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Surface Organic Matter in Bentgrass Greens

Research reveals the relationship between aeration methods and surface organic matter on sand-based greens.

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The USGA golf green recommendations were developed to create a rootzone medium that would exhibit good physical properties under continuous traffic, namely water infiltration and percolation, oxygen status, and resistance to soil compaction. Putting greens, however, are dynamic systems where the norm is changing over time, especially within the two-inch surface zone. The greatest changes in total organic matter content, thatch/mat status, turfgrass rooting, and even the nature of the organic matter often occur during the first two years of grow-in, but changes also may continue over future years. All of these factors may influence water infiltration and percolation, as well as soil oxygen status.

Several researchers have documented decreases in saturated hydraulic conductivity (SHC, the infiltration rate under saturated profile conditions) as putting greens mature.[7,10] Concurrent with a reduction in SHC has been an increase in organic matter content within the surface two inches. An upper limit of 4.5% (by weight) of organic matter in a sand medium was suggested by Murphy et al.[8] because macropores important for rapid SHC are insufficient above this level. McCoy[6] recommended a maximum of 3.5% organic matter (by weight) based on his work and a review of others, since macroporosity starts to decline above this value. The decline in root growth often observed within two to three years after establishment has been attributed to accumulation of organic matter in the surface.

University of Georgia researchers are investigating how various aeration methods can limit organic matter buildup in newly constructed greens. This example shows the organic matter buildup found in an ultradwarf bermudagrass green after one year if not managed properly.

SUMMER BENTGRASS DECLINE: PATHOLOGICAL OR PHYSICAL?

The USGA-sponsored project "Organic Matter Dynamics in the Surface Zone of a USGA Green: Practices to Alleviate Problems" arose from observations in the late 1980s of summer bentgrass decline (SBD) on creeping bentgrass greens in the southern zone of bentgrass adaptation. From field observations and a review of the literature, I came to the hypothesis that many of the primary problems on high-sand bentgrass/annual bluegrass greens, including SBD, were due to changes in soil physical conditions in the surface two inches. It appeared that either too much organic matter accumulation or rapid death of surface roots could result in reduced water infiltration and higher water-holding capacity. This resulted in decreased oxygen content within the zone and O_2 diffusion across the zone.

Other secondary problems can arise if the primary problem is organic matter accumulation and/or change in the nature of the surface organic matter. These include more disease activity, severe physiological O_2 stress, and further root decline during summer, as well as softer greens. Achieving a reduction in these secondary problems requires correction of the physical conditions within this zone.

TWO TYPES OF SURFACE ORGANIC MATTER PROBLEMS

The two common surface organic matter problems are suggested from field observations and the turfgrass science literature. The first organic matter problem is excessive accumulation of organic matter in the surface zone. USGA specification greens normally contain less than 3% (by weight) organic matter throughout the rootzone mix. Research has consistently demonstrated

Table 1

Factors favoring rapid organic matter (OM) accumulation.

O.M. accumulation is enhanced by:

- Prolonged cool temperatures on cool-season turfgrasses when temperatures are between 32°F and 55°F, where microbial (especially bacteria) activity declines, and, thereby, OM decomposition declines. Cool, humid temperate climates may have such conditions most of the year, while in the southern regions of bentgrass adaptation this climatic condition may be for 5-7 months per year.
- Use of aggressive bentgrass or bermudagrass cultivars that exhibit high rates of OM accumulation. Many of the newer greens types exhibit this tendency.
- Poor air drainage that allows the surface to remain excessively moist for long periods. This allows for longer periods of anaerobic conditions and stimulates production of adventitious surface rooting, contributing to more OM load. These are often the secluded greens with many trees in the surrounds, little natural air drainage, and shade on the green surface for a period of time.
- Inadequate integration of sand to sustain a medium where sand is the dominant matrix rather than OM. Sand must be applied not just by topdressing, but also in vertical channels by hollow-tine core aeration that removes plugs of OM and allows large quantities of sand to be added.
- Addition of OM to the surface as sod (even washed sod), compost, or OM-containing amendments.
- Acidic pH at < 5.5, which limits bacteria and actinomycete populations and activity.
- Maintenance toward rapid growth or thatch buildup such as high N use, frequent irrigation, high mowing height.
- Low earthworm activity.

