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Cultivation Effects on Organic Matter Concentration and Infiltration Rates of Two Creeping Bentgrass (*Agrostis stolonifera* L.) Putting Greens

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Abstract

Soil cultivation is commonly used to manage organic matter (OM) accumulation in golf course putting greens. Our objectives were to determine: (i) if hollow-tine cultivation is more effective than solid-tine cultivation at managing OM and water infiltration, (ii) if venting methods are effective at managing OM and water infiltration, and (iii) if venting alters or interacts with effects of early- or late-season cultivation. The study was a 3 × 5 factorial repeated on two 'Providence' creeping bentgrass (*Agrostis stolonifera* L.) research putting greens. Tine treatments were hollow-tine, solid-tine, or no-tine cultivation. Venting treatments were Hydroject, PlanetAir, quad needle tine, bayonet tine, or no venting. Soil samples were collected and analyzed for OM content using loss on ignition. Water infiltration rates were determined in situ. After 2 years, there were few consistent differences found among the tine and venting treatments, and there were no significant interactions regarding OM concentration. This response was attributed to the small amount of surface area impacted by cultivation and to the equalization of topdressing quantity across all treatment combinations. Hollow-tine and solid-tine cultivation increased infiltration compared with no cultivation. In general, Hydroject treatments increased water infiltration rates more than all other venting treatments regardless of tine treatment.

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Abbreviations: HTC, hollow-tine cultivation; LOI, loss on ignition; OM, organic matter; STC, solid-tine cultivation.

Conversions: For unit conversions relevant to this article, see Table A.

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ORGANIC MATTER ACCUMULATION in creeping bentgrass putting greens has been a concern since the innovation of sand-based root zones (Gaussoin et al., 2013). Accumulation of OM can increase thatch in a putting green, creating a soft, saturated surface that results in decreased playability (Glasgow et al., 2005). Equipment and foot traffic can also cause surface imperfection (e.g., ruts, scalping, and foot imprints) on putting greens with high OM content (Oatis, 2010). Excessive OM decreases water infiltration rates and increases surface water retention (Hurto et al., 1980). Excess surface water retention for extended periods decreases gas exchange (O_2, CO_2, CH_4) between the soil and atmosphere, which can have a negative impact on turfgrass growth (Carrow et al., 2001; Hillel, 2004).

Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
2.54	inch	centimeter, cm (10^{-2} m)
10	percent, % (must specify the base and if by weight or volume)	unknown molecular weight in fresh or dry plant material, gram per kilogram. g/kg

Soil cultivation is one of the primary cultural practices used to manage OM accumulation in golf course putting greens. Traditionally, hollow-tine cultivation (HTC) in the spring and fall (early and late season) is used to manage OM accumulation in concert with sand topdressing. Soil cultivation is done in the spring and fall on cool-season turfgrasses to ensure that the turf is actively growing and to minimize recovery time (Beard, 1973). Hollow-tine cultivation reduces soil compaction, increases water infiltration, and improves soil aeration and rooting (White and Dickens, 1984; Brauen et al., 1998). One of the major drawbacks to HTC is the disruption of the putting green surface—an inconvenience to golfers. In a 2002 United States Golf Association (USGA) report of the top 10 questions frequently asked by golfers, three questions pertained to the need for soil cultivation on putting greens (Maloy, 2002). Hollow-tine cultivation is also an expensive process requiring many hours of labor to remove cores and backfill holes with topdressing sand. Solid-tine cultivation (STC) in combination with sand topdressing has been used to manage OM accumulation. Solid-tine cultivation has several advantages, including reduced cleanup of the putting surface, reduced labor, faster healing time of the putting surface, and the ability to cultivate more frequently (Murphy and Rieke, 1990).

