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University of Georgia researchers are investigating how various aeration methods can limit organic matter build-up in newly constructed putting greens (as shown above). This information sheds new light on the effectiveness of conventional aeration methods.

Volume 2, Number 17
September 1, 2003

PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 225 projects at a cost of $21 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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USGA Turfgrass and Environmental Research Committee

Surface Organic Matter in Bentgrass Greens

Robert N. Carrow

SUMMARY

Organic matter build-up in the surface of newly constructed putting greens is a serious issue affecting the long-term performance of the putting surface. Researchers at the University of Georgia investigated several aerification methods to limit this phenomon. Among their findings include:

- The immediate increase in saturated hydraulic conductive (SHC) following cultivation treatment demonstrates that the surface conditions do control SHC on high content sand greens and that creation of temporary macropores across this zone results in SHC that is substantially higher.
- Most cultivation operations that create at least of ¼-inch diameter hole can dramatically and immediately enhance SHC. Saturated hydraulic conductivy then declines over time. These responses have impact on cultivation timing and frequency.
- When hollow-tine core aeration is conducted with holes filled by topdressing, the duration of improved SHC is usually 5-8 weeks for ½- to 5/8-inch diameter holes on high sand greens.
- Non-disruptive cultivation (i.e. high-pressure water injection) should be initiated within five to eight weeks after a hollow-tine cultivation operation and repeated on a three-week schedule to maintain high rootzone SHC and gas exchange during the summer months.

Why be concerned about organic matter ?

The USGA golf green specifications were developed to create a rootzone media that would exhibit good physical properties under continuous traffic; namely, water infiltration/percolation, oxygen status, and resist soil compaction. Golf greens, however, are dynamic systems where the "norm" is change over time, especially within the surface 2-inch (5.1-cm) zone (18,20). During the first couple years of grow-in the greatest changes often occur, but changes also may continue over years, and within a year in total organic matter content, thatch/mat status, turfgrass rooting, and even the nature of the organic matter. All of these may influence water infiltration/percolation and soil oxygen status.

In long-term field studies, Waddington et al. (20) noted that saturated hydraulic conductivity (SHC, the infiltration rate under saturated profile conditions) decreased to 30-40 % of the initial within two years after establishment on high sand mixes. A 10-fold decrease in infiltration within six months was reported by Murphy and Nelson (15) and 33-94 % reduction within one to two years by Neylan (18).

Concurrent with a reduction in SHC has been an increase in organic matter content within the surface 0-2 inches (1,2, 14, 15, 16, 20). An upper limit of 4.5 % (by weight) of organic matter in a sand media was suggested by Murphy et al. (16) because macropores important for rapid SHC were insufficient above this level. McCoy (14) recommended a maximum of 3.5 % organic matter (by weight) based on his work and a review of

Greens such as this secluded green with poor air circulation and drainage often exhibit excessive organic matter in the surface layer. Excessive organic matter induces high moisture and lower oxygen content in the rootzone inhibiting microbial decomposition of the organic matter.

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USGA Turfgrass and Environmental Research Online 2(17):1-10.
TGIF Record Number: 91781

other studies using sand and organic matter mixes with or without a turfgrass, since macroporosity starts to decline after 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 (13, 17, 18).

Summer bentgrass decline: pathological or physical ?

The USGA sponsored project, "Organic Matter Dynamics in The Surface Zone of a USGA Green: Practices to Alleviate the Problems" arose from observations in the late 1980s of summer bentgrass decline, or SBD, on creeping bentgrass greens in the southern zone of bentgrass adaptation. At that time, the prevalent theory for the underlying cause of SBD was root pythium. However, from field observations and a review of the literature cited in the previous section, I came to the hypothesis that many of the primary problems on high sand bentgrass/annual bluegrass greens, including summer bentgrass decline (SBD), were due to changes in soil physical conditions in the surface zone (top 2 inches) related to organic matter dynamics in this zone.

This rootzone profile is of a one-year-old putting green showing the organic matter build-up near the surface. One goal of putting green management is to limit this layer so that the rootzone maintains good physical and biological properties.

It appeared that either too much organic matter accumulation or rapid death of surface roots (i.e., the "nature" of the organic matter changed) could result in reduced water infiltration and higher water holding capacity, while decreasing O_2 content within the zone and O_2 diffusion across the zone. However, the author was unable to find any research in the early 1990s that actually determined O_2 status within the organic matter zone or below it.

