Dr. Marty Petrovic
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Cornell University
Principles of Water Movement and Drainage

• Normal or matrix water flow
• Preferential flow

Principles of Water Movement and Drainage, Normal water flow

Preferential Flow-finger flow in sand
Principles of Water Movement and Drainage, Preferential Flow—Earthworm channels

Typical turfgrass symptoms of soil problems

• shallow but extensive root system
• little or no roots below 4 inches
• little or no top growth (immediately after a major use of the site)
• off-color, very chlorotic tissue
Typical turfgrass symptoms of soil problems

- wilts easily, low turf density with weeds
- poor response to fertilization and soil related pesticides
- poorly drained, prolonged wet soils, making the use difficult
- water easily runs off the turf surface or collects in low spots

Causes of soil problems

- soil compaction during construction (often very deep compaction)
  “big equipment” syndrome
  hire contractors with turf construction experience

Causes of soil problems

- soil compaction from normal use such as
  games, golfing and normal maintenance
  often resulting in surface soil compaction (0 - 4 inches deep)
Causes of soil problems

• soil compaction from excess use
  - not enough fields
  - too many golfers
  - need for sidewalks, paths, roads, etc.

Causes of soil problems

• Improper soil for the intended use of the site

• poor construction techniques:
  soils too wet
  used heavy equipment

Causes of soil problems

wet soils

• poorly drained sites or sites with no drainage outlet

• use during wet conditions
  rutting (soil displacement)
  more compaction with wet soils than dry soils, why?

• thatch and other layers that impede water flow (perched water table concept)
What are we trying to manage?

Physical Properties

- Water flow in and through soils (drainage)
- Soil strength (root growth)
- Aeration (root growth, microbial activity, chemical reactions)
- Temperature (indirectly with drainage)

How do you know you have poor quality soil???
Step Back and Take a Look
Site Factors

• Topography

• Orientation

• Indicator Plants
SOIL DIAGNOSTIC TOOLS

Check percolation rate

Analyzing Existing Vegetation

- Identify plant species

- Note any indications of plant stress

- Note presence of any noxious weeds
KEY RESOURCES for PLANT ID

Don't forget to determine chemical properties

Options for managing soil physical problems

Reduce and/or change traffic patterns
  • control traffic patterns:
    use paths, fences, berms, etc. to direct traffic
Options for managing soil physical problems
Reduce and/or change traffic patterns
• control traffic patterns: use signs

Options for managing soil physical problems
Reduce and/or change traffic patterns
• control traffic patterns: use signs

Options for managing soil physical problems
control traffic patterns: use signs
Options for managing soil physical problems

Control traffic patterns: use compaction reducing materials: grass pavers, plastic grids

Built it correctly in the first place!

• Select the correct soil for the intended use: the more use the more sand
• Care in not over compacting the soil during construction
• Determine an acceptable level of compaction and stay within this range by testing during construction

Options for managing soil physical problems: Cultivation

Things to consider when using cultivation to correct compaction:

• Depth of cultivation must be deeper than compaction zone- or it is not as effective
• Normal traffic compacts the surface 3-4 inches, mostly in the surface inch, except for sand over finer texture soil (why?)
Things to consider when using cultivation to correct compaction:

- soil moisture content: the drier the better...
  cultivation can be less effective in wet soils, but!!
- cultivation can compact the soil by causing a cultivation pan below the depth of cultivation
- but dry soils are hard to cultivate

What is a cultivation pan?

A small zone of highly compacted soil below the depth of cultivation.
What is a cultivation pan? 2 months later

Types of Cultivation

Hollow tine coring:
- shallow-3" to deep-12"
- typical aerifiers to deep tine aerifiers (Vertidrain)
- holes ¼” to ¾ “
- spacing 2” to 6”

Hollow tine coring: shallow coring
Hollow tine coring: deep coring

Water injection cultivation

Water injection cultivation
Cultivation can reduce the effects of compaction two ways:

- lowering the bulk density by removing soil or lifting the soil
- creating a hole at the soil surface which allows:
  - water movement into the soil
  - gas exchange between the soil and the above ground atmosphere

How often should you cultivate?

