LATIS

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Planting Soils for Landscape Architectural Projects

Barrett L. Kays, FASLA

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Cover Photos

Upper left: Dwight D. Eisenhower Memorial, Washington, DC. Image courtesy of AECOM.

Lower right: Great Lawn in Central Park, New York, NY. Image courtesy author.

Publisher's Note

The American Society of Landscape Architects publishes the Landscape Architecture Technical Information Series (LATIS) to encourage professionals to share specialized expertise relating to landscape architecture. ASLA considers LATIS papers to be important contributions to a necessary and ongoing dialogue within a large and diverse community of landscape architecture researchers and practitioners. ASLA oversees a rigorous peer review process for all LATIS papers to ensure accuracy of content. Each author offers a unique perspective on the practice area covered, reflecting his or her portfolio of professional experiences.

Planting Soils for Landscape Architectural Projects is a technical manual that teaches and demonstrates how to apply modern soil science techniques to create the best possible soils for landscape plants and the environment. The manual presents important soil concepts and how they should be applied to the design of soils for both small and large landscape architectural projects. The proper design and management of soils is essential for successful landscapes, because soil is the basic infrastructure of landscape projects.

The manual presents a range of technical approaches to manage soils including the restoration and amendment of on-site soils, designing soils to solve difficult problems, importing and blending soils, designing structural soils, designing layered soils, and preparing soil management plans and construction specifications. The publication is intended as a resource for independent study and to improve landscape architects' understanding of soils and how to effectively manage soils on their projects.

Feedback on this LATIS and on the series in general should be sent to ASLA, c/o Professional Practice Manager, 636 Eye Street NW, Washington DC 20001. ASLA welcomes suggestions for future LATIS topics that will broaden awareness of new and/or rapidly evolving practice areas within landscape architecture and enhance technical proficiency for practicing in these areas.

About the Author

Barrett L. Kays, FASLA, is both a professional landscape architect and soil scientist. Kays has a B.S. Degree in Horticulture from Oklahoma State University, a M.L.A. Degree in Landscape Architecture from North Carolina State University, and a Ph.D. Degree in Soil Science from North Carolina State University. Kays conducted his doctoral research entitled "Relationship of Soil Morphology, Soil Disturbance and Infiltration to Stormwater Runoff in the Suburban North Carolina Piedmont" which was perhaps the first comprehensive study of urban soil infiltration and stormwater runoff in the United States.

Kays' landscape architectural practice has focused on design solutions for environmentally complex sites for over 34 years. He is a leader in environmentally sustainable design. Kays received a 1998 Honor Award from ASLA and the Best of 1998 Site Design Award from New York Construction News both for the restoration of Great Lawn and Belvedere Lake in Central Park. He received the 2008 Beyond Green High Performance Building Award for an integrated water management and reuse systems for the Northern Guilford Middle School campus in Greensboro, NC and the 2005 Nation's Top Exemplary Sustainable Building Award for an integrated water management system for the Heritage Middle School campus in Wake Forest, NC. He has served on design teams for six LEED Platinum projects, a carbon neutral university building and campus, and three projects receiving design awards from ASLA North Carolina Chapter.

Kays has been a speaker on soils issues at ASLA's annual meetings almost every year since 2007. He has received distinguished alumni awards in landscape architecture from Oklahoma State University and North Carolina State University, and in soil science from North Carolina State University. He has been an active member of ASLA since 1975. He has served on ASLA's Professional Practice Committee (PPC) and has been active in the PPC's and ARCOM's development of a new landscape soil specification system now used in MasterSpec.

Kays' soil, hydrologic, groundwater, and environmental science consulting practice has solved complex environmental problems for governments, corporations, and landscape architectural firms across the United States for over thirty-four years. He received the 2007 Soil Science Professional Service Award from the Soil Scientist Society of America. Kays has written two books, three book chapters, and numerous scientific papers on urban soil restoration and management, including two articles for Landscape Architecture Magazine.

