The organic matter journey......

- USGA/EIFG Greens Study (9 years).
- People a lot brighter than me
  - "Talking Turf" GCSEAA conversation.
  - Paul Rieke, USGA visit
  - Conversation with Paul Vermeulen, Director, Competitions
    Agronomy at PGA TOUR, former USGA Agronomist.
- Great funding support from USGA (initially), NE-GCSA, GCSA of SD, Peaks and Prairies GCSA, industry and a slew of GC supers (3 years).
- Road Show.

What do we want to discuss today?

ASA Monograph (3RD Edition)

Chapter 12
Characterization, Development, and Management of Organic Matter in Turfgrass Systems

R.E. Gaussoin, Dep. of Agronomy and Horticulture, Univ. of Nebraska
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C.A. Dockrell, Teagasc College of Amenity Horticulture, Dublin, Ireland
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Organic matter development: Are We the Problem?

Or:
is organic matter % the green speed of the new millennium?

How does organic matter accumulate?

- Organic matter; defined
  - dead or near dead plant residue which accumulates in the grass ecosystem

How much OM is produced annually?

- Roots = 3500 lbs/acre
- Leaves = 2000 lbs/acre
- Other = 2500 lbs/acre
- TOTAL = 8000 lbs/acre 8967 kg/ha

Fairway height blue/rye estimated annual production

Where does organic matter accumulate?

- Above ground
  - Thatch/Mat
  - clipping residue
    - relatively short term
    - "pseudo" thatch

- Below ground
  - root zone
  - rhizosphere

Importance of (P)OM in the rhizosphere

- deposition of particulate OM
- microbial niches
- nutrient uptake
- pathogen competition
Factors influencing rootzone (P)OM accumulation

- Mowing
  - increase height = increase rooting
- Irrigation
  - root growth restricted in waterlogged soils
- Cultivation
  - increase or decrease
- Fertility
  - increase or decrease
- Stress
seasonal root growth

With today's genetics & management, is this still true?

Thatch

A loose, intermingled, organic, layer of dead and living shoots, stems, and roots that develops between the zone of green vegetation and the soil

Greens Height Bentgrass Thatch Thickness (mm)

Fairway Height Bentgrass Thatch Thickness (mm)
Benefits of “Moderate” Thatch
- Improved resilience and cushion
- Improved wear tolerance
- Insulate soil/crown to temperature extremes

Problems with excessive thatch
- LDS

Problems with excessive thatch
- Footprinting

Problems with excessive thatch
- Scalping

Doug Soldat’s work at UW
- Next 3 slides
- Wetting agents, year differences and low and high OM greens

2009 - Wet Year - Low Organic Matter Putting Green

2009 - Wet Year - Low Organic Matter Putting Green

2009 - Wet Year - Low Organic Matter Putting Green
2010 – Wet Year – Low Organic Matter Putting Green

Problems with excessive thatch
- Overseeding Failure

2010 – Wet Year – High Organic Matter Putting Green

Mat
- Thatch that has been intermixed with mineral (soil) matter

Problems with excessive thatch
- Reduced Stress Tolerance
Because of inherent ambiguity in terminology and sampling techniques, the term “thatch-mat” has appeared frequently since the late 2000’s (McCarty et al., 2007; Barton et al., 2009; Fu et al., 2009).

and yet one more definition............

SOM- Soil Organic Matter

Physical And Chemical Characteristics Of Aging Golf Greens

Roch Gaussoin, PhD
Jason Lewis
Ty McClellan
Chas Schmid
Bob Shearman, PhD
Treatments

- rootzone Mix
  - 80:20 (sand/peat)
  - 80:15:5 (sand/peat/soil)
- Grow-In Procedure
  - Accelerated
  - Controlled

Materials and Methods

9 yr old green  10 yr old green  12 yr old green  13 yr old green

As of 2009

Project Schedule (Phase I)


Greens construction (one set per year)

Seeding

Data collection on soil physical, chemical, and microbial characteristics influenced by rootzone materials and grow-in procedures.