Remember cultivation is a stress on the turf so avoid stress periods!

- once before or after each intense use period (sport season, golf season, etc.)
- minimum: once or twice a year for areas with only one major use period
- maximum: 4 to 6 times per year
- less often with deep type cultivation unless a very aggressive root zone modification program is being followed
When should you cultivate?

• Before or just after a major intense use period
• Just before a major turfgrass root production period
  early spring
  early fall

When should you cultivate?

• What about weed issues?
  Crabgrass - no issue
  Annual bluegrass - early fall cultivation encourages more annual bluegrass

Improve Water Movement and Drainage
Improve Water Movement and Drainage: Normal water flow

Improve Water Movement and Drainage
surface drainage problems

Improve Water Movement and Drainage
Increase surface drainage
• Improve slope (>2 %, crowning)
Improve Water Movement and Drainage
Increase surface drainage-cultivation

Improve Water Movement and Drainage
Increase surface drainage: wetting agents in sand
Improve Water Movement and Drainage

Increase surface drainage: wetting agents in sand

Improve Water Movement and Drainage: Water repellent soil benefits from wetting agent

Improve Water Movement and Drainage

Increase drainage: Trench with drain pipe

Figure 4. A herringbone drainage design on an athletic field.
Improve Water Movement and Drainage

Increase drainage: Vertical trench

Figure 3. A vertical trench will rapidly remove surface water.

Improve Water Movement and Drainage

Increase drainage: sand grooving-injection

Figure 4. Soil profile of sand spray (Cambridge) zones.

Improve Water Movement and Drainage

• Amend root zones
Improve Soils by Modification

• Goals: improve one or more of the following soil characteristics-

Physical properties:
- infiltration and drainage
- compaction resistance
- stability to traffic
- aeration
- water holding capacity

Improve Soils by Modification

• Goals: improve one or more of the following soil characteristics-

Chemical properties:
- nutrient holding capacity (cation exchange capacity)
- nutrient source and pH

Improve Soils by Modification

Goals: improve one or more of the following soil characteristics-

Biological properties:
- general microbial activity
- disease suppression
- nutrient transformation and pesticide degradation
What to do first, analyze your site!

- Site analysis of soil properties includes checking:
  - drainage
  - rooting
  - footing
  - general condition of the area (shoot growth, appearance)
  - soil physical and chemical properties by testing

Selecting an amendment that best suits your needs

**organic amendments:**
  - improve water and nutrient holding capacity
    - improve microbial activity
    - reduce pesticide and nutrient leaching
    - provide nutrients
    - suppress diseases

Organic amendments: What to look for!

- organic matter content (if used on sand based areas) of at least 90%
- if compost, is it completely composted?
- level of salts and other contaminants
- physical consistency: can you spread it? too dusty, etc.
Selecting an amendment that best suits your needs

Inorganic amendments:
• physically dilute soil
• used to improve internal porosity
• not easily compressed
• Stable, not easily decomposted
• require large amounts to make a difference in some situations
• some improve nutrient and water retention

Some Organic Amendments
• peat
• yard wastes
• sewage sludge (bio-solids)
• industrial and pharmaceutical wastes
• agricultural manures
• municipal solid wastes (MSW)
• plant bi-products