Kays has developed new innovative stormwater systems including: soil renovation techniques for enhancing infiltration on urban sites, design and construction techniques for high rate infiltration systems, recirculating sand/organic filter stormwater treatment systems, structural soil systems for high impact urban landscapes, layered structural soil systems for subsurface stormwater storage, and various types of stormwater reuse systems. He is currently serving as consultant for an enhanced infiltration stormwater research program in the Department of Soil Science at North Carolina State University.

Kays has been a leader in the design of land based wastewater treatment system including ten municipal wastewater plants in North Carolina and Virginia. He has designed decentralized wastewater treatment and reuse systems for projects located adjacent to environmentally sensitive landscapes across five states.

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Preface

In the 1970s and 1980s several landscape architects, soil scientists, horticulturists and foresters formed an Urban Soils Group. They met annually in conjunction with the Metropolitan Tree Improvement Alliance (METRIA) meetings to discuss practical ways to manage urban soils. Over the ensuing years the group's work has led to the understanding that landscape architects need to expand and improve their knowledge about the use of soils in the design landscapes.

There has been limited emphasis on the study of urban soils by soil scientists. In the early years urban soil scientists learned by studying major landscape failures caused by our collective ignorance of how to properly specify the management of soils in construction documents. In 1983, the first soil workshop for landscape architects was held in Washington, DC. Subsequently, various universities have developed research programs that have focused on many of the problems and solutions to urban soils management.

ASLA's Professional Practice Committee (PPC) worked with ARCOM in developing a comprehensive planting soil specification system in MasterSpec. Out of that work, the PPC felt that a LATIS technical paper would supplement the new planting soil specifications and help to explain soil concepts, soil restoration, and soil design strategies to landscape architects.

This publication has been written with a limited amount of equations, graphs, and charts, but some are necessary to fully explain many of the key concepts. Many technical terms are introduced throughout the publication and they are footnoted to allow the reader to easily refer to them as the document is read.

Planting Soils for Landscape Architectural Projects has been prepared to present what has been learned thus far and to assist landscape architects in understanding and applying scientific knowledge of soils in their design work. This publication will allow landscape architects to better understand all aspects of use of soils in landscape design; as well as in their collaboration with soil scientists, soil engineers, and soil testing laboratories. This publication will not transform all landscape architects into soil scientists, but will allow landscape architects to more fully understand the scientific concepts and better perform in collaborative teams in the technical analysis and design of both small and large landscape architectural projects.

Introduction

Soil is the primary infrastructure element for landscape architects and practitioners need to understand the basic methods of soil survey, sampling, and analysis applicable to landscape planting soils. Landscape architects can effectively manage soils on their project sites by restoring the site soils through various amendments, importing native soils to the project site, and by specifying the use of manufactured soils.

Landscape architects need to know enough about soils to effectively engage with consulting soil scientists, soil engineers, and soil laboratories to provide them with the information they need to create successful soil design and management strategies. Part I of this publication provides a good basic knowledge for landscape architects to better understand soils and how to deal with them. Part II discusses more complex soil design and management challenges.

On-Site Soil Survey

Landscape architects need to conduct a soils analysis of their sites prior to starting the design. An on-site soil survey is just as important as a topographic survey to a successful design. The soil survey reveals what is under the topography, what will be exhumed or buried in grading the site, and how the development of the site will impact surface and subsurface water movement, as well as many other factors that may be important to the site and planting design. The soils present on the site should be analyzed to provide the detailed field and laboratory data that is important to the project's success.

The soil survey of disturbed soils in urban areas needs to be conducted differently from a soil survey of undisturbed soils. The degree of disturbance by grading, cutting, filling and compaction of soil is significant in urban areas[1]. Various researchers have applied soil survey methods to urban disturbed landscapes[2].

During the schematic design phase the recommendation is to conduct a comprehensive soil survey. At a minimum, conduct an on-site preliminary reconnaissance soil survey, anticipating a comprehensive soil survey during the design development phase. Some experienced landscape architects have learned to conduct their own reconnaissance examinations and collect soil samples for laboratory testing. However, practitioners should consider retaining a consulting soil scientist[3] to assist in conducting the soil survey or reconnaissance examination, but should be present for the site walk on the property to gain a better understanding of the soils and the survey report that is prepared by the soil scientist.