A current trend in the industry involves using tools that cause minimal surface disruption, such as spiking, slicing, needle-tine cultivation, and high-pressure water injection, for soil cultivation multiple times throughout the growing season. This type of minimally disruptive cultivation practice has been termed "venting" (Fontanier et al., 2011). Previous studies have shown that venting methods such as spiking and Hydroject can improve the infiltration rates of sand-base putting greens (Canaway et al., 1986; McAuliffe et al., 1993; Murphy and Rieke, 1994; Green et al., 2001; Fontanier et al., 2011). In contrast, results from previous studies have shown that HTC four times per year did not significantly reduce thatch compared to twice yearly (White and Dickens, 1984; McCarty et al., 2007). However, newer venting methods allow treatments to be applied more frequently because narrow, solid tines or blades reduce the healing time of the putting surface (Proctor et al., 2013). The increased frequency associated with venting treatments may result in better management of putting green OM concentrations. Examples of venting methods that are commonly used in the turfgrass industry include the Toro Hydroject, PlanetAir planetary gear-shatter-knife cultivator, and spiking with solid tines or blades. Solid tines now come in many sizes and shapes ranging from 1/4-inch to 7/8-inch diameter. There have also been advancements in tine mounts that allow for narrower tine spacing, effectively increasing the total area cultivated.

The objectives of this study were to determine (i) if early- or late-season HTC is more effective than STC at managing OM accumulation and increasing infiltrations rates, (ii) if venting methods are effective at managing OM accumulation and increasing infiltration rates, and (iii) if venting alters or interacts with early or late season cultivation.

CULTURAL MANAGEMENT PRACTICES AND TREATMENT DESIGN

Research was conducted from May 2007 to November 2008 at the University of Nebraska–Lincoln John Seaton Anderson Turfgrass Research Facility near Mead, NE (41°11′ N, 96°28′ W). Research was conducted on two putting greens constructed to USGA specifications (USGA Green Section Staff, 1993). Location 1 (1997 green) and Location 2 (2000 green) were established in May of 1997 and 2000, respectively. Both greens were seeded with 'Providence' creeping bentgrass at 1.5 lb/1000 ft^2. Putting greens were managed according to regional recommendations for golf course putting greens as described by McClellan et al. (2007). Turfgrass was mowed at 0.125 inch with annual fertility applications of N, P_2O_5, and K_2O at 6.0, 9.2, and 7.3 lb/1000 ft^2, respectively. The soil pH of the mat layer and original root zone were 7.3 and 7.5. Traffic was applied three times weekly with a greens roller. All plots received the same annual topdressing quantity (22 ft^3/1000 ft^2/year) regardless of tine or venting treatments. Plots receiving no cultivation received three applications of topdressing at reduced rates to equal the amount applied for each HTC and STC treatment. Low-rate (~1.0 ft^3/1000 ft^2), blanket applications of topdressing sand were applied to all plots following venting treatments. Sand topdressing was incorporated into each plot individually with a push broom.

The experimental design for the study was a randomized complete block with six replications in each location. Treatments were arranged in a 3 × 5 factorial with three tine treatments and five venting treatments. Tine treatments included HTC, STC, and no cultivation and were applied 30 May 2007, 17 Sept. 2007, 10 June 2008, and 15 Sept. 2008. Hollow and solid tines were approximately 0.5 inch in diameter with a spacing of 2 inches by 2 inches and a depth of 3.0 inches (see Table 1). Venting treatments consist of PlanetAir (model HD 50 Tow, PlanetAir Turf Products LLC, Owatonna, MN), Hydroject in the raised position (Model 3010, Toro Co., Bloomington, MN), bayonet tines, needle tines in the quad-tine mount (quad needle tines), and no venting treatment. Venting treatment

Table 1. Specifications of tine and venting treatments applied to two 'Providence' creeping bentgrass putting greens, Mead, NE, USA, in 2007 and 2008.

Tine type†	O.D.‡	Length	Spacing	Surface area impacted
		inches		%
Hollow tine	0.6	4.5	2 by 2	5.9
Solid tine	0.5	5.0	2 by 2	4.9
Quad needle tine	0.2	4.5	1 by 1	4.9

Blade type	Blade width	Thickness	Length	Spacing	Surface area impacted
			inches		%
Bayonet	0.7	0.1	4.8	2 x 2	2.1
PlanetAir	0.7	0.1	6.0	2 x 2	2.1

†Hydroject not reported due to lack of physical tine.

‡O.D., outside diameter.

specifications are described in Table 1. Venting treatments were applied every 2 weeks beginning 8 July 2007 and 17 July 2008 through 1 Aug. 2007 and 7 Aug. 2008. The plot size for the study was 4.0 ft by 4.5 ft.