Peat Moss
<table>
<thead>
<tr>
<th>Properties</th>
<th>Sphagnum</th>
<th>Reed-Sedge</th>
<th>Peat Humus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin</td>
<td>Canada bogs</td>
<td>&quot;</td>
<td>Peat Humus</td>
</tr>
<tr>
<td>Age</td>
<td>young</td>
<td>old</td>
<td>very well decomposed</td>
</tr>
<tr>
<td>Stability</td>
<td>long-term?</td>
<td>more</td>
<td>very</td>
</tr>
<tr>
<td>Water holding</td>
<td>10-14x</td>
<td>4-8x</td>
<td>3-5x</td>
</tr>
<tr>
<td>O.M. content</td>
<td>~95%</td>
<td>&gt;85%</td>
<td>92% or lower</td>
</tr>
<tr>
<td>pH</td>
<td>3.3 - 3.5</td>
<td>5.5 - 7.0</td>
<td>acidic</td>
</tr>
<tr>
<td>C:N ratio</td>
<td>high</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Density</td>
<td>low</td>
<td>dense/fine</td>
<td>dense/fine</td>
</tr>
<tr>
<td>Use</td>
<td>Sand-based</td>
<td>topdressing</td>
<td>topdressing</td>
</tr>
</tbody>
</table>
Yard Wastes
• grass, leaves, twigs, brush
• variable in quality
• breakdown in the root zone more quickly
• lower in nutrients
• contaminants
• soluble salt concentration is low

Bio-solids
• sewage sludge
• nutrient rich (especially N and P)
• pH typically 6.0 – 7.5
• treated to reduce pathogens
• may contain:
  heavy metals
  organic contaminants

Agricultural Manures
• chicken, dairy, turkey….
• fresh, raw > odor, weed seeds
• delay planting 2-4 weeks
• nitrogen subject to leaching
• aged is more stable
Food Wastes

- from food processors, restaurants, institutions
- high in popularity
- typically:
  - rich in nutrients
  - may have elevated salinity

Composts can be made from

- leaves and grass clippings - yard trimmings
- animal manures
- food wastes
- paper mill products
- bio-solids (sewage sludge)
- municipal solid waste - garbage

Organic Amendments

must be composted to:

- reduce volume
- improve the stability and physical condition of the materials
- reduce pathogens/weeds in the material
COMPOSTS for IMPROVING SOILS

_in sandy soils:_
- ↑ water holding ability
- provide some nutrients
- ↑ nutrient retention
- ↑ microbial activity

_in clay soils:_
- ↑ air and water permeability
- improve aggregation
- ↓ surface crusting
- provide some nutrients
- ↑ microbial activity

PROPERTIES OF A GOOD QUALITY COMPOST

they are not all the same

Compost Handling is Critical

Turning Curing Shipping

Time in Transit Site Placement Storage
APPEARANCE

- should resemble a dark topsoil
- be friable - loose, crumbly
- free of large stones, pieces of wood, trash
- appropriate size: 1/4” - 3/8”

pH

- pH can be 5.0 - 8.5
- nutrient deficiencies and toxicities can occur when soil pH is < 5.5 or > 8.5

METALS

- from municipal bio-solids (sewage sludges) often have heavy metal content (As, Cd, Cu, Pb, Mo, Ni, Mo, Zn)
- regulated to reduce the potential toxicity to humans, animals or plants
- state and federal agencies have established maximum allowable levels – in New York they are highly regulated
METALS
- some of these elements are required by plants
- reported on a dry weight basis
  ppm
  mg/kg

MOISTURE CONTENT
moisture content 40-50%
ideal for handling, surface application

wet composts (>60%):
  form clumps
  difficult to spread evenly
  hard to till in

dry composts (<20%)
  easy to handle
  may produce excessive dust
  hard to apply when windy

Bulk Density
Measured in g/cm³ and converted to lbs/yd³
- gives a good idea of porosity
- about 40-60% porosity

Most compost > 700-1200 lbs/yd³
Preferred > 800 – 1000 lbs/yd³
SOLUBLE SALTS

- excessive levels can cause injury to plants
  - ↓ water absorption
  - be toxic or both

- concentration where injury occurs depends:
  - type of salt
  - salt tolerance of plant
  - how compost will be applied

