagnum peat. The modified sand mix (97% sand, 1% silt, and 2% clay) had an initial pH of 6.5 and 10 g kg^{-1} of organic matter. The site was an existing stand of creeping bentgrass, which was treated with glyphosate [N-(phosphonomethyl) glycine] in September 2005 and the existing sod was removed. The site was seeded (50 kg ha^{-1} seed) with Providence creeping bentgrass. A total of 250 kg ha^{-1} N was applied between 20 Sept. and 11 Nov. 2005 with a 20–9–16 (N–P–K) fertilizer. Urea was applied biweekly at 4.9 kg ha^{-1} N from 1 May through 7 June and then weekly through 24 August for a total of 78.4 kg ha^{-1} N during the 2006 experimental period. A total of 71 kg ha^{-1} N was applied as urea between September and November 2006. In 2007, the bentgrass was fertilized weekly (4.9 kg ha^{-1} N) with urea between 30 April and 27 August to provide a total of 88.2 kg ha^{-1} N during the experimental period. Iprodione [3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide; 14.7 kg ai ha^{-1}] was applied to control dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) and brown patch (*Rhizoctonia solani* Kuhn) on a 10 to 14 d interval beginning mid-May and continuing through mid-August in 2006 and 2007. Iprodione was chosen since it has no known plant growth regulator effects. Turf was mowed three times weekly with a triplex mower to a height of 6 mm in the spring of 2006 and gradually reduced to 4 mm by 3 July 2006. The green was mowed to a height of 4 mm thereafter about five times weekly with a triplex mower and clippings were removed. The site was irrigated as needed to prevent wilt in all years. When irrigated, water was applied to wet the entire root zone and the site was syringed occasionally during sunny, rain-free periods. The green was not subjected to additional traffic stress beyond routine mowing and other management practices.

Three treatments were assessed in 2006 and 2007 as follows: SP only coring, SP + SU, and a noncored control. Spring coring involved larger diameter tines than summer coring since smaller tines would be expected to cause less injury to putting greens during summer stress periods. The SP treatment was performed using a Miltona Handi Aerifer (Miltona Turf Products, Miltona, MN). This hand-held, manual device had seven, 1.27 cm diam. hollow tines, which penetrated to a depth of 9 cm. Cores were removed on a 5-cm spacing, producing about 400 holes m^{-2}. Manual coring was performed to prevent damaging the minirhizontron tubes, which could not have been avoided by using a machine. Care was taken not to damage tubes by slowly inserting and removing the device once a tube was contacted. The SU corings were performed using one leg taken from a CoreMaster *12 Aerator (GreenCare, Sydney, Australia) equipped with a quadra-tine holder. The four, 0.64-cm diam. hollow tines penetrated to a depth of 5.5 cm on a right angle spacing of 3.8 cm and a diagonal spacing of 5.0 cm. The quadra-tine leg was manually forced into the turf and about 690 holes m^{-2} were made. Core spacing was performed visually without a template and overtime some holes would have been recored. Spring coring was performed on 27 Apr. 2006 and 29 Apr. 2007 using the 1.27-cm diam. tines described previously. Summer coring was performed using the previously described 0.64-cm diam. quadra-tines on 6 and 28 June and 25 July 2006 and 6 June and 3 and 31 July 2007. Topdressing using the previously described root zone mix was applied after all SP coring treatments to fill holes to the surface. Plots were brushed to re-incorporate sand brought to the surface with SU coring, but no additional topdressing sand was applied. Other than previously described, no topdressing program was imposed after summer coring.

