**Fri_B03  Healthy Soils**

I. Introduction: Soil or Dirt
  A. Natural soils and urban soils
  B. Goals of plants and soil in built landscapes

II. Physical Properties of Soil
  A. Texture
  B. Structure
  C. Density
  D. Profile
  E. Soil layers interface

III. Organic properties of Soil

  A. Organic matter
  Organic matter (% dry weight) vs compost and other organic amendments % moist volume  Why adding 10% compost to a soil does not increase organic matter by 10%

  B. The role of soil biology

  C. Links between soil biology and soil chemistry

IV. Chemical Properties of Soil

  A. Macro nutrients
  B. Micro Nutrients
  C. Ph and nutrient availability

V. Water movement **Hummel 10 min**

  A. Infiltration – water movement into soil
  B. Available water – water held with in the soil usable by the plant
  C. Drainage – Excess water moving out of the soil

VI. Analyzing existing site soil **Urban 15 min**
  A. Limitations on traditional soil analysis methods in areas of disturbed soils
  B. Developing a soil analysis
    1. Existing soils mapping
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    5. Surveying existing plants and using plant stress indicators
    6. Soil toxicity
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VII. Discussion and questions

**Organic properties in soils**

Organic matter is an important component of topsoil quality.  Organic matter accumulates naturally in soils due to the death and decay of plant material, microorganisms, and macroorganisms (insects, worms, other animals).

The benefits of organic matter in finer textured soils include:
- increased soil aggregation and aggregate stability

- increased water retention
- increased nutrient retention
- increased total pore space
- in some cases improved permeability

The benefits of organic matter on sand-based manufactured soils include:
- increased water retention
- increased nutrient retention
- provide a growth medium to support soil microorganisms
- usually decreases permeability (could be disadvantage depending on use)

Sources of organic matter in manufactured soils:
Peats:
1. Sphagnum moss peats
    - High organic matter content (> 95%)
    - Low density
    - Highly fibrous
    - High water holding capacity (holds 10 to 14 times their weight in water)
    - Is renewal resource
2. Reed Sedge peats
    - Mature peats - botanic origin is reeds and sedges
    - High organic matter content (80 - 90%)
    - Medium density
    - Fine textured
    - Medium water holding capacity (hold 3 to 5 times their weight in water)

Composts
- highly variable based on feed stock (yard waste, biosolids, animal wastes, mixed stock)
- organic matter content varies from 30% for yard waste composts up to 75% for some biosolids.
- High density
- Low to medium water holding capacity (hold 1 to 3 times their weight in water).
- Attractive choice because they are local and economically feasible.
- Maturity and stability are extremely important.

Guidelines for selecting composts:

Stable, humus-like organic material produced from the aerobic decomposition. Feedstock shall be yard waste trimmings and/or source-separated municipal solid waste, composted and cured until the maturity status complies with indices specified below.

1. Organic matter content no less than 35% (can be higher if biosolids are allowed).
2. Moisture content between 35 and 70%
3. Carbon/nitrogen ratio 15:1 to 30:1
4. Soluble Salts not to exceed 4 dS/m
5. Particle size percent passing 3/8’ screen 95-100%
6. Solvita stability test 5 to 8 (or other indices listed below)
7. pH (Reaction) 6.0 to 8.0
8. Proven to be non-phytotoxic
9. Must meet federal and state limits for heavy metals (for biosolids).

Listed below are maturity Indices for different methods (from *Compost Quality and Standard Guidelines,* William F. Brinton. Can be obtained at http://compost.css.cornell.edu/Brinton.pdf

| Test Method | Units/Rating | | |
|---|---|---|---|
| | Very Mature | Mature | Immature |
| Oxygen uptake ($O_2$/VS/hr) | < 0.5 | 0.5 - 1.5 | > 1.5 |
| $CO_2$ evolution (C/unit VS/day) | < 2 | 2 - 8 | > 8 |
| SCL $CO_2$ evolution (C/unit VS/day) | < 2 | 2 - 8 | > 8 |
| WERL $CO_2$ evolution (c/unit VS/day) | < 5 | 5 - 14 | > 14 |
| Dewar Temp rise ($^oC$) | < 10 | 10 - 20 | > 20 |
| Solvita Index Value | 7 - 8 | 5 - 6 | < 5 |

When evaluating composts, demand recent compost tests reports. Composts coming out of facilities can be variable over time. Most reputable composters test their product monthly and will have reports available for review.