During the schematic design it is important to delineate areas where the soil characteristic is undisturbed, disturbed, hydric[4], or non-hydric, etc. If the site is going to be graded, examine the subsoil's characteristics down to the maximum depth of anticipated cuts. If the site is not to be graded, examine the topsoil characteristics.

NRCS Soil Survey

A NRCS (Natural Resources Conservation Service) soil survey identifies major and minor changes in soils across a site according to their soil profiles[5]. Major soil differences are typically identified by a named soil series[6]. Minor differences are expressed as soil mapping units[7]. In a soil series

1 Evans, Delvin, and Short, "Human-Influenced Soils," Chapter 2; Kays, "Environmental Site Assessment," Chapter 3; Kays and Patterson, "Methodology for On-Site Soils Analysis," Chapter 7.

2 Short et al., "Soils of the mall in Washington, DC," 23:152-156; Craul, *Urban Soil in Landscape Design*; Kays, "Relationship of Forest Destruction."

3 Soil scientists – persons that professionally study soils and are either Certified Professional Soil Scientists by the Soil Science Society of America and, or are Licensed Soil Scientists by a state government.

4 Hydric soils – those soils that are wet long enough to periodically produce anaerobic conditions harmful to plants not suited for wetland conditions.

5 Soil profile – vertical section of the soil through all its horizons and extending downward to the extent of weathering or deposition; a soil profile typically extends downward for one to two meters or more.

6 Soil series – official names of major soils by NRCS of USDA; each series has an official soil series description.

7 Soil mapping unit – mapped polygon identified by name in the soil survey.

report, each named soil series is characterized by soil horizons[8] that have different physical, chemical, and biological properties. The physical and chemical characteristics can be described in general descriptive terms or can be described with specific field or laboratory testing data. The type of tests, numbers of tests, and depth of the tests should be based upon which data will be important in the design.

Figure 1. Profile of loamy acidic soil in eastern United States

Figure 2. Profile of clayey alkaline calcareous soil in western United States

The Sustainable Site Initiative™ (SITES)[9] requires development of a soil management plan, described in a later chapter, to protect healthy soil, restore soils disturbed by previous development, and restore soils to be disturbed during development of the site. In order to develop the soil management plan, an on-site soil survey is needed to characterize undisturbed reference soils and assess types and degree of disturbance that has occurred to the soils.

BASIC STEPS IN CONDUCTING AN ON-SITE SOIL SURVEY

I. Select transects across the site, conduct hand auger borings along transects, and field examine the differences in the soils. Determine the range of soil characteristics along each transect.

8 Soil Horizons – a layer of soil approximately parallel to the land surface and differing from adjacent layers in physical, chemical, and biological properties or characteristics such as color, structure, texture, consistency, organism presence, degree of acidity or alkalinity, etc. Horizons are designated as A, AB, B, BC, and C horizons.

9 Sustainable Sites Initiative. 2009. The Sustainable Sites Initiative: Guidelines and Performance Benchmarks 2009. Available at http://www.sustainablesites.org/report.

A. Identify the main soil series on the site,

B. Determine how to differentiate soil mapping units (mapping units boundaries must fall within but not cross a soil series boundary):

1. Consider differentiating the mapping units by depth and soil texture[10] of the A-horizons (site that will have minimal grading),

2. Consider differentiating the mapping units by depth and texture of subsoil horizons, depth of weathering, or depth to rock, etc.,

3. Consider differentiating the mapping units by depth to seasonally high water table for sites that are seasonally wet,

4. Consider differentiating the mapping units by types of previous soil disturbance such as depth and texture of fill soils, degree of erosion, degree of soil compaction, and

5. Consider differentiating the mapping units by some or all of the above criteria.

II. Identify the differences in the soils using a field book for describing soils[11].

A. Differences between soil series, and

B. Differences between soil mapping units.

III. Map the location of each different soil mapping unit across the site and select locations for soil descriptions and sampling.