Root measurements were obtained using the minirhizotron imaging technique as described by Murphy et al. (1994) and Liu and Huang (2002). Before treatments were imposed, two soil cores (5-cm in diam. by 60-cm long) were removed from each plot in April 2006 at a 30 degree angle from the soil surface. Two clear butyrate tubes of a size equivalent to the voids were plugged with a black rubber stopper at the bottom end, sealed with waterproof silicon sealant, and manually forced into holes in each plot for root observation. Each tube was positioned in the ground with the upper end oriented north and closed with a black rubber stopper that was flush with the soil surface such that tubes did not interfere with mowing. Tubes remained in ground over winter between April 2006 and September 2007. Images of roots visible against the surface of the tubes were recorded sequentially from the soil surface using a high-magnification minirhizotron camera (Bartz Technology Corp, Santa Barbara, CA). Image size was 1.4 by 1.8 cm and a total of 35 images were taken in each tube on each monitoring date. Root images were captured as bitmap (BMP) files on a personal computer. All visible roots were traced and analyzed using an image analysis program (RooTracker 2.0, Duke University, Durham, NC). This program determines root number, length, and diameter. Total root count was measured as the sum of all roots observed within a specified soil depth (hereafter root zone) range. Similarly, TRL was measured as the sum of all root lengths within a specified root zone range. Since the quadra-tines penetrated to a 5.5-cm depth, data were averaged at 6 cm increments for the 0- to 6- and 6- to 12-cm depths. Since there were few differences at the 12- to 18- or 18- to 24-cm root zone depths, data were averaged over the 12- to 24-cm root zone depth. Data also were summed over the entire 0- to 24-cm root zone. Rooting was assessed on 5 July, 3 and 28 Aug. 2006, and 30 May, 13 July and 4 Sept. 2007.

Air and soil temperatures were measured and reported in a companion study on the same research green (Fu and Dernoeden, 2009). Maximum and minimum air temperatures were determined in July and August in 2006 and 2007. Mean maximum and minimum air temperatures in July were 31.6 and 20.0°C in 2006 and 31.0 and 17.5°C in 2007, respectively. Mean maximum and minimum air temperatures in August were 31.6 and 18.2°C in 2006 and 31.5 and 20.2C in 2007, respectively. Soil

Table 1. Analysis of variance among coring treatments, root zone depths, and measurement dates and their effects on total root count and total root length in Providence creeping bentgrass in 2006 and 2007.

Source	2006 Total root count	2006 Total root length	2007 Total root count	2007 Total root length
Coring (C)	**	**	**	**
Depth (DE)	**	**	**	**
Date (DA)	**	*	**	*
C × DE	*	*	†	†
C × DA	ns‡	ns	*	†
DE × DA	*	*	*	*

* Refers to the 0.05 significance level.
** Refers to the 0.01 significance level.
† Refers to the 0.10 significance level.
‡ Nonsignificant *F* test.

Table 2. Providence creeping bentgrass total root count (TRC) in the 0- to 24-cm root zone in response to spring only cored, spring plus summer cored, and noncored treatments on three measurement dates in 2006 and 2007.

	TRC		
Corings	5 July	3 Aug.	28 Aug.
	2006		
SP + SU†	245.4c‡	219.7b	256.9b
SP§	310.4a	258.2a	297.3a
N-C¶	270.8b	241.8a	296.9a
	2007		
	30 May	13 July	4 Sept.
SP + SU	243.4a	122.2a	152.5a
SP	227.9ab	128.9a	118.5b
N-C	175.9b	104.4b	126.6b

† Spring plus summer (SP + SU) corings were performed on 27 Apr., 6 and 28 June, and 25 July 2006. Spring plus summer corings were performed on 29 Apr., 6 June, and 3 and 31 July 2007.
‡ Means in a column followed by the same letter in a year are not significantly different based on Fisher's protected least significant difference test ($P \leq 0.05$).
§ Spring only (SP) coring was performed on 27 Apr. 2006 and 29 Apr. 2007.
¶ N-C designates the noncored control treatment.

Table 3. Providence creeping bentgrass total root count (TRC) in response to spring only cored, spring plus summer cored and noncored treatments at different root zone depths in 2006 and 2007.