Project Schedule (Phase II)

2002  2003  2004  2005

Data collection on soil physical and chemical characteristics as influenced by age, rootzone materials and grow-in procedures.
Formation of Mat

- Formation of mat layer increased approximately 0.65 cm annually (following establishment year).
- No visible layering, only a transition is evident between mat and original rootzone.
- Topdressing program
  - Light, Frequent
    - every 10-14 days (depending on growth) and combined with verticutting
  - Heavy, Infrequent
    - 2x annually (spring/fall) and combined with core aerification

Materials and Methods

- 2004 rootzone samples taken below mat layer from each soil treatment and sent to Hummel labs for Quality Control Test (24 total samples) & tested against original quality control test (z-score).
- Other analysis also completed

Comparison of preconstruction $K_{sat}$ values to $K_{sat}$ values taken 10/04.
Change in Rootzone Particle Size Distribution

- All rootzones tested in 2004 showed increased proportion of fine sand (0.15 – 0.25 mm) with decreased proportion of gravel (> 2.0 mm) and very coarse sand (2.0 – 1.0 mm).

- 5 of 8 rootzones were significant (z-score) for increased fine sand content.

Root Zone: Mat vs. Original

- pH:
  - Mat < Original for all USGA and California Greens.

- CEC, OM, and all Nutrients tested:
  - Mat > Original for all USGA and California Greens.

Conclusions

- The $K_{sat}$ decrease over time may be due to organic matter accumulation above and in the original rootzone and/or the increased fine sand content originating from topdressing sand.

Want to know more?

Why is high OM considered to be “bad”?

- Loss of infiltration
- Decreased aeration
- Traps “toxic” gases
- Are these concerns real or imagined?
- Why the confusion?
Infiltration

Green Age (years)

Analysis Methods

- Many exist, but the most relevant is “combustion” or “loss on ignition”
- The sample represents both dead and living organic matter
  - Food for thought…….

Organic Matter Recommendations

- Range
  - 1.5 – 2.5% between 0.25 to 1-inches
  - 8 – 15%
- Recommendations for almost every point in between

Organic Matter Sampling Protocols

1. thatch + mat layer
2. between 0.5” and 1.5”
3. between 0 and 35 cm
4. between 0 and 25 cm
There is no “magic” number

“the squeeze test” (courtesy of Dave Oatis-USGA Director NE-US)

OM Testing

- Know how your sample was taken and compare notes with others that use the same protocol
- Take annual tests to determine long-term trend
  - Same time of year
  - Same location and green
- Correlate your test results with turf quality and performance during stressful environmental conditions to determine need for changes in management program
- Threshold/critical levels likely vary across the United States and from course to course

Seasonal Variation (One Location)

<table>
<thead>
<tr>
<th>Date Sampled</th>
<th>LSD 0.175</th>
</tr>
</thead>
<tbody>
<tr>
<td>JUNE</td>
<td>a</td>
</tr>
<tr>
<td>SEPT</td>
<td>ab</td>
</tr>
<tr>
<td>DEC</td>
<td>b</td>
</tr>
</tbody>
</table>

How do you get rid of OM?

??????
**How do you get rid of OM?**

- **Decomposition (microbial)**
  - Increase surface area and aeration
  - Inoculation (???)

- **Removal**
  - Power raking, verticutting, dethatching, core aerification

- **Dilution**
  - Topdressing

**Organic Matter Degradation Study**

**Locations**

- **KY Bluegrass Tee Box**
  - Native Soil
- **Bentgrass Green**
  - California Green
- **KY Bluegrass Sports Turf**
  - Sand based
  - 2.5” Mowing

**Plot Set-Up**

14 Treatments, 3 Reps

**Treatments**

- **Aerator (Granular)**
- **Aerator (Liquid)**
- **EXP072**
- **EXP074**
- **EXP076**
- **Carbo-Plex**
- **Bio-Blend**
- **Carbo-Plex + Bio-Blend**
- **Bio-Groundskeeper (Granular)**
- **Bio-Groundskeeper (Liquid)**
- **Thatch X**
- **EXP070M**
- **EcoChem Lawn Thatch Reducer**
- **Untreated Control**

**Each Plot Core Aerified before Application of Products**
Data Collection

• Infiltration
• Penotrometer
• Thatch
• Organic Matter
  – Thatch, 0-3”, 3-6”

Analysis Summary

<table>
<thead>
<tr>
<th>Source</th>
<th>Thatch (mm)</th>
<th>Clegg (g)</th>
<th>Infiltrat (in/hr)</th>
<th>Thatch (OM %)</th>
<th>0-3” (OM %)</th>
<th>3-6” (OM %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Trtmnt</td>
<td>NS</td>
<td>NS</td>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Summary

• No product increased degradation of OM

How effective is removal?