IV. Prepare a narrative soil description for each mapping unit using these basic field estimated criteria:

A. Depth, texture, and textural modifiers of each soil horizon,

B. Matrix[12] and mottle[13] soil colors[14] of each horizon, and

C. Redoximorphic features[15] by type, size, abundance, and color,

D. Grade, size, and type of soil structure[16] for each horizon,

E. Soil consistency for each horizon including rupture resistance, manner of failure, stickiness, plasticity, and penetration resistance,

F. Quantity, size, and type of soil pores for each horizon,

G. Reaction (pH) for each horizon,

H. Effervescence carbonate test for each horizon,

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10 Texture – the relative proportion of sand, silt, and clay particles and are grouped into textural classes having one of the following names: sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, or clay.

11 *Field Book for Describing and Sampling Soils,* National Soil Survey Center.

12 Matrix Color – the dominant or codominant color of the soil.

13 Mottle – spots or blotches of different color or shades of color interspersed with the dominant matrix color.

14 Soil Color – specific names and numeric colors defined by the Munsell Color System.

15 Redoximorphic Features – soil properties associated with wetness that result from the reduction and oxidation of iron and manganese compounds in the soil after saturation with water and desaturation, respectively.

16 Soil Structure – the combination of primary soil particles into secondary units or peds. The secondary units are characterized on the basis of size, shape, and grade.

I. Salinity class for each horizon,

J. Description of landscape, landform, and micro-features,

K. Slope gradient, complexity, shape, and hill slope position,

L. Soil taxonomic classification[17], and

M. Inclusions[18] of other soils in the mapping unit.

V. Prepare a technical soil description for each mapping unit using physical test data:

A. Particle size analysis[19] of each horizon using hydrometer laboratory test data,

B. Particle size analysis of sand and fragment fractions using sieve laboratory test data,

C. Infiltration rates of surface horizon using field test data, and

D. Saturated hydraulic conductivity[20] of major horizons using field test data.

VI. Prepare a technical soil description for each mapping unit including laboratory test data.

VII. Prepare a soil survey report containing a narrative description of each soil series, a narrative description of each soil mapping unit, a table of field test data, a table of laboratory test data, and a soil map showing the location of each mapping unit and location of each soil description, each field test, and each sample for laboratory testing.

As a beginning point, download an electronic copy of the soil survey map for the site using the NRCS Soil Web Survey[21]. The NRCS soil survey map provides a good idea of the types of soils on and around the site. Extreme caution should be taken using the county soil survey maps since they are not accurate for a given site, may incorrectly represent the types of soils on the site, and do not accurately locate the mapped soils on the site. NRCS provides a list of county soil surveys[22] and some of these soil survey reports are available on the web.

Selecting Soil Tests

The landscape architect will need to have certain soil tests conducted to characterize the actual soils on the site. There are many different types of soil tests. Some of the most frequently used soil tests will be discussed. However, other tests may be useful for specific sites or issues that are of concern. Some tests are best performed on the site and are referred to as field tests, while other tests are performed in the laboratory.

17 Soil Taxonomic Classification – a procedure classifying soil pedons into scientific names based upon the genesis, morphology, and other physical, chemical, biological, and mineralogical characteristics of soils. Soil pedons are classified in orders, subgroups, great groups, subgroups, families, and series.

18 Inclusions – minor soils within a soil mapping unit that are so small or the pattern is so complex that they cannot be reasonably delineated based upon the scale of the map.

19 Particle Size Analysis – the determination of the various amounts of sand, silt, and clay particles by their size through sedimentation or sieving.

20 Hydraulic Conductivity – the measurement of the viscous flow of water in soil and is normally used in Darcy's law of fluid dynamics. The measurement can be of saturated hydraulic conductivity or varying degrees of unsaturation (unsaturated hydraulic conductivity) based upon the soil moisture tension.

21 Soil Web Survey http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

22 List of County Soil Surveys http://soils.usda.gov/survey/printed_surveys/

I. Basic Soil Testing
   A. Particle size analysis using hydrometer test[23],
   B. Soil pH[24], and
   C. Soil fertility analysis.