	TRC		
Corings	0–6 cm	6–12 cm	12–24 cm
	2006		
SP + SU†	132.3ab‡	53.9b	54.5c
SP§	143.8a	63.5a	81.3b
N-C¶	125.2b	45.2c	99.4a
	2007		
SP + SU	97.0ab	41.9a	33.8a
SP	105.2a	33.0b	20.3a
N-C	86.8b	21.4c	27.3a

† Spring plus summer (SP + SU) corings were performed on 27 Apr., 6 and 28 June, and 25 July 2006. Spring plus summer corings were performed on 29 Apr., 6 June, and 3 and 31 July 2007.
‡ Means in a column followed by the same letter in a year are not significantly different based on Fisher's protected least significant difference test ($P \leq 0.05$).
§ Spring only (SP) coring was performed on 27 Apr. 2006 and 29 Apr. 2007.
¶ N-C designates the noncored control treatment

temperatures were supraoptimal and averaged 31.8°C in July and August 2006 and 2007.

Plots were 1.8 by 2.4 m and there was a 60-cm creeping bentgrass perimeter border separating each plot. Treatments were arranged in a completely randomized block design with four replications. Data were subjected to the analysis of variance using the general linear model procedure of Statistical Analysis System (SAS Institute, 2001). Initially, analysis of variance was conducted to include the effect of year; however, data for each year were analyzed separately since there was a significant interaction between year and coring. Thus, analysis of variance assessed the effects of coring, soil depth, and measurement dates using a 3 × 3 × 3 factorial arrangement, except for total root zone (0–24 cm) data. The coring × depth × date interaction was not significant in either year. Thus, only the coring × depth and coring × date data are presented. Significant differences among means were separated by Fisher's protected least significant difference test ($P \leq 0.05$).

RESULTS

Total Root Count

The Providence creeping bentgrass turf was established from seed in September 2005. There were significant coring, root zone depth, and sampling date effects on TRC and TRL data in both years (Table 1). Total root count was lower in noncored plots vs. the SP cored plot on 5 July 2006 (Table 2). The TRC generally was lowest in all treatments on 3 Aug. 2006. The SP + SU cored plots had a lower TRC on all three dates in 2006 compared to SP only coring and noncored plots. Total root count over the entire 0- to 24-cm root zone was lowest in noncored plots on 30 May and 13 July 2007 and was higher for SP + SU plots compared to SP plots on 4 Sept. 2007 (Table 3). When TRC data were summed over measurement dates, all three treatments had greater TRC in 2006 than 2007($P \leq 0.05$). There was a 28, 45, and 50% reduction in TRC in SP + SU (722 vs. 518), SP only (865 vs. 475), and noncored (810 vs. 407) plots in 2006 vs. 2007, respectively.

In 2006, TRC at the 0- to 6-cm root zone depth was greater in SP cored plot vs. noncored plot (Table 3). In the 6- to 12-cm root zone, TRC was the highest in SP only cored plots, followed by SP+SU cored plots and noncored plots. Plots in both coring treatments had lower TRC in the 12- to 24-cm root zone than noncored plots. Spring + SU cored plots had lower TRC in the 12- to 24-cm root zone compared to SP only cored plots.

In 2007, lower TRC in the 0- to 6-cm depth were observed in noncored plots compared to SP only cored plots (Table 3). Total root count in the 6- to 12-cm root zone depth was highest in SP + SU cored plots, intermediate in SP only cored plots, and lowest in noncored plots. No differences in TRC at the 12- to 24-cm root zone depth were observed among treatments. When TRC data were summed over the 0- to 24-cm root zone, SP + SU cored plots had the highest TRC.

Total Root Length

Total root length was greater in SP only cored plots than SP + SU cored plots throughout 2006 and noncored plots on 5 July. Spring + SU cored plots had the lowest TRL on the last two measurement dates of 2006 (Table 4). The lowest TRL was observed in noncored plots on 30 May and 13 July and was among the lowest on 4 Sept. 2007. Total root length was greater in SP + SU cored plots than SP only cored plots on 4 September. Total

Table 4. Providence creeping bentgrass total root length (TRL) in the 0- to 24-cm root zone in response to spring only cored, spring plus summer cored and noncored treatments on three measurement dates in 2006 and 2007.