Other secondary problems could arise if the primary problem was organic matter accumulation and/or change in nature of the surface organic matter, such as more disease activity, severe physiological O_2 stress and further root decline during summer, softer greens, etc. But achieving a reduction in occurrence of these secondary problems requires correction of the physical conditions within this zone.

As with any turfgrass management problem, it is essential to understand the enemy---what causes it to happen, what specific challenges arise from changes in surface organic matter conditions, what are the logical corrective/preventative practices to deal with it, and under what conditions will it occur again. Only with a good understanding of a problem can effective site-specific management options be developed and refined by golf course superintendents. Approaching the problems of surface organic matter as primarily physical (3, 4, 14, 16, 18) in nature that have adverse physiological consequences (3, 6, 10, 11) rather than due to pathogens (7, 8, 12) has a major influence on management approaches---and whether the underlying (primary problem) is the focus of management or whether management focus is on secondary problems.

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 situation is excessive accumulation of organic matter in the surface zone. As noted in the previous discussion of the literature, this problem has been substantiated. USGA specification greens normally contain 1 to 3 % (by weight) organic matter throughout the rootzone mix. Research has consistently demonstrated 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 >0.08 mm diameter between sand particles decreases due to plugging by organic matter (1, 14, 16, 18). Even with very good turfgrass management, the organic matter content in the surface two inches is often observed to be >3.0% by weight: 4.4 to 16.8% (4); 4.7 to 7.0% (G. Landry, bentgrass cultivar trial, 1999, personnel communcation); 4.5 to 20.3% (9).

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 more cool, humid, temperate climates. However, this is not always the case as illustrated in Table 1. In fact, in climates that strongly favor organic matter accumulation, this is likely the most prevalent problem on high sand greens or athletic fields.

<u>Factors Enhancing Organic Matter Accumulation</u>

- Prolonged cool temperatures on cool-season turfgrasses when temperatures are between 32 F and 55 F, where microbial activity declines and organic matter 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 five to seven months per year.

- Use of aggressive creeping bentgrass or bermudagrass cultivars that exhibit high rates of organic matter accumulation. Many of the newer greens-type cultivars 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 organic matter. These are often the secluded greens with many trees in the surrounds, little natural air drainage, and shade on the green surface for much of the day.

- Inadequate integration of sand to sustain a media where sand is the dominant matrix rather than organic matter. Sand must be applied not just by topdressing, but also in vertical channels by hollow-tine core aeration that remove plugs of organic mater and allows large quantities of sand to be added.

- Addition of organic matter to the surface as sod (even washed sod), compost, or organic matter-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 levels of nitrogen use, frequent irrigation, and high mowing height.

- Low earthworm activity.

Table 1. Factors enhancing organic matter build-up

Treatment[a]	**Description**	**Topdressing per 1000ft^2**[b]	
		Annual	June-Sept
		-----------ft^3-------------	
Control	No cultivation	10.7	2.5
CA	Hollow-Tine, Core-aeration; 5/8" dia. Time; March and Oct.	19.0	2.5
HJL	Hydro-Ject Lowered; 3" spacing; 1/8"dia. hole; June 1+ every 3 weeks	10.7	2.5
HJR	Hydro-Ject Raised; 3 ½" spacing; ¼" dia/ hole; June 1+ every 3 weeks	10.7	2.5
HJR + Sand	See HJR. Additional sand topdressing at 0.75ft^3 per 1000ft^2 5x per summer	14.5	6.3
HJR + Greenchoice	See HJR. Greenchoice as topdressing at 0.75ft^3 per 1000ft2 5x per summer	14.5	6.3
HJR + WA	See HJR. Wetting agent (Naid) at 3oz per 1000ft^2 5x per summer	10.7	2.5
HJR + C	See HJR. Cytokinin as CytoGro (0.005% ai) at 1 oz per 1000ft^2 4x per summer	10.7	2.5
HJR + Sand + WA	See previous treatments descriptions	14.5	6.3
HJR + Sand + WA + C	See previous treatments descriptions	14.5	6.3
LP + Greenchoice I.	LandPride dry injection of 0.75ft^3 Greenchoice per 1000ft^2, 5x per summer	14.5	2.3

[a] CA = Core aeration; HJL = Hydro-Ject run in lowered position; HJR = Hydro-Ject run in raised position; Greenschoice = fired calcined clay; WA = wetting agent; C = cytokinin.