SOLUBLE SALTS

- measured in dS or mmhos/cm

- additions of amendments can contribute or dilute soluble salt concentrations

- manures tend to be higher in SS
- yard wastes and bio-solids tend to be lower

Maturity

assesses the level of biological activity in a moist, warm, well aerated compost pile

determined by:
  - measuring CO₂ and volatile ammonia
Maturity

immature compost - unstable
   critters consuming N and O
   generating heat + CO₂ + water vapor
   ammonia or volatile organic acids

mature compost - stable
   little N and O consumed
   little heat generated

Solvita Maturity Index

<table>
<thead>
<tr>
<th>Index</th>
<th>Approximate Stage of the Compost Process</th>
<th>Major Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Highly mature, well aged, for all uses</td>
<td>FINISHED Compost</td>
</tr>
<tr>
<td>7</td>
<td>Well matured, cured, ready for most uses</td>
<td>ACTIVE Compost</td>
</tr>
<tr>
<td>6</td>
<td>Compost finishing curing, ready for some uses</td>
<td>ACTIVE Compost</td>
</tr>
<tr>
<td>5</td>
<td>Curing can be started; limited uses</td>
<td>RAW Compost</td>
</tr>
<tr>
<td>4</td>
<td>Compost in moderately active stage</td>
<td>RAW Compost</td>
</tr>
<tr>
<td>3</td>
<td>Very active compost; not ready for most uses</td>
<td>RAW Compost</td>
</tr>
<tr>
<td>2</td>
<td>Very active, fresh compost</td>
<td>RAW Compost</td>
</tr>
<tr>
<td>1</td>
<td>Fresh, raw compost; extremely unstable</td>
<td>RAW Compost</td>
</tr>
</tbody>
</table>

ODOR

• “earthy aroma” - like in the woods or forest

• should not be offensive - strong ammonia or sulfur-like smell
ORGANIC MATTER CONTENT

• not all the material in composts is OM can vary 20-80%
• lab can determine OM content
• OM content may not tell you about the “quality” of the OM

Composting Method Influences Organic Matter Content of Composts

Generally High OM Levels (30-50%)

Low OM Levels (12-35%)

CARBON : NITROGEN RATIO

• when <10:1 critters may liberate ammonia from OM
• when >20:1 may indicate compost is not finished
• when >30:1 critters may immobilize N not available to plants
NUTRIENTS

- Composts have ↓ amount of nutrients
- Most N in organic form - slow release
- Small amount of quick release N
  only 10-20% of total N available 1st season
- Animal composts ↑ in nutrients than yard waste composts
- Need large amounts

Compost Comparison

<table>
<thead>
<tr>
<th></th>
<th>Poultry</th>
<th>Dairy</th>
<th>Yard Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Moisture</td>
<td>26.8</td>
<td>47.1</td>
<td>54.3</td>
</tr>
<tr>
<td>% OM</td>
<td>37.3</td>
<td>13.4</td>
<td>49.1</td>
</tr>
<tr>
<td>pH</td>
<td>8.8</td>
<td>8.4</td>
<td>7.6</td>
</tr>
<tr>
<td>% Total N</td>
<td>1.53</td>
<td>.7</td>
<td>.8</td>
</tr>
<tr>
<td>Amm N (mg/kg)</td>
<td>569</td>
<td>2.37</td>
<td>18.4</td>
</tr>
<tr>
<td>Soluble salts</td>
<td>8.04</td>
<td>1.73</td>
<td>2.42</td>
</tr>
</tbody>
</table>

WEED SEEDS

- If properly composted and stored should not contain many seeds
- The process will destroy nearly all viable seeds
GUIDELINES FOR CHOOSING

Choose a reputable and trusted supplier

Know:
- compost type
- composting process and length of composting
- how compost handled when finished