	TRL		
Corings	5 July	3 Aug.	28 Aug.
	cm		
	2006		
SP + SU†	153.1b‡	126.3b	136.9b
SP§	201.5a	153.4a	161.6a
N-C¶	168.9b	143.3a	165.6a
	2007		
	30 May	13 July	4 Sept.
SP + SU	112.6a	73.5a	79.7a
SP	103.5a	74.4a	59.2b
N-C	79.0b	62.5b	62.7b

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

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

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

¶ N-C designates the noncored control treatment.

root length declined in SP only and SP + SU cored plots by 13 July and remained unchanged through 4 September. However, TRL over the entire root zone did not change between 13 July and 4 September in noncored plots throughout 2007.

In 2006, there were no TRL differences in the 0- to 6-cm and 6- to 12-cm root zone among treatments (Table 5). Spring + SU cored plots had a shorter TRL in the 12- to 24-cm root zone depth than noncored plots in 2006. In 2007, TRL was lowest in the 0- to 6-cm root zone in noncored vs. the two coring treatments. Total root length in the 6- to 12-cm root zone was greatest in SP + SU cored plots, intermediate in SP only and lowest in noncored plots. In the 12- to 24-cm root zone, TRL was greater in the SP + SU vs. SP only plots, but TRL was similar in noncored plots compared to both coring treatments.

DISCUSSION

Over the entire root zone (0–24 cm), rooting was greater and more consistent over dates during 2006 (Tables 2 and 3) than during 2007 (Tables 4 and 5). A substantial decline in rooting among all treatments occurred between 30 May and 13 July 2007. As previously noted, soil temperatures were monitored on the research green and averaged 31.8°C in July and August 2006 and 2007 (Fu and Dernoeden, 2009). Bentgrass root decline in summer is a common phenomenon and occurs in response to high temperature stress (i.e., ≥18.9°C) and/or poor soil aeration (Huang et al., 1998; Bigelow et al., 2001; Fry and Huang, 2004). Total root count data indicated that rooting improved between 13 July to 4 Sept. 2007. Similarly, Murphy et al. (1994) observed a decline in TRC in creeping bentgrass putting green turf between late June and mid-July and an increase in TRC beginning in early to mid-September in Michigan.

The percentage of the TRC in the surface 0- to 6-cm root zone depth averaged over three measurement dates was 48 to 53% and 33 to 44% among all treatments in 2006 and 2007, respectively. Hence, a large percentage of rooting occurred in the upper 6 cm of the root zone. These percentages correspond well with creeping bentgrass root distributions of minirhizotron data reported by Murphy et al. (1994). It also was interesting to note that there were more and longer roots in 2006 vs. in 2007. Greater rooting in 2006 may be due to higher N fertilizer use in the year of establishment, lower thatch levels or was a function of seedling vigor. The aforementioned phenomenon often is observed by golf course superintendents for newly constructed golf course putting greens, but has not been previously reported in the literature. The general lack of change in TRC and TRL throughout the entire 0- to 24-cm root zone from the first to last rating date in 2006 may have been a reflection of a larger and more vigorous root system.

Both TRC and TRL data generally indicated that SP + SU coring promoted rooting in the second year particularly by late summer of 2007; whereas, the SP + SU treatment reduced TRC and TRL in 2006. Improved rooting from SP + SU coring during late summer 2007 was most evident in the 6- to 12- and 12- to 24-cm root zone depths. Similarly, less rooting in 2006 was evident at lower depths; however, reduced rooting was observed in the 0- to 6-cm root zone depth by late summer 2006. The reduction in TRC and TRL over the entire 0- to 24-cm root zone by SP + SU coring in 2006 was attributed to mechanical injury caused by coring tines, which penetrated to a depth of 9.0 cm in SP and 5.5cm in SU. Murphy and Rieke (1994) reported that minirhizotron observations confirmed root damage at the 5- to 10-cm depth was caused by coring during late summer and autumn on creeping bentgrass. Murphy et al. (1993) reported that root weight density of Penneagle creeping bentgrass was lower after hollow tine coring, however, new root development was observed in coring holes the following spring. Interestingly, rooting in the 0- to 6-cm root zone in the current study generally was unaffected by coring in 2007. Indeed, throughout the entire 0- to 24-cm root zone, TRC and TRL were lowest in noncored plots on all rating dates in 2007. Hence, the current study differs from that of Murphy et al. (1993) in that we observed improved rooting at the end of the 2007 summer in response to SP + SU coring in mature creeping bentgrass. Notable methodology differences among the aforementioned studies included root assessment technique and timing, soil texture, cultivars, environmental conditions and N fertility. Additionally, this study differed from those reported by Murphy and colleagues (1993, 1994) as follows: bentgrass was grown in a sand-based rather than a finer-textured soil; coring was initiated and concluded earlier; large diameter tines were used in the spring and holes were filled to the surface with sand;