[b] All plots received 10.7ft^3 sand topdressing per year with 2.5 ft^3 per 1000 ft^2 in the summer at 0.5 ft^3 per 1000 ft^2 every three weeks.

Table 2. Treatment summary. Except for the core aeration 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.

A second situation suggested to cause problems is 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. The author hypothesized that this sequence of events was the primary reason for SBD in hot, humid climates or weather conditions. The hypothesis was based on field observations of SBD and the symptoms before, during, and after the injury. This situation is most likely to occur on a cool-season grass during hot, humid weather that induces rapid root death; therefore, 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 breakdown the fresh organic matter to prevent excessive sealing. Under unusually hot, humid weather for one to two weeks or for a prolonged period, 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) by altering the nature of the organic matter. The remaining live, but O_2 stressed roots, cannot obtain enough water uptake for transpirational cooling because of the low O_2.

When rootzone O_2 is low, root cells lose their ability to take up water. This is the same situation that occurs for wet wilt, but without standing water. 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. The more the organic matter content is 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.

However, even relatively low organic matter contents of 3 to 5% seem to be sufficient to enhance SBD as the gel-like material from recently killed roots retains considerable water, and these dead roots tissues are very effective in sealing the surface pores. This physical stress basis as the primary cause of SBD rather than a pathological one is now considered by many to be the number one cause of summer bentgrass decline

(SBD) under hot, humid weather conditions (3). 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 inability of remaining roots to take up sufficient moisture for transpirational cooling.

In the late 1990s, Huang et al (10, 11) 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 rated (ODR) measurements in a study funded by The Toro Company from 1992 to1995 within the surface zone and found numerous periods when ODR was less than 20 to 40 mg 0_2 cm^{-2} min^{-1}, which is considered sufficiently low to limit rooting of grasses. In the very hot, humid summer of 1995, almost all readings were well below this limit.

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 1996-1998 at Griffin, GA on an experimental golf green with the rootzone mix meeting USGA recommendations. Treatments are summarized in Table 2 and consisted of various non-intrusive cultivation approaches that would not cause surface disruption in the summer, topdressing, wetting agent, sand substitute, and cytokinin combinations.

Saturated Hydraulic Conductivity

One of the most important characteristics for bentgrass golf greens in the summer time is the ability for excess moisture to infiltrate into the surface and percolate through the rootzone. If

Treatment	**Average SHC (1996-1998)** 1-7DAC	17-26DAC	**Lowest SHC**	**Readings >0.20 micrograms 0_2 cm^{-2} min^{-1}[b]** 1996	1997	1998	**Organic Matter at 30 months** (0-3cm)
	----------------inch hr^{-1}--------------------			------------%------------			--% (wt.)--
Control	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 + Greenchoice	20.2**	10.8	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 + Greenchoice I	7.9	5.9	3.2	---	---	---	9.0
LSD $_{(0.05)}$	9.7	6.9	---				2.2
F-test	**	**	---				0.38

[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 micrograms 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 seven time periods during summers of 1996-1998.

Table 3. Treatment effect on summer saturated hydraulic conductivity (SHC)[c], oxygen diffusion at 1.2-inch depth, and organic matter content in the 0 to 1.2-inch zone at 30 months after treatment initiation.

Treatment and Contrast[a]	**Visual Quality**[a]		**Shoot Density**[a]	
	<	>	<	>
	%			
Control versus:				
CA	29	0	29	0
HJL	0	19	0	38
HJR	0	14	0	24
HJR + Sand	0	0	0	0
HJR + Greenchoice	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 + Greenchoice I	48	0	33	0

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

Table 4. Summary of treatment effects on turfgrass visual quality and shoot density

saturated flow (called saturated hydraulic conductivity, SHC) does not occur in a rapid fashion, a saturated surface can occur. In Table 3, SHC values at 1-7 and 17-26 days after cultivation treatment are presented as the average SHC values of seven summer-time measurements during 1996-1998. Within 1-7 days after cultivation, SHC increased at least 3.4-fold to more than 20.2 inches per hour for all HJR treatments (HJR = HydroJect operated in the up position to provide a hole of approximately ¼-inch diameter at treatment) compared to 5.9 inches per hour in the non-cultivated control (Table 3).

The plots that were core-aerated in March exhibited no difference in SHC compared to the control. This illustrates that the effectiveness of spring hollow-tine cultivation on SHC declines over time as holes refill with root mass; and would suggest that cultivation methods that are normally non-disruptive of the surface, such as HydroJect or solid quad-tines, would 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 a 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 aerificaiton 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 0_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 (20), 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 that keep 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.