Obtain:
- a complete analysis from supplier

GUIDELINES FOR CHOOSING

Appearance and Odor

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>uniform</td>
</tr>
<tr>
<td>Color</td>
<td>brown to black</td>
</tr>
<tr>
<td>Size (surface applications)</td>
<td>1/4 to 3/8 inch</td>
</tr>
<tr>
<td>Size (incorporated)</td>
<td>1/4 to 1/2 inch</td>
</tr>
<tr>
<td>Odor</td>
<td>earthy</td>
</tr>
</tbody>
</table>
CHEMICAL PROPERTIES

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>0.4 – 3.0%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.2 - 1.5%</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.4 – 1.5%</td>
</tr>
<tr>
<td>pH</td>
<td>6.0 – 8.0</td>
</tr>
</tbody>
</table>

PROPERTIES

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C:N ratio</td>
<td>~ 15:1 – 30:1</td>
</tr>
<tr>
<td>Moisture content</td>
<td>30 – 60%</td>
</tr>
<tr>
<td>Organic matter</td>
<td>&gt;30%</td>
</tr>
<tr>
<td>Solvita Maturity Index</td>
<td>5-8</td>
</tr>
<tr>
<td>Soluble salts</td>
<td>EC &lt;4.0 dS</td>
</tr>
</tbody>
</table>

Some Other Considerations

- Compost Properties are Constantly Changing
  - The compost you received last year will not have the same properties as it did when you received it
  - Perform analyses frequently
  - The more mature and stable, the more slowly the material will change

- Storage and Handling can Dramatically Affect Compost Properties
When establishing turf...

for soil incorporation (into 4-6” of soil):

1” layer = 3.1 cubic yards
2” layer = 6.2 cubic yards

• want thorough mixing
• do not want layers to form at surface
• may need several passes with tiller

Selecting an amendment that best suits your needs

Inorganic amendments:

• physically dilute soil
• used to improve internal porosity
• not easily compressed
• Stable, not easily decomposted
• require large amounts to make a difference in some situations
• some improve nutrient and water retention

Inorganic amendments include:

• sand: quartz sand is preferred (chemically inert and physical stability)
• calcine clay: made by heating clay minerals to temperatures close to 700 degrees C and processing them to sand particle size
• calcine diatomite: made by calcinating diatomaceous earth (a fine siliceous deposit) and processed to sand particle size
Inorganic amendments include:

- zeolite: this mineral occurs naturally, large capacity to retain nutrients, processed to sand size particles
- expanded shale: a calcined shale
- gypsum: calcium sulfate

Selecting an amendment that best suits your needs

| Soil Amendments-Properties | Bulk Density | CEC
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>----------------------------</td>
<td>-------------</td>
</tr>
</tbody>
</table>
| Sand                       | 1.23-1.35    | < 1
| Caliche Clay               | 0.5-0.6     | < 1
| Caliche Dolomite           | 0.36        | 100-200 (10-20)
| Zeolite                    | 0.7         | 10-200 (10-200)
| Pestic                     | 0.1-0.3     | 125-150 (3-6)

* CEC in greeen mix
**Types of soil modification**

- **total modification**: at establishment amending a major portion of the root zone (6-12”)
- **partial modification**: change in the surface 1-4” of the root zone
- **topdressing**: is a long term process of changing the root zone. It is done often done in conjunction with cultivation to get more of the amendment deeper into the soil.

**Benefits of soil modification:**
- establishment
Benefits of soil modification: establishment
Benefits of soil modification: establishment

Soil amendments: How stable are they?

Amendments can break down due to weathering and crushing forces from traffic

Soil Amendments: How stable are they?

<table>
<thead>
<tr>
<th>Soil Amendments - Weathering Stability</th>
<th>Unchanged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bentonite Clay</td>
<td>98</td>
</tr>
<tr>
<td>Lime (Pulverized)</td>
<td>98</td>
</tr>
<tr>
<td>Calcium Bluestone (Asphalt)</td>
<td>94</td>
</tr>
<tr>
<td>Zeolite (6)</td>
<td>87-92</td>
</tr>
<tr>
<td>AM Products</td>
<td>96</td>
</tr>
</tbody>
</table>

A value < 88% is considered not stable (comp. mountain soil)
Soil amendments: How stable are they?