DATA COLLECTION AND STATISTICAL ANALYSIS

Soil samples were taken pretreatment on 1 May, and then on 10 July, 13 Aug., and 1 Nov. 2007, and 2 July, 20 Aug., and 2 Nov. 2008. Two soil samples per plot were taken on each sampling date to determine OM concentration (gravimetric concentration). Samples were taken with a 0.75-inch diameter Turf-Tec tubular soil probe (Model TSS1-S, Turf-Tec International, Tallahassee, FL) to a depth of 6 inches. Verdure was removed from the sample and discarded. The sample was then cut at 3.0 inches below the verdure and the excess soil was discarded. Soil samples were stored at −4°F ± 2°F until analysis to prevent microbial degradation of soil OM. Soil samples were analyzed for OM concentration using the loss-on-ignition (LOI) method (Nelson and Sommers, 1996) at 750°F ± 5°F for 12 h, which is below the temperature at which calcium carbonate would interfere with the LOI measurement of OM (Rabenhorst, 1988).

Two water infiltration rate measurements were taken per plot on each sampling date. Infiltration rates were taken with a single thin-walled ring using the falling head infiltration method described by Bouwer (1986). Infiltration rates were obtained pretreatment on 21 May 2007, and then on 5 July 2007, 1 Oct. 2007, 1 July 2008, and 20 Oct. 2008.

Data were analyzed with the general linear model procedures in SAS statistical software (version 9.2.1, SAS Institute, Cary, NJ). The cultivation by venting factorial was replicated six times in each location; replications were nested within location (Hicks, 1993). Means were separated by Fisher's protected least significant difference $P \leq 0.05$ (Dowdy et al., 2004).

EFFECTS OF CULTIVATION ON ORGANIC MATTER CONCENTRATION

The effects of cultivation and the venting treatments on OM concentration were consistent across both locations (no interaction), except on 10 July 2007 (Table 2). On this date, location interacted with venting treatments; consequently, treatments were analyzed separately for both locations. As expected, the 1997 green had a consistently greater OM concentration throughout the study (Table 2). Previous research performed at these locations showed that putting green age and depth had a significant impact on the OM content (McClellan et al., 2009). In this study, the 1997 green had a significantly greater OM concentration compared with the 2000 green in the root-zone surface (0–3 in). No differences in root-zone OM concentrations were found at the 3.0- to 6.0-inch depth.

Tine treatments had an effect on the OM concentration on three of the seven sampling dates (Table 2). At the initial pretreatment sampling, the HTC plots had lower OM concentrations than the STC plots; the no-cultivation plots were not different from either treatment. This difference was short-lived; by the first posttreatment sampling date (10 July 07), the STC plots had significantly lower OM concentrations than both the HTC and no-cultivation treatments (Table 2). On the final significant rating date (1 Nov. 07), both the HTC and STC plots had lower OM concentrations than the no-cultivation plots. The short-lived decreases in OM concentration from tine treatments suggest that roots may be quickly colonizing the sand-filled cultivation holes, counteracting the dilution effect of sand (McClellan, 2005). Another possible explanation was that the consistent topdressing quantity applied across all treatments overrode the effect of tine treatment. Beard (1973) suggested that topdressing is more effective than cultivation or vertical mowing at controlling thatch, which would explain why few consistent differences were seen between the tine treatments. Sorokovsky et al. (2007) reported similar findings in a 2-year study performed on USGA sand-based putting greens, where core aeration applied twice per year did not reduce the OM content compared with no core aeration, even though sand topdressing was

Table 2. Analysis of variance and effects of tine and venting treatments on organic matter concentration of two 'Providence' creeping bentgrass putting greens located near Mead, NE, USA, in 2007 and 2008.