Table 5. Providence creeping bentgrass total root length (TRL) in response to spring only cored, spring plus summer cored and noncored treatments at different root zone depths in 2006 and 2007.

	TRL		
Corings	0–6 cm	6–12 cm	12–24 cm
	cm		
	2006		
SP + SU†	70.4a‡	35.4a	33.0b
SP§	81.1a	42.4a	49.5ab
N-C¶	69.5a	29.7a	60.1a
	2007		
SP + SU	44.7a	24.3a	19.6a
SP	48.1a	18.4b	12.6b
N-C	38.8b	13.2c	15.9ab

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

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

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

¶ N-C designates the noncored control treatment.

and smaller diameter tines were used in summer and sand was re-incorporated by brushing. Therefore, it is possible that these factors allowed coring to be less destructive to roots and stems thus promoting root longevity and growth in the second study year.

There is indirect evidence that the lower TRC observed in the first summer following establishment could have reduced turf performance. Turf color and quality data from this study were previously reported by Fu et al. (2009). Turf color and quality were much more adversely impacted by coring in 2006 vs. 2007. In the first year, turf quality in SP + SU cored plots was generally below the acceptable threshold (0–10 visual scale where 0 = dead turf, 7 = minimum acceptable level of discoloration or injury and 10 = optimum color and quality)from late June to early September. However, in the second summer quality seldom went below the 7 threshold during the entire test period. It is likely that most of the reduction in color and quality during the first summer was mechanical in nature, but reduced rooting caused by coring may also have been a factor since the recovery period was very long compared to the second summer.

Rooting was improved well below the penetration depth of the 5.5-cm-long quadra-tines (i.e., 6- to 12- and 12- to 24-cm root zone depths) by late summer of the second year (i.e., 2007) in SP + SU cored plots. However, rooting was reduced by SP + SU coring at most root zone depths by late summer of the first year (i.e., 2006). The beneficial rooting effects from summer coring in the second year presumably were due to thatch-mat control, enhanced air exchange and water infiltration, and stimulation of rooting through severing of stems (Beard, 1973). Furthermore, coring also reduces soil bulk density and increases macroporosity of soil (Murphy et al., 1993; Murphy and Rieke, 1994). Coring tines used in this study penetrated to 9.0 cm (SP) and 5.5 cm (SU), which through a combination of improved air and water drainage as well as reduction of bulk density may have enhanced root elongation deeper (i.e., ≥9.0 cm) into the soil in the current study. A deeper root system would be expected to better tolerate periods of drought and would be more efficient in scavenging nitrates and other nutrients (Bowman et al., 1998).

In conclusion, the results of this study indicated that summer coring with small diameter tines can be employed to promote root growth and/or longevity in creeping bentgrass putting greens grown on sand-based root zones in late summer of the second year following establishment when turf is more mature. Coring creeping bentgrass putting greens can be detrimental during the first summer after autumn establishment. These findings may apply only to Providence creeping bentgrass since cultivars can vary in rooting depth and architecture (Bowman et al., 1998). Furthermore, chemical, nutrient, macroporosity, organic matter, microbial biomass, and other soil properties change as greens age (Murphy et al., 1993; Kerek et al., 2002; McClellan et al., 2007; McClellan et al., 2009). For logistical reasons associated with the laborious minirhizotron imaging technique (Murphy et al., 1994; Fu and Dernoeden, 2009), this study was not repeated on separate stands of equal age. Hence, additional research will be required to corroborate findings of the current study. Since coring newly established turf can be injurious to rooting, future studies should consider the effects of coring to thatch-mat depth without disturbing much soil or young root systems during the first summer of creeping bentgrass establishment.

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