• Surface disruptive, short and long term
• Core aeration is the most widespread practice recommended for OM management

0-3” OM %

Sports Turf  Green  Fairway
### Tine Size and Surface Area Chart

<table>
<thead>
<tr>
<th>Tine Size (in.)</th>
<th>Spacing (in.)</th>
<th>Holes/ft²</th>
<th>Surface Area of One Tine</th>
<th>Percent Surface Area Affected</th>
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</thead>
<tbody>
<tr>
<td>1/4</td>
<td>1.25²</td>
<td>100</td>
<td>0.049</td>
<td>3.4%</td>
</tr>
<tr>
<td>1/4</td>
<td>2.5²</td>
<td>25</td>
<td>0.049</td>
<td>0.9%</td>
</tr>
<tr>
<td>1/2</td>
<td>1.25²</td>
<td>100</td>
<td>0.196</td>
<td>13.6%</td>
</tr>
<tr>
<td>1/2</td>
<td>2.5²</td>
<td>25</td>
<td>0.196</td>
<td>3.4%</td>
</tr>
<tr>
<td>5/8</td>
<td>2.5²</td>
<td>25</td>
<td>3.07</td>
<td>5.3%</td>
</tr>
</tbody>
</table>

### Organic Matter Management

- Funded by:
  - USGA (2006)
  - Nebraska Golf Course Superintendents Assoc. (2007-2009)
  - Golf Course Superintendents Assoc. of South Dakota (2006-2009)
  - Peaks & Prairies GCSA (2007-2009)

### Project Objective

- National Survey
- Determine cause and effect relationship among maintenance practices and their interactions relative to surface OM accumulation
**Sampling Procedures**

*Years 1, 2, & 3*
- At least 3 different greens per golf course sampled
- Soil samples taken from 3 different area per green
- Samples are evaluated for OM levels using LOI
- GPS location

*Management & Site survey*

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**2006/07/08 Samples**

- **Sixteen states**

- **117 golf courses sampled**
  - More than 1600 samples

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**Sampling Methods**

- Samples from at least 3 greens per course
  - (1) Problematic, (1) Non-problematic plus rebuilt or varied age/management
- 3 samples from each green
- Samples taken with ¾ inch soil probe

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**Verdure Layer**

Verdure Layer Removed

Sample Layer

3 inches

---

**Problematic vs Non-problematic**

<table>
<thead>
<tr>
<th></th>
<th>Good</th>
<th>Average</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>3.0</td>
<td>3.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>
Superintendent predicted vs actual

Organic Matter in USGA Specification Rootzones

Green Age

Mat Development with Age

Is the age effect misleading?
- Sampling issue:
  - Mat depth increases as green ages resulting in more OM in the same volume soil.

State Differences
(highly correlated with age)
Survey Summary

- None of the variables collected, by themselves, or in combination with others, predicted OM.
- Courses using >18 cubic ft/M of topdressing with or without “venting” consistently had the lowest OM.
- Of the known cultivars, no differences in OM were evident.

*1 ft³ = 100 lbs of dry sand; yd³ = 2700 lbs

Onsite NTEP Cultivar Evaluation

1. L-93
2. Putter
3. Cato
4. Crenshaw
5. LCB-103
6. Penncross
7. Backspin
8. Trueline
9. Providence
10. SR 1020
11. SR 1119
12. Viper
13. Century
14. Imperial
15. Penn A-1
16. Penn A-4
17. Penn G-6
18. Penn G-1

Onsite NTEP Bentgrass Evaluation

“New ultra-dense varieties of bentgrass and bermudagrass are especially susceptible to excessive organic matter accumulation due to high shoot density and the ability to grow a deep, dense root system in sand-based rootzone material. Working topdressing into a tight canopy of turf is a challenge, and much of the sand can be removed with the clippings.”

Vavrek, 2006

Topdressing and the new bents

Easy or hard???
Pulling cores or poking holes?