II. Soil Tests for Compacted Soils
   A. Infiltration rates of surface horizon, and
   B. Saturated hydraulic conductivity using constant head permeameter[25].
   C. Particle size analysis of sand and fragments[26] using a sieve test,
   D. Bulk density[27] of each horizon using undisturbed soil core[28] testing, and
   E. Saturated hydraulic conductivity using undisturbed soil core testing.

III. Soil Tests for Acidic (low pH) Soils
   A. Cation exchange capacity[29], and
   B. Base saturation[30].

IV. Soil Tests for Alkaline (high pH) Soils
   A. Reaction (pH) of each horizon,
   B. Cation exchange capacity,
   C. Base saturation, and
   D. Soil salinity[31].

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23 Hydrometer – method of measuring sand, silt, and clay fractions in a soil using the principle of sedimentation.

24 pH – A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid, and higher values more alkaline.

25 Permeameter – device for measuring the hydraulic conductivity of a soil; the preferred device is a constant head permeameter.

26 Fragments – rocks larger than 2 millimeters in diameter including fine gravel (>2 to 5 mm), medium gravel (>5 to 20 mm), coarse gravel (>20 to 76 mm), cobbles (>76 to 250 mm), stones (>250 to 600 mm), and boulders (>600 mm); note 1 foot equals 304.8 mm.

27 Bulk density – the density per unit volume and is expressed in units of grams/cubic centimeter.

28 Undisturbed Soil Core – a cylinder of soil dug using a specially design soil core sampler so that the sample is reasonably undisturbed; typically the samplers extract a core with a diameter of 1.5, 2, 2.5, or 3 inches. The diameter needs to match the size needed for the laboratory's testing equipment.

29 Cation Exchange Capacity – the sum of the exchangeable bases plus acidity of the soil. The CEC is a measure of the available electron charges on clay or soil organic matter particles and is expressed in milliequivalent/100 grams of soil.

30 Base Saturation – the ratio of the quantity of exchangeable bases to the cation exchange capacity. It is a measure of the amount of electron charges that are occupied by the cations: primarily calcium, magnesium and potassium vs. aluminum and hydrogen. A high base saturation reduces soil acidity and increases supply of other plant nutrients.

31 Salinity – the amount of soluble salts in a soil. The conventional measure of soil salinity is the electrical conductivity of a saturated extract.

V. Soil Tests for Saline Soils

A. Cation exchange capacity,

B. Base saturation, and

C. Soil salinity.

VI. Soil Tests for Wet Sites

A. Redoximorphic analysis to determine depth to seasonally high water table,

B. Redoximorphic analysis to determine depth to normal water table,

C. Infiltration rates of surface horizon, and

D. Particle size analysis of sand and fragment fractions using sieve test,

E. Bulk density of each horizon using undisturbed soil core testing,

F. Vertical saturated hydraulic conductivity using undisturbed soil core testing, and

G. Horizontal[32] saturated hydraulic conductivity using undisturbed soil core testing.

VII. Soil Tests for Soil Biology

A. Soil organic matter[33],

B. Nitrogen mineralization[34], and

C. Microbe[35] analysis by organism count.

VIII. Soil Tests for Stormwater Retention (Water Garden)

A. Determination of depth to restrictive horizon[36] and rock,

B. Redoximorphic analysis to determine depth to seasonally high water table,

C. Redoximorphic analysis to determine depth to normal water table,

D. Infiltration rates of surface horizon, and

E. Saturated hydraulic conductivity using constant head permeameter.

Determining the Number of Soil Samples

The number of soil tests and samples to be collected will depend upon the depth of soil needed for the purposes of the design. At a minimum a soil sample of the surface horizon and subsoil sample should be taken for analysis. There are four types of samples collection procedures:

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32 Horizontal Core – the core sample is taken in perpendicular to the ground surface.