Because of differences in density, organic matter content, and moisture content, the actual amount of organic matter obtained in a unit volume of peat or compost will vary. We refer to this as organic yield of a product.

**Organic Matter by Volume ≠ Organic Matter by Weight**

Here are examples of the amount of organic matter you can obtain in a cubic yard of organic matter, these from actual examples.

| Compost | Moisture (%) | Organic Matter (%) | Density (lb/cu yd) | Organic Yield (lb OM/cu yd) |
|---|---|---|---|---|
| Biosolid | 29.4 | 62.4 | 603.4 | 265.7 |
| Yard waste (poor) | 35.1 | 18.3 | 1075.6 | 127.7 |
| Yard Waste (good) | 55.0 | 30.5 | 1144.8 | 156.6 |
| Sphagnum peat | 50.5 | 97.3 | 257.0 | 89.4 |

My point in all this is to demonstrate the danger of specifying an organic percentage by volume rather than weight. Say you specify a mix calling for 20% of organic matter by volume. If someone used the poor yard waste compost in the table above, you would get only half as much organic matter by weight in the mix than if someone used the biosolid compost.

Always specify an organic matter content by weight. Select a target organic content by weight that you want in a mix, but be reasonable. I have recently seen specifications calling for more than 12% by weight. For someone to manufacture a mix with such a high organic matter content could require more than 60% compost by volume. This might be OK for annual beds that are reworked every year but could be disastrous for permanent plantings. I had one project recently that specified 12 to 15% by organic matter by weight that required 90% compost by volume to produce; this for a tree planting. I fully expect these trees to blow over in the near future.

**Soil Microbiology**

The soil is a dynamic world for soil microorganisms. A single gram of soil will contain millions of these microscopic organisms that can include bacteria, fungi, actimomycetes, algae, and others. That nice earthy smell you often get from a healthy soil is from actinomycetes. On the other hand, a septic smell is a result of sulfur reducing bacteria changing soil sulfur into hydrogen sulfide - a sign of a poorly drained soil. Off course we all know about plant pathogens that reside in the soil as well. There are also natural competitors in the soil to help keep these pathogens in check.

Soil microorganisms play a critical role is soil health. They control soil chemical reactions. They decompose organic matter into humus, which again helps with aggregate stability.

The activity of soil microorganisms is influenced by soil temperature, available oxygen, soil pH, and amount and type of organic matter. Microbial activity increases with increasing temperature and available oxygen. The optimum pH range for most microorganisms is 6 to 7. Microbial activity increases with the introduction of organic matter as the organic carbon is the energy source to support microbial growth. Any activity or practice that encourages soil microbial activity will enhance soil health.

Adding microbial supplements is likely a waste of money. To quote Dr. Eric Nelson, a respected soil microbiologist and ecologist at Cornell University, doing so "is like adding a drop of water to the ocean". I qualify this by saying that there may be some advantage to compost teas and similar products from a plant health standpoint post plant.

**Chemical Properties of Soils**
The chemical properties of soils are important in soil and plant health. Like all living organisms, plants have need for nutrition that only comes from the soil. The chemical properties of soils are easier to modify than soil physical properties, especially after the soil is installed. Therefore, design emphasis should be placed on soil physical properties.

*Soil pH* - the soil pH is a measurement of the hydrogen ion concentration in the soil solution. A soil pH of 7 is considered neutral. A pH above 7 is considered alkaline, while a pH below 7 is acidic.

The soil pH is probably one of the most important chemical properties and is one that you should include in a soils specification. Soil pH controls chemical reactions in the soil, to a large extent influencing the availability of other plant nutrients. Nutrients such as iron, manganese, and others are tied up in unavailable forms at higher pHs, potentially producing pH-induced deficiencies. Conversely, phosphorus can have limited availability at lower pHs. Aluminum and manganese can be toxic at low pHs. Soil microorganism activity is influenced by soil pH, this being maximum in the 6.5 to 7.2 range.

Most lawn and landscape plants like their soil in a pH range of 6 to 7. Of course the exception would be acid-loving plants. As a whole, plants are more tolerant of alkaline conditions than acidic conditions. Acidic soils are easier to correct than alkaline soils. Therefore, pH adjustments usually only focus on raising acidic soil pHs. Lowering pH on alkaline soils is much more difficult.