- In 2005, 45 of 141 courses surveyed* planned no core removal
  - Many had not pulled cores for 2-20 years
- 75 planned to pull cores
  - 35 of the 75 had no agronomic reason to pull a core (based on USGA Agronomist evaluation) while 40 “needed” to pull cores
- With current and evolving cultivation/topdressing/rootzone technologies is pulling a core always necessary?
- Finally, is core cultivation an effective way to manage OM?

* Mid-continent region USGA

Let’s take a quick look at that…

Concrete/PVC placeholders

Template with 0.5” diameter cores at 2.5” spacing

Cores removed to 5” depth; cores filled with sand topdressing

New bents = denser and more upright
Modified soil probe simulates 0.5" diameter hollow-tine core aeration

Stabilizer block to ensure vertical probe entry

Bolts insert into placeholders to ensure exact location for resampling

Organic Matter Management Study

Objectives
1. Determine if conventional hollow tine is more effective than solid tine aerification at managing organic matter accumulation

Study initiated 22 June 2005; concluded 11 Nov. 2005

2 USGA Putting Greens
– Constructed in 1997 and 2000

Sample every 2 weeks for 20 weeks

2 depths of interest
– 3 & 6"

Organic Matter Management Study

Objectives
1. Determine if conventional hollow tine is more effective than solid tine aerification at managing organic matter accumulation
2. Determine if venting (less invasive cultivation) methods are effective at managing OM accumulation

Time after core creation (weeks)

<table>
<thead>
<tr>
<th>Putting Green</th>
<th>Depth</th>
<th>Organic Matter Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 yr</td>
<td>3&quot;</td>
<td>79 73 70 71 69 66 67 66</td>
</tr>
<tr>
<td></td>
<td>6&quot;</td>
<td>71 64 60 63 59 56 57 56</td>
</tr>
<tr>
<td>5 yr</td>
<td>3&quot;</td>
<td>73 66 61 62 62 61 59</td>
</tr>
<tr>
<td></td>
<td>6&quot;</td>
<td>66 56 51 51 52 52 51 49</td>
</tr>
</tbody>
</table>

Treatments

<table>
<thead>
<tr>
<th>Tine Treatment</th>
<th>Venting Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2X Hollow tine</td>
<td>PlanetAir</td>
</tr>
<tr>
<td>2x Solid tine</td>
<td>Hydroject</td>
</tr>
<tr>
<td></td>
<td>Bayonet tine</td>
</tr>
<tr>
<td></td>
<td>Needle tine</td>
</tr>
</tbody>
</table>

15 Trts per Rep
6 Reps per year
2 different years
= A whole lot of fun for one graduate student or 180 trts
All treatments received the same topdressing quantity (22 ft³/M) but different frequency.

Regional Survey

- Annual topdressing rate for 10 well maintained courses in each region
  - Stable maintenance program during past 5 growing seasons
  - Same general turf conditions
- Surveys are not research!
  - Fertility
  - Traffic
  - Green construction
  - Etc.

Survey Anticipated Results

- Cool-season - gradual increase in annual topdressing rate from north to south and east to west corresponding to length of growing season
- Warm-season - changes in annual topdressing rate corresponding to overseeding practices, length of growing season, annual rainfall
- Surveys are not research!
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  - Etc.

Survey Expectations

- Cool-season - gradual increase in annual topdressing rate from north to south and east to west corresponding to length of growing season
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Central United States – Cool-season