	Date						
ANOVA source	1 May 2007	10 July 2007	13 Aug. 2007	1 Nov. 2007	2 July 2008	20 Aug. 2008	2 Nov. 2008
Rep	***	NS†	NS	***	***	NS	***
Location (LOC)	**	***	**	***	**	**	NS
Tine	**	**	NS	*	NS	NS	NS
LOC × tine	NS	NS	NS	NS	NS	NS	NS
Venting	NS	NS	*	NS	NS	*	NS
LOC × venting	NS	*‡	NS	NS	NS	NS	NS
Tine × venting	NS	NS	NS	NS	NS	NS	NS
LOC × tine × venting	NS	NS	NS	NS	NS	NS	NS
CV%	9.7	8.5	9.0	8.7	8.6	10.0	19.7
	Organic matter concentration						
	%						
Location							
1997 green	2.08	1.94	1.86	2.44	2.51	2.34	3.40
2000 green	1.59	1.58	1.66	2.08	2.19	1.99	2.48
$LSD_{0.05}$	0.20	0.07	0.08	0.07	0.16	0.15	–
Tine							
No cultivation	1.83	1.79	1.74	2.31	2.35	2.20	2.90
Hollow-tine cultivation	1.79	1.79	1.75	2.23	2.33	2.12	2.97
Solid-tine cultivation	1.89	1.71	1.78	2.23	2.37	2.17	2.94
$LSD_{0.05}$	0.06	0.05	—	0.07	—	—	—
Venting							
No venting	1.82	1.77	1.75	2.29	2.34	2.24	3.06
PlanetAir	1.84	1.74	1.78	2.25	2.34	2.21	2.93
Hydroject	1.86	1.82	1.81	2.26	2.35	2.13	2.90
Bayonet tines	1.83	1.76	1.74	2.19	2.36	2.13	2.98
Quad needle tines	1.83	1.72	1.70	2.29	2.35	2.11	2.81
$LSD_{0.05}$	—	—	0.07	—	—	0.10	—

*Significant at $P \leq 0.05$.

**Significant at $P \leq 0.01$.

***Significant at and $P \leq 0.001$.

†NS, not significant.

‡Location × venting interaction occurring on 10 July 2007 is listed in Table 3.

not consistent across treatments. Murphy et al. (1993) reported that HTC actually increased the total OM content compared with STC and no cultivation but reduced the OM fraction, resulting in a thicker thatch-mat layer. This result probably occurred because soil cores from the HTC treatment were reincorporated into the turf and no sand topdressing was applied during the study. These results differ from those observed on a bentgrass fairway by Brauen et al. (1998), who found that HTC was more effective than STC in reducing thatch buildup across a 5-year period. Differences in results between their studies and our study are probably due to differences in sampling procedures and duration. Brauen et al. (1998) sampled exclusively from the thatch region, whereas our samples were collected from the thatch, mat, and surface soil layers to a depth of 3.0 inches. Brauen et al. (1998) applied cultivation treatments for 5 years, whereas our study concluded after 2 years. Cultivation effects may require more than 2 years to be discernible, because of the small area and volume affected by cultivation treatments. For example, the HTC treatments used in our study impacted only 5% of the surface area per application (Table 1). Another possible explanation for the absence of differences in OM at the conclusion of this study may also be attributed to the soil sample size (diameter) and the number of samples collected per plot. In this study, two 0.75-inch-diameter soil samples were collected per plot, which may not be sufficient to accurately quantify subtle variations in OM content resulting from cultivation and venting treatments. In warm-season putting surfaces, Kauffman et al. (2013) suggest that between two and five cup-cutter-size (3.9-inch-diameter) samples should be collected per plot to detect OM differences.

The location-by-venting interaction that occurred on 10 July 2007 indicated that Hydroject treatment in the 2000 green resulted in a higher OM concentration than all other venting treatments (Table 3). No differences were found between venting treatments in the

1997 green. Venting treatments also influenced OM concentration on 13 Aug. 2007 and 20 Aug. 2008 (Table 2). On 13 Aug. 2007, Hydroject had higher OM concentrations than bayonet tines and quad needle tines. Planet Air treatments also produced greater OM concentrations than quad needle tine treatments on this date. The nonventing treatment resulted in the highest OM concentration on 20 Aug. 2008. Planet Air treatments also produced greater OM concentrations, significantly higher than quad needle-tine treatments. At the conclusion of this study, there was no difference between venting treatments. This result is similar to those of Fontanier et al. (2011), who found no differences in thatch-mat accumulation and OM density between venting treatments (PlanetAir, 0.25-inch hollow tine and 0.25-inch solid tines) applied to three bermudagrass cultivars across a 2-year period. Minimal differences in OM concentration resulting from venting treatments are probably the result of the low surface area affected.