*What is important to know regarding pH?*
Knowing the optimum pH range for the plants to be grown and specifying that range. Be cognoscente that in some parts of the country high pH soils predominate and plants do just fine. In other words don't specify a pH range of 6 to 7 if you are in the southwest United States, or along the limestone belt from Western Massachusetts to Iowa. You probably won't get there.

Know that pH is routinely done in a soil test lab. In the case of acidic soils the lab should do a buffer pH so that an accurate lime recommendation can be made.

Know that lowering the pH of alkaline soils is difficult and often unnecessary. For one, nutritional deficiencies associated with high pHs often are not present. Much depends on the sensitivity of the plant (e.g. Pin oak). Avoid such plants where you know high pH soils exist. Second, it may be more economical to treat the nutritional deficiency with fertilizers than trying to adjust soil pH. Third, you have to know what is driving the pH. If a soil has even a small amount of free calcium carbonate, reducing the pH will be impractical if not impossible.

*Plant nutrients*
There are 14 plant nutrients that are essential for plant growth. Here are the only ones you need to worry about 99% of the time.

Nitrogen - nitrogen is required in the largest amount of any plant nutrient. While soil organic matter may provide some nitrogen, this is the most common element applied in fertilizers. There is no decent soil test for determining nitrogen requirements. Since nitrogen availability is closely tied to microorganism activity, transformation of nitrogen forms is constant. Don't waste a contractor's time and money requiring nitrate nitrogen and/or ammonium nitrogen tests on soils. The results are meaningless from a plant nutrition standpoint. An ammonium test may only tell you something about the maturity of the compost used.

Phosphorus - phosphorus is required in fairly large amounts by plants. Since it is mostly immobile in soils, it is advantageous to get it mixed into the soil prior to plant establishment. Require soil chemical testing of soils or mixes prior to establishment to determine phosphorus requirements.

Potassium - potassium is found in plant tissue concentrations second only to nitrogen. Potassium is readily leached in sandier soils so it may be deficient pre-plant in such soils. Require soil testing to determine potassium requirements.

*Soluble salts*
The presence of large amounts of salts can be detrimental to plant health. The use of compost can contribute salts to a manufactured soil or planting mix and should be monitored. The testing is fairly straight forward. We want to measure the concentration of salts in the soil solution (aqueous phase), this by measuring the electrical conductivity of the soil solution. The problem is, we have to add water to the soil to get that measurement, which dilutes the salts. Therefore, the method by which this is tested is important.

The best method is the saturated paste extract method. This method uses the least amount of water and is most accurate. It is a time consuming method, so most high volume labs don't use it. More common methods are 1:1 soil to water or 1:2 soil to water. Again, remember that the more water we use the more diluted the salts. There is decent interpretation information on the saturated paste extract method and the 1:1. I have not found any guidelines on the 1:2 method.

Here are some guidelines for interpretation of these results using these methods

| | **Salinity potential/units = sD/m** | | | |
|---|---|---|---|---|
| **Test Method** | **Low** | **Moderate** | **High** | **Very high** |
| Saturated Paste Extract[1] | < 1.5 | 1.6 - 3.9 | 4 - 5 | > 5 |
| 1:1 soil to water[2] | < 1.4 | 1.4 - 2.8 | 2.8 - 4.5 | > 4.5 |

1 From US Salinity Lab
2 Adapted from Recommended Chemical Soil Test Methods for North Central Region, some adjustments need to be made for soil type

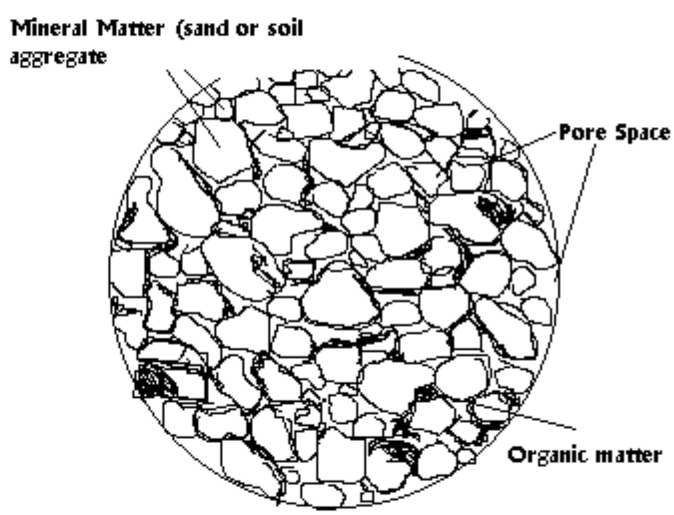
Therefore, when you write a specification for soluble salts, select one of these two methods and an appropriate limit.