Only the CA 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 above 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. Golf course superintendents may use infiltrometers to determine SHC on their greens in the field. 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:

- If field SHC is taken at several weeks after a cultivation event 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, 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 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 or a layer, and a high organic matter layer that

This rootzone profile demonstrates a putting green that has developed a surface organic matter problem that has limited gas exchange which has led to the development of black layer beneath the organic matter layer.

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.

A suggested protocol to determine the SHC with and without the influence of surface conditions is to conduct the field SHC determination using a field infiltrometer and record the value. Then, while the infiltrometer is still in place, push a ¼ inch diameter solid-tine with a sharpened end to a depth of three inches a couple times into the turf surface within the infiltrometer; then repeat the infiltrometer reading. Do not go deeper than three inches so that the zone that controls SHC can be identified. If the reading is similar to the initial reading but low for both of the above determinations, push the rod in the same holes to the bottom of the rootzone mix (i.e. about 10-12 inches) and determine SHC. If readings dramatically increase, this would indicate that conditions from 3 to 12 inches control SHC rather than surface conditions. But if SHC greatly increases after creating macropores just within the surface three-inches, then the controlling zone is at the surface.

Another implication of this study is that it demonstrated that when surface conditions control SHC, most cultivation operations that create at least of ¼-inch diameter hole can dramatically and immediately enhance SHC. But, SHC will then decline over time. These responses have impact on cultivation timing and frequency. 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. This is the basis for suggesting an approximate three-week schedule of non-disruptive cultivation treatments. Personal observation has been that sites receiving appreciable sodium and/or very heavy traffic will exhibit hole closure at a faster rate.
- 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 5/8-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.

In another study (20) where the focus was not on the summer but cooler months, we found the lowest SHC and O_2 values came in the December to February period. Since cooler weather favors bentgrass root growth and regrowth from the summer, it appeared that the massive root growth in the surface two inches essentially plugs the macropores with live roots to the point that water and air movement are greatly reduced. The implication is that rooting could be limited during this period and until core aeration occurs. Thus, a non-disruptive cultivation application in late winter/early spring before the temperatures are favorable for hollow-tine core aeration and/or a application at 5-8 weeks after fall coring could assist in maintaining macropores for water and air movement in cool periods. The very low soil O_2 in the winter to early spring may be a primary reason for the long-term observation that rooting declines in high sand greens after the initial one to two years.

Low O_2 within the surface two inches due to high moisture retention by the organic matter means that the lower crown, lower portion of stolons, and roots in the layer are exposed to low O_2, especially in wet or humid years where drying of the surface is slow. Perhaps this is the primary problem that weakens the plant and triggers diseases that are associated with root-rot injuries. If so, than primary preventative control measures would be to dilute the organic matter layer, remove some of the organic matter, maintain macropores, and improve air drainage to dry the zone.

An excellent article by O"Brien and Hartwiger (19) reports on 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 view on this question is based on experiences gained from several cultivation studies, visiting golf courses in a number of locations in the world, and from the literature previously cited. These views 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. The more organic matter increases above this value the greater the potential for these problems. This level is a guideline to assess the potential for certain problems and to indicate when more aggressive management is needed. It is not a specific level that means turf death is imminent.
- 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 media and maintain a balance between moisture retention versus aeration porosity. If the soil physical reasons are true at establishment to maintain < 3.0 %, they continue to be valid 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 for low soil O_2 to occur in conjunction with hot, humid, wet weather are greater. However, such hot, humid, wet periods can also occur during certain years in many cooler regions.
- I have heard turf managers indicate that the organic matter content in their greens are higher than 4 % and they do not see any problems. As noted, in cooler climates, it is more likely that organic matter will accumulate to greater than 4 % unless a vigorous control program is followed. It is within these climates that SBD is most rare. However, the onset of low O_2, waterlogged, soggy greens becomes more dominant over time in these same climates, as well as the pathogens that such conditions may enhance.
- Another reason that somewhat higher organic matter content 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 for 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 agronomist recommended twice annual core aeration plus heavy topdressing (15-20 ft^3 of sand per 1000 ft^2 per coring operation). Why would this be the recommended practice except to dilute the on-going problem of organic matter accumulation in the surface?

History often has a story to tell us today.

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