<table>
<thead>
<tr>
<th>Soil Amendments Stability</th>
<th>Impact (NPR%, min)</th>
<th>After (% change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>0.33</td>
<td>0.33 (0%)</td>
</tr>
<tr>
<td>Calcia Clay</td>
<td>0.66</td>
<td>0.64 (4%)</td>
</tr>
<tr>
<td>Calcia Diatomite</td>
<td>0.74</td>
<td>0.67 (9.5%)</td>
</tr>
<tr>
<td>Calcia Thatch</td>
<td>0.54</td>
<td>0.50 (8%)</td>
</tr>
<tr>
<td>Southern Zoysia</td>
<td>0.58</td>
<td>0.57 (2%)</td>
</tr>
<tr>
<td>Southall Zoysia</td>
<td>1.01</td>
<td>1.01 (0%)</td>
</tr>
<tr>
<td>SMM Calciocrete</td>
<td>0.99</td>
<td>1.01 (2%)</td>
</tr>
<tr>
<td>SMM All Purpose</td>
<td>2.41</td>
<td>1.22 (45.5%)</td>
</tr>
</tbody>
</table>

NPR%: Average particle diameter, TA Abrasion Test

Thatch management: What is thatch?

- layer of dead or dying organic matter composed of roots and stems (rhizomes, stolons and crowns) and little or no clippings
Thatch management:

Properties of thatch

- well aerated having very large pores
- resists compaction
- little or no water and nutrient holding capacity
- acts as a bio-filter of pesticides
- greater temperature extremes than soil

Thatch management:

Problems with thatch

- root often limited to thatch layer
- more drought susceptible
- lower tolerance of high and low temperature
- more insect and disease problems
- scalping
- poor root zone pest control
- increase in pesticide phytotoxicity

Thatch management:

Why does thatch accumulate?

- imbalance between production and degradation of organic material
- some species and cultivars produce more thatch (more lignin)
- too high or too low nitrogen applications
- late fall applied nitrogen (more root growth)
Thatch management: Why does thatch accumulate?

• high mowing heights (more roots)
• low soil pH < 6)
• temperature and moisture extremes (low microbial break down)
• some pesticides increase thatch by: increasing growth or reducing reduction

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Thatch (mm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>12</td>
<td>4.7</td>
</tr>
<tr>
<td>lime</td>
<td>3</td>
<td>6.7</td>
</tr>
<tr>
<td>gypsum</td>
<td>4</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Thatch management:

• modify situations if they are present, pH

Thatch management: cultivation and topdressing
Thatch management:

- cultivation and topdressing

### Changes in thatch as affected by cultivation

<table>
<thead>
<tr>
<th>Number</th>
<th>Depth</th>
<th>Weight</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>30</td>
<td>15</td>
<td>2.2</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>10</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>5</td>
<td>6.4</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>2</td>
<td>11.0</td>
</tr>
</tbody>
</table>

*Numbers of cultivations by Brockman, Mclean and Buxton (1980)*

---

Thatch management:

- cultivation and topdressing

### Cultivation effects on surface soil (0-3 cm) organic matter

<table>
<thead>
<tr>
<th>Treatment</th>
<th>6 June</th>
<th>11 Aug.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>19.2</td>
<td>18.1</td>
</tr>
<tr>
<td>Cultiv + sodl.</td>
<td>4.1</td>
<td>7.7</td>
</tr>
<tr>
<td>Hydropl.</td>
<td>9.7</td>
<td>10.2</td>
</tr>
</tbody>
</table>

*Going to Nace, from R. Crowe, USDA, 1987, Reprinted*
Thatch management:

- Dethatching, how effective is it?
  Only 2-5% thatch removal

Final comments