Table 3. Location by venting interaction effect on organic matter concentration of 'Providence' creeping bentgrass putting greens located near Mead, NE, USA, collected 10 July 2007.

Venting	Location	
	1997 green	2000 green
	—Organic matter concentration (%)—	
None	1.99	1.54
PlanetAir	1.92	1.57
Hydroject	1.94	1.70
Bayonet tines	1.93	1.59
Quad needle tines	1.93	1.52
$LSD_{0.05}$	0.10†	

†LSD within and between columns.

EFFECTS OF CULTIVATION ON WATER INFILTRATION

The tine and venting treatment effects on the rate of water infiltration were consistent across both locations

Table 4. Analysis of variance and effects of tine and venting treatments on infiltration rates of two 'Providence' creeping bentgrass putting greens located near Mead, NE, USA, in 2007 and 2008.

ANOVA source	Date				
	21 May 2007	5 July 2007	1 Oct. 2007	1 July 2008	20 Oct. 2008
Rep	***	***	***	*	***
Location (LOC)	***	**	**	*	*
Tine	NS†	***	***	***	***
LOC × tine	NS	NS	NS	NS	NS
Venting	NS	***	***	***	***
LOC × venting	NS	NS	NS	NS	NS
Tine × venting	NS	NS	NS	NS	**‡
LOC × tine × venting	NS	NS	NS	NS	NS
CV%	20.5	28.8	30.4	25.0	32.6
	Infiltration rate				
	——in/h——				
Location					
1997 green	9.9	11.1	11.2	16.8	11.0
2000 green	14.8	19.9	14.6	19.9	16.5
$LSD_{0.05}$	1.7	4.9	2.2	2.4	3.9
Tine					
No cultivation	12.3	14.1	10.4	14.1	11.8
Hollow tine cultivation	12.2	17.1	14.7	22.0	15.4
Solid tine cultivation	12.6	15.3	13.6	19.0	14.1
$LSD_{0.05}$	—	1.4	1.4	1.6	1.5
Venting					
No venting	12.2	14.1	8.9	16.8	12.4
PlanetAir	12.2	14.0	8.2	16.1	9.8
Hydroject	12.2	13.8	21.1	22.3	19.6
Bayonet tines	13.0	14.9	10.8	16.4	11.8
Quad needle tines	12.3	20.8	15.5	20.1	15.3
$LSD_{0.05}$	—	1.8	1.8	2.1	1.9

*Significant at $P \leq 0.05$.

**Significant at $P \leq 0.01$

***Significant at $P \leq 0.001$

†NS, nonsignificant.

‡Tine × venting interaction occurring on 20 Oct. 2008 is listed in Table 5.

Table 5. Tine by venting interaction effect on infiltration rates obtained on 'Providence' creeping bentgrass putting greens located near Mead, NE, USA, collected 20 Oct. 2008.

Venting	Tine type		
	None	Hollow tine	Solid tine
	Infiltration rate (in/h)		
No venting	8.4	15.8	13.0
PlanetAir	5.9	12.3	11.2
Hydroject	20.8	18.8	19.1
Bayonet tine	8.7	14.2	12.5
Quad Needle tines	15.2	16.0	14.8
$LSD_{0.05}$		3.4†	

†LSD within and between columns.

(no interaction; Table 4), thus they were combined for analysis. In general, the water infiltration rate increased over time as a result of tine treatments at both locations. The 2000 green had higher infiltration rates than the 1997 green on all five sampling dates (Table 4), which was expected because of the greater OM concentration found in the 1997 green.