There are many units used for electrical conductivity, making it confusing. Most labs use dSm, which is the same as mmho/cm. You can convert electrical conductivity to soluble salts by multiplying by 640. For example, a soil with an EC of 1.0 would have a soluble salt concentration of 640 ppm (parts per million).

*Soil Testing - What's Important to know for writing specifications.*
Other than pH and electrical conductivity, do not write specific ranges.
Know that there are different methods for soil testing that will produce different results.
**Specify a lab you or your soils consultant are familiar and confident with.** Using different labs will likely produce different test values and make interpretation confusing. You will get used to reading a test report you see over and over again.
**Know that what is important is the interpretation.** Soil test labs should make interpretations on the results relative to the test methods they are using so that your contractor can apply fertilizer as needed.

**V. Water Movement**

The mineral matter of a soil (sand, silt, clay, stones) typically makes up 40 to 60% of the soil volume. Organic matter may make up another 5 to 10% of the volume, with the remainder being the voids or pore spaces between the soil particles or aggregates, or pores within the soil aggregates.




The soil pores vary in size and geometry, and both of these determine if that pore is going to be filled with water or air.

Drainage or gravitational water moves through the larger diameter pores between the sand grains or soil aggregates. Pore size and continuity of pores influence the rate of drainage, a measurement we call saturated hydraulic conductivity (Ksat), infiltration rate, or permeability. Larger diameter pores will drain faster, as we see in very sandy soils. We call it gravitational water because it is gravity that is influencing the movement of water. When drained, these larger pores (macropores) fill with air, which provides the oxygen that is necessary for root growth. The percentage of a volume of soil or mix that is occupied by air after free drainage is called aeration or air filled porosity.

Water molecules have a strong attraction to surfaces, which is called adhesion. There are also is a strong attraction between water molecules, which is referred to cohesion. The forces of adhesion and cohesion hold the water in the small diameter (capillary) pores. The forces become stronger as the pore size decreases. Plants must overcome these forces to absorb water from the soil or mix.

Water is retained against the force of gravity in a soil or mix as water films on soil particles, in wedges where two or more soil particles meet, or in organic or peat fibers. Again, it is the capillary forces that keep the water from draining out. What is important to understand is that not all water held in soils is going to be available to the plants. A portion of the water in soils will be held at tensions so strong that it isn't available to plants. For example, soils high in clay may have a large water holding capacity because of the high percentage of small diameter pores. Much of the water is unavailable to the plant because it is held at tensions too high to be available. We refer to this and unavailable water. On the other hand, a sandy soil may not hold as much water, but a larger percentage of water held will be available to the plant because of the weaker capillary forces.

Water in a soil that can be used by the plant is called plant available water or water retention capacity. It is interesting to note that this is very rarely addressed in engineered soils, the exception being sand-based mixes for high performance turf installations, and green roof mixes. This is something that can be tested in the laboratory in the design of mixes.

*Saturated Hydraulic Conductivity/Permeability*

Most designers and end uses can relate to soil permeability, especially when there is a problem. Soil permeability is influenced by soil texture, soil structure, and soil density.

The effect of soil texture on permeability is easy to understand. Sandy soils have larger pores and therefore drain faster (typically). Fine textured soils drain more slowly because of the smaller pore size.

A soil that is well aggregated will have better drainage than a soil that is not. I have seen well aggregated clay loam soils drain very well because of the large voids between the soil aggregates. What is important to understand from a design standpoint is that soil aggregation can be fragile. Excessive handling of a soil and/or excessive cultivation can destroy soil structure to the detriment of soil drainage. Don't remove a soil from a site if only minor grading is required. Think about how many times a soil is handled if your strip it off site, maybe screen it, move it back on site, rough grade it, and then fine grade it.