that as organic matter content in a sand mix increases to above 4% to 5% (by weight), the percent of larger soil pores (macropores, aeration pores) of >0.08mm diameter between sand particles decreases due to plugging by organic matter.[6,8] Even with very good turfgrass management, the organic matter content in the surface two inches is often observed to be more than 3.0% by weight.[2,3]

Table 1 summarizes the most common conditions that cause excessive organic matter accumulation, especially when several of these conditions occur simultaneously. Normally, the extreme instances of organic matter accumulation occur in the cool, humid, temperate climates. However, this is not always the case. In fact, in climates that strongly favor organic matter accumulation, this is likely the most prevalent problem on high-sand greens or athletic fields.

A second situation suggested to cause problems occurs when the nature of the organic matter changes from structured organic matter (mainly as live roots) into a gel-like consistency as roots die, plug macropores, and cause O_2 stress. This situation is most likely to occur on a cool-season grass during hot, humid weather that induces rapid root death, so this problem would be more common in the warmer regions of bentgrass adaptation.

Root dieback/death occurs every summer to some extent, but microorganisms can sufficiently break down the fresh organic matter to prevent excessive macropore sealing. Under unusually hot, humid weather for one to two weeks or more, root death occurs more rapidly and can induce low infiltration and low aeration. Fresh dead roots hold more water and are gel-like, so macropore sealing occurs. The remaining live, O_2-stressed roots cannot obtain enough water uptake for transpirational cooling. Low soil O_2 in the surface layer where the remaining live roots are present leads to reduced water uptake, stomatal closure, and direct high-temperature kill. This is usually evident by yellowing of the turf and death over one to three days of hot, humid weather when plant and microbial oxygen demand is very high.

As organic matter content increases above 3% by weight, the more likely a massive root dieback from hot, humid weather would cause a rapid O_2 stress and plant death. It is not the lack of roots from root dieback that is the problem, but the creation of an excessively moist layer with very low O_2 during hot weather in response to the rapid root dieback, resulting in the inability of remaining roots to take up sufficient moisture for transpirational cooling.

In the late 1990s, Huang et al.[4,5] provided strong evidence of adverse effects of the combination of high temperature and low O_2 on bentgrass root viability. Also, the author conducted oxygen diffusion rate (ODR) measurements within the surface zone in a study from 1992 to 1995 and found numerous periods when ODR was less than 20 to 40 mg O_2 cm^{-2} min^{-1}, which is considered sufficiently low to limit rooting of grasses.

RESEARCH APPROACH USED IN THE STUDY

The focus of the research in this study was on management of the second problem: change in nature of the surface organic matter during the summer months. Research was conducted from 1996 to 1998 at Griffin, Georgia, on an experimental golf green with a rootzone mix meeting USGA recommendations. Treatments are summarized in Table 2 and consisted of various non-disruptive cultivation techniques, topdressing, wetting agent, sand substitute, and cytokinin combinations.

SATURATED HYDRAULIC CONDUCTIVITY

One of the most important characteristics for bentgrass golf greens in the summertime is the ability for excess moisture to infiltrate into the surface and percolate through the rootzone. If saturated flow (saturated hydraulic conductivity) does not occur in a rapid fashion, a saturated surface can occur.

In Table 3, SHC values at 1 to 7 and 17 to 26 days after cultivation treatment are presented as the average SHC values of seven summertime measurements

Table 2

Research treatments to investigate the change in nature of surface organic matter during the summer months. Except for the core aeration (CA) treatments in March and October, all other cultivation, supplemental topdressing with sand or Greenschoice sand substitute, wetting agent (WA), or cytokinin (C) treatments were applied in summer.