Tine type impacted the infiltration rate on all post-treatment dates (Table 4). On 5 July 2007 and 1 July 2008, the HTC plots had greater infiltration rates compared with the STC or no-cultivation plots. Also, on both dates in 2008, STC produced greater infiltration than no cultivation. Both HTC and STC produced greater infiltration rates than the no-cultivation treatment on 1 Oct. 2007, but there was no difference between the two. Results indicate that yields with HTC yields slightly greater water infiltration rates than STC, and both had greater water infiltration rates the no-cultivation treatment. Similar results were found by Fontanier et al. (2011), who saw few differences in saturated hydraulic conductivity (K_{sat}) between small-diameter HTC and STC treatments applied to three bermudagrass cultivars. However, our results were less dramatic than those reported by Murphy et al. (1993), who found that HTC increased K_{sat} by 49% compared with STC by the end of a 3-year study in which no sand topdressing was applied.

Similar to tine type, venting type impacted infiltration rates on all dates (Table 4). On the first posttreatment sampling (5 July 2007), quad needle-tine treatments produced greater infiltration rates compared with the other four treatments, but no differences were found among those other treatments. On the final three sampling dates, Hydroject treatments resulted in significantly greater infiltration rates than the other treatments, with some dates having almost double the infiltration rate of the no-venting, PlanetAir, and bayonet-tine treatments. Quad needle tines also increased infiltration rates on these dates compared with the no-venting, PlanetAir, and bayonet-tine treatments, but the increased in infiltration was less dramatic than with the Hydroject treatment. One explanation for the difference between venting treatments is the variable amount of surface area affected by the treatments. The bayonet-tines PlanetAir, and no-venting treatments affected the least amount of surface area of all the treatments, whereas the Hydroject and QTN affected at least twice as much surface area (Table 1). This is especially true for the Hydroject treatments, which created much larger holes that remained open for an extended period of time. Green et al. (2001) and McAuliffe et al. (1993) observed similar increases in infiltration rates in plots that received Hydroject treatments compared with the untreated control. Green et al. (2001) also showed that the Hydroject must be run in the raised position to see dramatic increases in infiltration rate. Murphy and Rieke (1994) found fewer dramatic differences between the Hydroject and untreated control when their Hydroject was operated in the lowered position. Operating the Hydroject in the raised position will cause the high-pressure water stream to fracture near the soil surface, whereas the lowered position allows the water stream to penetrate further into the soil before fracturing. Fracturing of the stream near the surface will create vertical and horizontal pores near the surface and thus increase water infiltration. McAuliffe et al. (1993) also suggested that increases in infiltration rates are the result of the formation of deep, continuous large pores rather than improved soil conditions.

An interaction between tine and venting treatments occurred on the last sampling date in 2008 (Table 4). Interaction data indicates that within each tine treatment, Hydroject produced significantly greater infiltration rates than all other treatments except within HTC treatments, where the quad needle-tine and no-venting treatments were not different from the Hydroject (Table 5). Interestingly, the Hydroject treatment in the uncultivated plots produced the greatest infiltration rate on this date, although it was not significantly different from the Hydroject treatment that also received HTC or STC. The lowest infiltration rates observed on this date were found in plots that received no cultivation and PlanetAir treatments; however, it was not significantly different from the no-venting and bayonet-tine treatments.

CONCLUSIONS

After 2 years, there were no differences in OM concentration among tine treatments because of the relatively small amount of surface area impacted by cultivation during the study. Differences in OM among venting treatments were inconsistent during the study and not significant at the conclusion. These results suggest that sand topdressing plays a critical role in managing OM accumulation in putting greens. Tine type and frequency are less important, as long as sufficient topdressing is applied. Infiltration rates were significantly increased by HTC and STC treatments, with HTC having the highest infiltration rates. Hydroject treatments consistently increased infiltration rates over both years of the study. The highest infiltration rates observed at the conclusion of the study were seen in the Hydroject plots, regardless of tine treatment. Across a 2-year period, both STC and

HTC were ineffective at reducing OM concentration; however, both were effective at increasing water infiltration rates on a sand-based root zone. Venting treatments such as Hydroject and quad needle tines are effective at increasing water infiltration rates, whereas treatments such as PlanetAir and bayonet tines were less or not at all effective. While these results suggest that cultivation and venting treatments were not effective at reducing OM content in a 2-year period, turfgrass managers should continue to use these to tools to aid sand incorporation (i.e., OM dilution) and maintain water infiltration rates.

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