Soil compaction is without question the number one problem I see in new installations. Soil compaction destroys desirable soil structure and decreases the percentage of large pores. The end result is an installation that doesn't drain well and performs poorly. You can have the best soil in the world and have it perform poorly if it is overly compacted. Consider specifying a maximum compaction level (e.g 85% standard proctor) and monitor it during construction. Realize that there is a fine line between having a soil that has little risk of settlement versus one that is too compacted.

Finally, a healthy population of earthworms will do wonders for drainage is soils because the channels they create provide a channel for preferential flow of water into the soil.

Permeability of a soil or engineered soil mix can be determined in the lab. The most useful way of doing this is to have a standard proctor test (ASTM D698) run on the soil to determine the maximum density that the soil can be compacted to. Cores can then be compacted to a certain percentage of that maximum density and permeability determined. We typically run these at 85 to 90% of maximum density. Structural soils are usually run at higher percentages. This information will give you an ideal of the drainage characteristics with that soil compacted to a density you hope for in the field. You can then monitor compaction in the field to make sure the density doesn't exceed the test density.

Permeability and water retention characteristics of green roof mixes and high performance sand-based mixes are performed by test methods specific to those types of mixes; ASTM E2399 and ASTM F1815, respectively.

I have included in this handout a description of common test methods used for soils and engineered soils, and their appropriate ASTM Method.

## Understanding Your Soil Test Report

**Norman W. Hummel Jr.**

Soil physical testing is an important first step in the successful construction of quality planting soils for golf, sports fields, and landscapes. Due to the technical nature of the soil physics testing, some people have difficulty understanding the testing, what are reasonable expectations of soil testing, and what the test values mean. I prepared this article to offer an explanation of the more common soil physical tests.

### PARTICLE SIZE ANALYSIS

The particle size analysis determines the distribution of different sized particles in a soil or planting mix. The particle size of a soil or sand-based mix has probably the greatest impact on how the soil will perform in the field.

We determine the gravel content, and the sand, silt, and clay percentages. Using U.S. Department of Agriculture designations, gravel is defined as any particle larger than 2 mm in size. Sand is any particle 0.05 mm (50 μ) to 2 mm in size. Silt is any particle 0.002 mm (2 μ) to 0.05 mm (50 μ), while clay is any particle less than 2 μ in size (microscopic).

In sand-based root zones or in soils high in sand, the size distribution of of the sand will influence performance. Therefore, we sieve the sand into 5 fractions: very coarse sand (1 to 2 mm), coarse sand (0.5 to 1 mm), medium sand (0.25 to 0.5 mm), fine sand (0.1 to 0.25 mm), and very fine sand (0.05 to 0.1 mm). Some specifications including the USGA Greens construction guidelines will use the 0.15 mm sieve to separate the fine and very fine sand fractions.

Reporting of particle size may vary. Typically sand based mixes the sum of gravel, sand, silt, and clay should be 100%. In the testing of soils, the gravel is often pulled out and reported separate from the sand, silt, and clay, which will add up to 100%. The reason for this is that with soils we will report a soil textural class (USDA) based on the percentages of sand, silt, and clay, not including gravel.

**Particle shape -** The particle shape is the predominant shape of sand particles in a sand-based mix. Shape is of most concern when sand shapes are uniform, and at the extremes. Sands that are very rounded and spherical may be unstable. At the other extreme, sands that are flat and angular may pack excessively, even though the size distribution may be favorable.

**D85 –** Particle diameter of a particular root zone mix whereby 85% of the sand particles are finer and 15% are coarser. This number is used to determine if a sand-based root zone mix will meet bridging requirements with a drainage stone.

**Uniformity coefficient (Cu) -** It is a numerical expression of the particle size uniformity. Research conducted in Minnesota several years ago found that the acceptable range is 2 to 4 for sand-based mixes. The higher the value, the less uniform the sand or mix, and the greater the potential for particle packing. Sands with Cu values less than 2 may not pack at all, resulting in unstable surfaces during grow in , and sometimes beyond. For soil amending sands, a coarse uniform sand is preferred. The Cu is determined by the following equation:

$$Cu = D_{60}/D_{10}$$

**Gradation Index (GI)** – Is another numerical expression of particle size uniformity of the sand in the middle 80% of the particle size range. It is the D90/D10. Other indices such as these are frequently used by some designers, including D80/D30 and D70/D20.