Treatment[a]	Description	Topdressing per 1,000 sq. ft. Annual[b]	June-Sept.
		------- cu. ft.	-------
Control	No cultivation	10.7	2.5
CA	Hollow-tine core aeration, ⅝" diameter, March and October	19.0	2.5
HJL	HydroJect Lowered, 3" spacing, ⅛" diameter hole, June 1 and every 3 weeks	10.7	2.5
HJR	HydroJect Raised, 3½" spacing, ¼" diameter hole, June 1 and every 3 weeks	10.7	2.5
HJR + Sand	See HJR. Additional sand topdressing at 0.75 cu. ft. per 1,000 sq. ft. 5 times per summer	14.5	6.3
HJR + Greenschoice	See HJR. Greenschoice as topdressing at 0.75 cu. ft. per 1,000 sq. ft. 5 times per summer	14.5	6.3
HJR + WA	See HJR. Wetting agent (Naid) at 3 oz. per 1,000 sq. ft. 5 times per summer	10.7	2.5
HJR + C	See HJR. Cytokinin as CytoGro (0.005% ai) at 1 oz. per 1,000 sq. ft. 4 times per summer	10.7	2.5
HJR + Sand + WA	See previous treatment descriptions	14.5	6.3
HJR + Sand + WA + C	See previous treatment descriptions	14.5	6.3
LP + Greenschoice I	LandPride dry injection of 0.75 cu. ft. Greenschoice per 1,000 sq. ft. 5 times per summer	14.5	2.3

[a]CA = core aeration, HJL = HydroJect run in lowered position, HJR = HydroJect run in raised position, Greenschoice = fired calcined clay, WA = wetting agent, C = cytokinin

[b]All plots received 10.7 cu. ft. sand topdressing per year with 2.5 cu. ft. per 1,000 sq. ft. in the summer at 0.5 cu. ft. per 1,000 sq. ft. every 3 weeks

during 1996-1998. Within 1 to 7 days after cultivation, SHC increased at least 3.4-fold to more than 20.2 inches per hour for all HydroJect (HJR) treatments (HJR = HydroJect operated in the up position to provide a hole of approximately ¼ inch), compared to 5.9 inches per hour in the non-cultivated control.

The plots that were core-aerated in March exhibited no difference in SHC compared to the control. This illustrates the effectiveness of spring hollow-tine cultivation as SHC declines with time as holes refill with root mass, and suggests that cultivation methods that are normally non-disruptive of the surface (i.e., HydroJect or solid quad-tines) may be necessary to maintain higher SHC during the summer periods.

Comparing HJL (HydroJect operated in the lowered position) to HJR treatments at 1-7 days after cultivation demonstrated that the larger hole formed by the HJR operation was more effective in increasing initial SHC. The LandPride device did not result in any increase in SHC when a sand substitute was injected. LandPride cultivation alone (without amendment injection) was not evaluated in the study. The same sand substitute amendment when applied as topdressing after HJR cultivation tended to decrease SHC, especially at 17-26 days after cultivation.

At 17 to 26 days after cultivation, all HJR treatments exhibited SHC 2.2 to 3.6 times greater (10.8-18.0 inches per hour) than the control (5.1 inches per hour). The lowest summertime SHC observed on the non-cultivated control was 0.8 inches per hour versus more than 3.2 inches per hour for plots that received cultivation in the summer. The decline in SHC from 1-7 days to 17-27 days after cultivation is expected as the surface starts to reseal from root mass growing across the aeration holes or collapse of the holes themselves.

OXYGEN DIFFUSION RATE

Oxygen diffusion rate (ODR) readings were taken in the surface 1-inch depth during the summer months for selected treatments and results varied by year (Table 3). In 1996, readings were < 20 mg O_2 cm^{-2} min^{-1} most of the time, regardless of treatment. There were periods of limited O_2 within the surface zone in other years. These results, plus similar ODR findings from a subsequent study,[10] confirmed that critically low O_2 levels can occur even under non-saturated conditions. Low oxygen diffusion rates would be expected more frequently when rain is frequent or daily irrigation is practiced, keeping the surface zone moist.