<table>
<thead>
<tr>
<th>Region</th>
<th>Mean (ft³/1000 ft²/yr)</th>
<th>Range (ft³/1000 ft²/yr)</th>
<th>Standard Deviation</th>
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<tbody>
<tr>
<td>North-Central, Elm Grove, WI</td>
<td>20.7</td>
<td>8.4 – 34.5</td>
<td>8.2</td>
</tr>
<tr>
<td>Mid-Continent, White Heath, IL</td>
<td>20.7</td>
<td>15.8 – 30.6</td>
<td>4.5</td>
</tr>
<tr>
<td>North-Central, Covington, KY</td>
<td>18.5</td>
<td>8.3 – 25.4</td>
<td>7.6</td>
</tr>
<tr>
<td>Mid-Continent, Carrollton, TX</td>
<td>12.3</td>
<td>0 – 30</td>
<td>0</td>
</tr>
<tr>
<td>Region</td>
<td>Location</td>
<td>Topdressing (ft³/1,000 ft²/yr)</td>
<td>Mean</td>
</tr>
<tr>
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<tr>
<td><strong>Central United States – Cool-season</strong></td>
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<tr>
<td>North-Central, Elm Grove, WI</td>
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<tr>
<td><strong>Southwest, Santa Ana, CA</strong></td>
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<td>38.3 – 85.5</td>
<td>53.7</td>
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<tr>
<td>Florida, Rotonda West, FL</td>
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<td>90.2 – 147.5</td>
<td>125.4</td>
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<td><strong>Eastern United States – Cool-season</strong></td>
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<tr>
<td>Northeast, Palmer, MA &amp; Easton, PA</td>
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<td>31.9</td>
<td>31.9</td>
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<td>14.5 – 51.1</td>
<td>33.1</td>
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<tr>
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<td>0</td>
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<td>125.4</td>
</tr>
</tbody>
</table>

Empirical Rule

68% of measurements are within plus or minus one standard deviation (s) of the mean (y).
### Regional Topdressing Survey Summary

<table>
<thead>
<tr>
<th>Region/Turf</th>
<th>Ave. Rate ft³/1,000 ft²/yr</th>
<th>Range ft³/1,000 ft²/yr</th>
<th>Standard Deviation</th>
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<tbody>
<tr>
<td>Florida – Upper / ultradwarf, overseeded</td>
<td>90.2</td>
<td>62.9 – 147.6</td>
<td>36.6</td>
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<tr>
<td>Florida – Lower / ultradwarf, non-overseeded</td>
<td>15.8</td>
<td>7.5 – 26.3</td>
<td>6.7</td>
</tr>
<tr>
<td>Mid-Atlantic – Eastern / cool-season</td>
<td>27.1</td>
<td>16.3 – 51.1</td>
<td>11.1</td>
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<tr>
<td>Mid-Continent – Lower / cool-season</td>
<td>38.1</td>
<td>22.3 – 85.5</td>
<td>17.3</td>
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<tr>
<td>Mid-Continent – Upper / cool-season</td>
<td>20.8</td>
<td>12.7 – 30.6</td>
<td>4.5</td>
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<td>North-Central – Upper / cool-season</td>
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<td>North-Central – Lower / cool-season</td>
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<td>5.0</td>
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<td>Northeast / cool-season</td>
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<td>10.7 – 25.4</td>
<td>4.2</td>
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<tr>
<td>Northwest - Coastal / cool-season</td>
<td>31.6</td>
<td>22.5 – 39.4</td>
<td>5.8</td>
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<td>Northwest - Inland Northern Rockies / cool-season</td>
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<td>15.7 – 43.1</td>
<td>11.5</td>
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<td>Southeast – Lower / ultradwarf, non-overseeded</td>
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<td>10.7 – 70.3</td>
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<tr>
<td>Southeast – Upper / cool-season</td>
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<td>12.4 – 34.5</td>
<td>3.2</td>
</tr>
<tr>
<td>Southwest - Coastal California / cool-season</td>
<td>38.0</td>
<td>10.7 – 70.3</td>
<td>23.8</td>
</tr>
<tr>
<td>Southwest - Desert / warm-season, overseeded</td>
<td>24.1</td>
<td>11.4 – 33.7</td>
<td>12.0</td>
</tr>
</tbody>
</table>

### Survey Review

- Regional differences were found, however not exactly as predicted.
- Some differences did not appear to have a basis in agronomy or climatic conditions.
- Survey results generated multiple questions regarding current industry practices and suggest need to conduct further research in the area of organic matter management.
- It is premature to conclude that the survey provides guidance for establishing sound topdressing recommendations due to the broad range of the data and the very high standard deviation found in most regions.

All treatments received the same topdressing quantity (22 ft³/M) but different frequency.