The two test methods most commonly used for particle size analysis are:

ASTM F-1632. Standard Test Method for Particle Size Analysis and Sand Shape Grading of Golf Course Putting Green and Sports Field Rootzone Mixes.

ASTM D422. Standard Test Method for Particle Size Analysis of Soils (Hydrometer method).

ASTM F-1632 is the preferred method for very sandy soils (> 85% sand) or sand-besed mixes because it is more precise in the separation of silt and clay

**PERFORMANCE TESTING**

Performance testing ususally refers to determination of soil physical properties that provide a reasonable assessment of how an engineered soil or root zone miz may perform in the field. In reality, it is a risk assessment that provides some assurance that such soils will perform as expected.

There are different performance test procedures for different types of mixes. For example, ASTM F1815 was designed specifically for sand based root zone mixes for sports fields and golf greens. It would not be an appropriate test method for a finer textured soil (< 85% sand). Samples are subjected to a standard compaction treatment prior to running the tests.

For native and engineered soils we often run a proctor density test on the samples per ASTM D698. A proctor test is one whereby we can determine the maximum density that a soil can be compacted to using this method. Cores can then be packed to some percentage of this maximum density, usually 85 to 90%, to simulate the soil density the soils should be compacted to in the field. Performance tests similar to those run by ASTM F1815 can then be run on the soils at those densities.

Listed below are the tests performed in ASTM F1815 or on soils compacted to a known density.

**Saturated Hydraulic Conductivity -** This is a measure of the engineered soil's ability to conduct water under saturated conditions, this being one dimensional flow (downward). Sometimes called infiltration rate, it is expressed in inches per hour.

**Particle Density (ASTM D5550 and others) -** The particle density is the density (mass per unit volume) of dry, solid soil particles. If you could melt the soil or root zone mix down into a solid mass of known volume, without any pore space, this would be its particle density. Silica sands are about 2.65 g/cc. Calcareous sands are usually higher.

The addition of peat or compost decreases the particle density. This value is used for calculating total porosity.

**Bulk Density -** The bulk density is the mass per unit volume of soil. Soils and root zone mixes are not solid mineral masses. There is a matrix of pores that exist between the soil particles that is very important in the quality of the soil or root zone mix as a growing medium. The higher the bulk density, or the closer this value gets to the particle density, the more dense or compacted the soil. Bulk density is used to calculate the total porosity.

**Total Porosity -** This is the percentage of a volume of soil or mix that is occupied by space (voids) between or within the mineral or organic components of the root zone mix. An ideal sand based root zone mix would have 40 to 50% of the volume being pore space.

**Aeration (Non-capillary) Porosity -** This is the percentage of space within a volume of soil or mix that is occupied by air after free drainage (field capacity). We are referring to the larger diameter pores, which actually conduct water downward due to the force of gravity when the soil is saturated. When all free drainage is complete, or all gravitational water removed from these pores, they are occupied by air. These pores provide the gas exchange in the soil, bringing needed oxygen to the roots. Ideally, half of the total pore space would be these larger air-filled pores.

**Capillary Porosity -** This is the percentage of space in a volume of soil or mix that is occupied by water after free drainage. Water is held in these small pores, against the force of gravity, due to capillry forces. It is within these small pores where the water holding capacity of a soil is provided. Ideally, half of the total pore sapce would be made up of these smaller pores.

**Pore Space Distribution/Field Capacity/Percent Saturation -** Field capacity is the hypothetical condition whereby all of the larger diameter pores are drained and the capillary pores are filled with water. The percentage of air and water filled pore space or the pore space distribution is determined at "field capacity". In the lab, we subject the samples to some amount of suction or pressure to extract water from the samples to simulate field capacity. Per ASTM F1815, the pore space distribution of a sand based mix is usually determined at 30 cm of soil suction (0.3 kpa). For engineered or native soils, we often do this at 100 cm (1/10 bar, 1 kPa), or 300 cm pressure (1/3 bar, 3.3 kpa). The percent saturation is the percentage of the total pore space that is occupied with water.

**PERFORMANCE TESTING - GREEN ROOF MIXES**

Performance testing on green roof mixes is performed by ASTM E2399. Test determined by this method includes saturated hydraulic conductivity, and air and water content (porosity) at maximum water capacity. The air and water content are determined after the core is allowed to drain for two hours. Since load bearing is often limited in green roof systems, densities of the drained soils are determined as well.