33 Soil Organic Matter – the organic fraction of the soil excluding undecayed plant and animal residues. Soil organic matter is primarily finely divided and fully decomposed particles that cannot be seen by eye.

34 Nitrogen Mineralization – the microbial process of conversion of organic form of nitrogen to an inorganic form that can be utilized by plants.

35 Microbe – term for all microscopic organisms

36 Restrictive Horizon – a horizon that is dense and, or cemented sufficient to restrict the movement of water and gas. In humid climates the types include: fragipans, iron pans, plinthite, and spodic horizons. In arid climates the types include: caliche, duripans, petrocalcic, petroferric, and petrogypsic horizons.

COMPOSITE SAMPLES

A mixture of numerous samples collected across an area of the site. A composite sample is used typically for analysis of surface soils in an area thought to be homogeneous. A ½-inch push probe is used and approximately 50 to 100 samples are collected per acre. The samples are placed into a bucket and thoroughly mixed. A sample of the soil from the bucket is sent to the laboratory for particle size analysis, pH, cation exchange capacity, base saturation, and / or fertility analysis.

CORE SAMPLES

Sample taken at a specific location and for a specific depth. A 3 inch diameter soil core is taken using a soil core sampler; normally the soil core is 3 inches in height. Core samples are typically taken for several or more different horizons in a soil profile. The core diameter and height is dependent upon the type of soil core sampler used, but the size must be consistent with the laboratory testing equipment. Since the soil core is a discrete sample of a very small area approximately 12 to 18 soil cores are collected per acre of area to adequately characterize the area. Each soil core is independently tested and the results are statistically analyzed and reported as a geometric mean. Core samples are used for laboratory analysis of bulk density, porosity, saturated hydraulic conductivity, and soil moisture release curves.

Figure 3. Collecting undisturbed soil core samples, Central Park, NY, NY

IN-SITU FIELD TESTS

A test taken on the soils as they exist on the site. Each type of in-situ test is performed differently and each test provides an accurate test value for specific location and depth in the soil. In-situ tests are typically performed for infiltration tests and saturated hydraulic conductivity tests using a constant head permeameter. Since each in-situ test is at a discrete location and depth, approximately 12 to 18 tests are taken per acre of area to adequately characterize the area. Test values results are statistically analyzed and reported as a geometric mean.

Figure 4. Soil pedestals for in-situ saturated and unsaturated hydraulic conductivity testing, Charlotte, NC

BULK SAMPLES

A large sample taken usually from a specific location and horizon on the site. A sample of approximately ½ to 1 cubic feet is collected and sent to the testing laboratory. The bulk sample is typically used to perform a series of compaction tests. It can also be used to weigh samples, mix amendments, and determine a soil mix for the planting design. This is typically performed when a native soil is to be imported to the site, if a custom soil mix is to be manufactured, or if a structural soil mix is needed. The laboratory is often asked to blend bulk soil materials and perform various tests, thus allowing the laboratory to determine which soil mix best fits the required test data in the soil specification(s).

Data from a Geotechnical Report

A geotechnical report provides information for engineering purposes; however, it will also contain information that can be useful in the design of planting soils. The site map and cross sections of soil boring data are helpful in understanding the overall site conditions. Note that the soil engineering terminology is different from that of soil science. The geotechnical boring logs are useful to determine the depth to ripable rock, depth to blastable rock, and depth to apparent water table[37]. The gradation analysis is also referred to as a soil particle analysis, but uses different definitions for gravel, sand, silt, and clay. The identification of soil groups is fundamentally different than the soil textural classification system used by soil scientists. The compaction tests to determine maximum density of soils is helpful, but the density needs to be converted to bulk density for soil science applications.

37 Apparent Water Table – is the water table in the bore hole at the end of drilling when the water level may not be stabilized. The water table depth twenty-four after drilling is used to define the depth to the water table.

Bench Testing of Soils

Bench tests are used to determine critical standards for planting soil mix. Soil components are mixed and then tested in the laboratory to determine the best mix for the design purpose. Bench tests are used to determine the correct amount of organic matter or organic humus to add to a planting soil. They are used to evaluate different soil component mixes to determine the best mix for meeting both the plant available water content and the hydraulic conductivity and also to determine the best mix to achieve a desired bulk density and hydraulic conductivity. The following are examples of different possible bench tests.