_Equilibrated to identify differences of the practices in question._

### Materials and Methods

- **Green Age:**
  - 12 years
  - 9 years
- **Data collected:**
  - OM% (pre-cultivation/monthly)
  - Single wall infiltration (monthly)
OM Data Analysis Year 1
• No differences between green age except for higher % in older green

OM Data Analysis Year 2
• No differences between green age except for higher % in older green

OM Data Analysis Year 1
• No differences between green age except for higher % in older green
• No differences among venting methods

OM Data Analysis Year 2
• No differences among venting methods

OM Data Analysis Year 1
• No differences between green age except for higher % in older green
• No differences among venting methods
• No interactions with solid/hollow/none

OM Data Analysis Year 2
• No differences between green age except for higher % in older green
• No differences among venting methods
OM Data Analysis Year 2

- No differences between green age except for higher % in older green
- No differences among venting methods
- No interactions with solid/hollow/none

What these data do/don’t suggest

- Topdressing is the most consistent and repeatable factor in OM management
- Cultivation was insignificant as a means to control OM
- However, a superintendent must use whatever tools they have at their disposal to insure sand is making it into the profile and not the mower buckets

OM Data Analysis Year 2

- No differences between green age except for higher % in older green
- No differences among venting methods
- No interactions with solid/hollow/none
- No differences among solid/hollow/none

Topdressing interval relative to Tine/LIC combinations (22 cu ft/M)*

- NONE/NONE
  - 5-10 days
- Solid & Hollow/NONE
  - 7-14 days
- Solid & Hollow/LIC
  - 14-18 days

*Observed and calculated based on displacement and surface area opened
GreenKeeper Survey
cool season only, mark all that apply
In the last 5-10 years, on our greens, our facility has:
- Increased topdressing quantity.
- Increased topdressing frequency.
- Increased hollow (equal or greater than 0.5”) tine aeration.
- Increased solid tine (equal or greater than 0.5") aeration.
- Decreased hollow (equal or greater than 0.5") tine aeration.
- Decreased solid tine (equal or greater than 0.5") aeration.
- Made minimal changes in topdressing application quantity/frequency.
- Made minimal changes in cultivation practices.
- Increased "venting" practices.

Survey Respondents via Greenkeeper

Topdressing
Old Tom Morris (1821–1908) is thought to have discovered the benefits of topdressing accidentally when he spilled a wheelbarrow of sand on a putting green and noted how the turf thrived shortly afterward (Hurdzan, 2004).

J.B. Beard is his classic textbook “Turfgrass Science & Culture, 1973 writes:
“The most important management practice for OM management is topdressing”

How much sand to use for topdressing?
- Generic recommendation is 20-40 ft² per 1000 sq. feet/yr (about 0.5 inch/M/yr)
  - UNL worked showed 20-24 ft² for OM management.
- Varies by amount of:
  - Traffic
  - Grass species or cultivar
  - Nitrogen Applied
  - Water Applied
  - Microclimate/Location

Key is matching your growth rate to optimize topdressing
Growth Potential

- #clipvol
- Pace Turf
- Micah Woods
- Bill Kreuser
- Others...

Layering

- Water retention is non-uniform
- Thatch/mat layers can store twice as much water than the root zone

**Wheel of Golf Course Soil Problems**

- Compaction
- Excessive organic matter and thatch accumulation
- Layering

**Layering**

- Water retention is non-uniform
- Thatch/mat layers can store twice as much water than the root zone

- Not a function of drainage
- Rather it is the difference in pore size distribution among layers

**Avoid creating layers**

- 3 cu ft sand every 3 weeks
- 6 cu ft sand every 6 weeks
- 12 cu ft sand spring and fall
“the solution to pollution is dilution”

Soil Macropores

Compacted

Continuity of Soil Pores
Pulling a core makes perfect sense when layering is excessive (depth & number of layers).

How do you get rid of OM?

- Decomposition (microbial)
  - Increase surface area and aeration
  - Inoculation
- Removal
  - Power raking, dethatching, core aerification
- Dilution
  - Topdressing

Clarification/over-simplification regarding OM Management on sand based rootzones

- One size does not fit all
- The optimal % OM has not been scientifically/universally determined and may be mythical
- Cultivation is critical to increase efficiency in sand incorporation
- Solid are not different than coring tines
- The benefits of topdressing continue to be identified.
What is the “best” way to get sand into the profile?

Organic Matter Update

• "the solution to pollution is dilution"
• Next Steps
  • Topdressing impacts on structure and fluid dynamics
Acknowledgements

- USGA
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