TURFGRASS QUALITY AND SHOOT DENSITY

Improved turfgrass quality and shoot density were noted for most of the HJR and HJL treatments compared to the control (Table 4). The reduction in turf quality and shoot density of core-aerated plots occurred in the early summer when some residual effects from the spring treatment were still evident. Generally, when sand or a sand substitute was applied immediately after the summer cultivation operation, visual quality and shoot density ratings were not as high as when the topdressing was omitted.

Table 3

Treatment effect on summer saturated hydraulic conductivity (SHC),[c] oxygen diffusion at 1.2" depth, and organic matter content in the 0" to 1.2" zone at 30 months after treatment initiation.

Treatment and Contrast	Average SHC (1996-1998) 1-7 DAC	Average SHC (1996-1998) 17-26 DAC	Lowest SHC	Readings > 0.20 $\mu g\ O_2\ cm^{-2}\ min^{-1}$[b] 1996	1997	1998	Organic Matter at 30 months (0-3 cm)
	-------- inch hr^{-1}	--------		------ %	------		% (wt.)
Control vs.	5.9	5.1	0.8	—	—	—	9.8
CA	9.3	5.8	3.2	0	100	87	7.3*
HJL	12.9	13.2*	3.2	—	—	—	9.9
HJR	23.5**	16.0**	7.6	14	84	75	9.1
HJR + Sand	24.0**	18.0**	6.2	—	—	—	9.3
HJR + Greenschoice	20.2**	10.8H	6.4	—	—	—	9.3
HJR + WA	25.6**	16.2**	5.8	29	100	100	8.9
HJR + C	23.0**	15.8*	4.0	—	—	—	10.3
HJR + Sand + WA	20.2**	14.8*	4.5	—	—	—	10.0
HJR + Sand + WA + C	21.5**	14.4*	4.3	—	—	—	9.1
LP + Greenschoice I	7.9	5.9	3.2	—	—	—	9.0
LSD (.05)	9.7	6.9	—				2.2
F-test	**	**	—				.38

[a]Core aeration was in March and October, but SHC readings were in the July-to-September period, so SHC for the CA treatment is not at 1-7 or 7-26 DAC
[b]An ODR rate of > 0.20 to 40 $\mu g\ O_2\ cm^{-2}\ min^{-1}$ is considered as non-limiting for root growth, while below this value root growth is less than optimal
[c]Average of 7 time periods during summers of 1996-1998

Only the hollow-tine core aeration treated plots received spring core aeration with sufficient topdressing to fill the holes (Table 2). The surface organic matter accumulation was the least in this treatment, illustrating the importance of hollow-tine core aeration, which allows for more sand to be incorporated into the surface organic matter zone than by topdressing alone. All treatments resulted in organic matter levels greater than the < 4.5% level desired.

IMPLICATIONS FROM THIS STUDY

The immediate increase in SHC following cultivation treatment demonstrates that the surface conditions do control SHC on high-sand greens and that creation of temporary macropores across this zone results in SHC that are substantially higher. One question that often arises is whether the field SHC will be the same as the laboratory SHC for the rootzone mix without a turf sod on the surface. The answer to this question is yes and no, depending on the following circumstances.

- If field SHC is taken at several weeks after cultivation and the holes have had time to seal, the SHC can be appreciably less than lab SHC.
- If field SHC is measured within the time period when the cultivation holes may still be partially open, the SHC rate may be intermediate compared to obtaining the SHC rate within a few days after cultivation. SHC measured within a few days after cultivation often is within the same general range as the laboratory SHC if the rootzone mix below the surface couple of inches has not been appreciably altered after construction.

Factors often observed to alter the SHC below the surface two inches include movement of salts that precipitate within this zone, movement of fine materials during grow-in into the subsurface, and a high organic matter layer that becomes buried. This may include thatch that develops during grow-in that has not had sufficient sand integrated into it and is buried with subsequent topdressing.

Some observations from the current study and other cultivation studies that the author has conducted over many years are:

- The holes made by HJR, ¼-inch solid quad tines, and the Aerway Slicer 100 greens cultivation device all initially enhance SHC, but by about three weeks their effectiveness starts to decline. The HJR is least affected, probably because a hole is cut out instead of created by pushing materials to the side.
- When hollow-tine core aeration has been conducted with holes filled by topdressing, the duration of improved SHC is usually 5-8 weeks for ½- to ⅝-inch diameter holes on high-sand greens.

The responses just noted would suggest that non-disruptive cultivation should be initiated within five to eight weeks after a hollow-tine cultivation operation and repeated on a three-week schedule to maintain high SHC conditions during the summer months.

Table 4
Summary of treatment effects on bentgrass putting green visual quality and shoot density.

Treatment and Contrast	Visual Quality[a] <	Visual Quality[a] >	Shoot Density[a] <	Shoot Density[a] >
	%			
Control vs.	—	—	—	—
CA	29	0	29	0
HJL	0	19	0	38
HJR	0	14	0	24
HJR + Sand	0	0	0	0
HJR + Greenschoice	10	0	0	10
HJR + WA	0	14	0	29
HJR + C	0	14	0	14
HJR + Sand + WA	5	19	0	24
HJR + Sand + WA + C	0	0	0	10
LP + Greenschoice I	48	0	33	0

[a]Based on percent of ratings (18) when the treatment was significantly less than (<) or greater than (>) the control

An excellent article by O'Brien and Hartwiger (*USGA Green Section Record*, 2003, 41(2):1-7) reports options for controlling the organic matter zone. One question that arises in their article, as well as our study, is, "What is an acceptable level of organic matter in the surface two-inch zone?" The author's views on this question are summarized as follows:

- Regardless of climate zone, greater than 4% organic matter content in the surface two-inch zone becomes a red flag value that indicates the probability of developing low O_2, excessive surface water retention, and reduced SHC. As organic matter content increases above this value, the greater the potential for these problems.
- In the USGA green construction method, organic matter mixed throughout the rootzone mix is capped at about 3% (by weight) since above this level it is difficult to achieve a mix that allows sand to be the dominant medium and maintain a balance between moisture retention versus aeration porosity. If the USGA method requires organic matter levels to be less than 3% for the sake of avoiding problems, then it follows that organic matter should not greatly exceed this level after establishment. Who recommends 4-10% by weight of organic matter within high-sand green mixes?
- Within the southern zone of bentgrass adaptation, the 4% organic matter level is especially critical because the opportunities are greater for low soil O_2 to occur in conjunction with hot, humid, wet weather. However, such hot, humid, wet periods also can occur during certain years in many cooler regions.
- Another reason that organic matter content somewhat greater than 4% seems to occur in some situations (or even at times within a year) at a location without evident problems may be that much of the organic matter is present as live roots. Live roots have a structure that allows better air exchange and water movement compared to when many of the roots die and the organic matter becomes more of a massive, spongy nature with macropores less defined.
- Maintaining sand as the primary surface matrix rather than organic matter (remembering that 1% organic matter by weight equals about 5% organic matter by volume) is also important to maintain a firm putting surface as well as one that will support greens mowers without scalping.

It is informative to remember that since the very early days of USGA greens and high-sand greens that preceded the formal USGA recommendations, early agronomists recommended twice annual core aeration plus heavy topdressing (15-20 cu. ft. of sand per 1,000 sq. ft. per coring operation). Why would this be the recommended practice except to dilute the ongoing problem of organic matter accumulation in the surface?

History often has a story to tell us today.

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