BENCH TESTS FOR COMPACTION

Each type of soil has a range of densities depending upon the method of compaction, the number of passes of the compaction equipment, and the moisture content of the soil. A bench test or mock up test is performed to determine the change in hydraulic conductivity vs. the bulk density; and the change in hydraulic conductivity vs. the percent of plant available water.

BENCH TESTS FOR AMENDING SOIL PH

An incubation bench test is useful in evaluating the amount of ground limestone to add to a highly acidic soil or the amount of sulfur to add to a highly alkaline soil to reach the desired soil pH. Various samples of the soil are mixed with increasing amounts of either ground limestone or sulfur, and then allowed to incubate for several months prior to soil testing. When the desired change in pH is large and difficult to achieve, the incubation test will often provide a more accurate amount of amendments to add to the soil.

BENCH TESTS FOR ORGANIC MATTER AMENDMENTS

A bench test is also useful in determining the type and amount of organic matter to add to achieve a desired percent of soil organic matter, a desired amount of plant available water, or the needed type and amount of fertilizer to add to the mixture. The soil material is mixed with various amounts of organic humus and each of the samples is sent to the laboratory for testing. After reviewing the testing report, the percent of organic humus to be used is determined based upon the amount of plant available water data for each of the mixes.

Bench tests are more complicated and therefore an experienced soil testing laboratory should be specified to set up the soil testing procedures and to interpret the results.

Understanding Soil Concepts

Understanding soils concepts will help the landscape architect better understand what is important for landscape projects. Soil concepts are complex, therefore each concept is presented primarily in narrative form. Equations and graphs are used only when needed to further explain the concepts.

Soil Physical Concepts

A mineral soil profile[1] is one that is dominated by mineral soil material[2]. An organic soil profile[3] is one that is dominated by organic soil material[4].

PARTICLE SIZE ANALYSIS

One of the principal ways to describe mineral soils is by their texture. The texture name is based upon the particle size class (Figure 5). A soil profile may have several different textural names (Figure 9, 10, and 11) at various depths within a soil mapping unit. Landscape architects frequently refer to a soil by its textural name, e.g. loam. However, one textural name does not describe an entire soil profile which may include different textural names at different depths.

Gravel* Fraction	Particle Size Range (mm)	Particle Size Range (in)
Coarse gravel	>20 to 76	>0.79 to 2.99
Medium gravel	>5 to 20	>0.20 to 0.79
Fine gravel	>2 to 5	>0.08 to 0.20
Fine Earth Fraction		
Very coarse sand	>1 to 2	>0.04 to 0.08
Coarse sand	> 0.5 to 1	>0.02 to 0.04
Medium sand	>0.25 to 0.5	>0.01 to 0.02
Fine sand	>0.10 to 0.25	>0.004 to 0.01
Very fine sand	>0.05 to 0.10	>0.002 to 0.004
Coarse silt	>0.02 to 0.05	>0.0008 to 0.002
Fine silt	>0.002 to 0.02	>0.00008 to 0.0008
Clay	<0.001 to 0.002	<0.00004 to 0.00008

*Gravel is typically not included in planting soils, but occurs in many native soils that may be delivered to the site for landscape projects, therefore they are included in the above list. Landscape architects also specify gravel for drainage in layered soils and certain types of structural soils.

Figure 5. Particle Size Classes of Mineral Soil Material

1 Mineral Soil Profile – a soil consisting of predominately mineral matter, but may contain an organic surface layer of up to 30 cm (12 inches) thick.
2 Mineral Soil Material– a soil that has 10 percent or less of humus or soil organic matter.
3 Organic Soil Profile– a soil where the sum of the thicknesses of layers dominated by organic matter is greater than the sum of the thicknesses of layers dominated by mineral matter.
4 Organic Soil Material– a soil with has 10 percent or more of humus or soil organic matter.

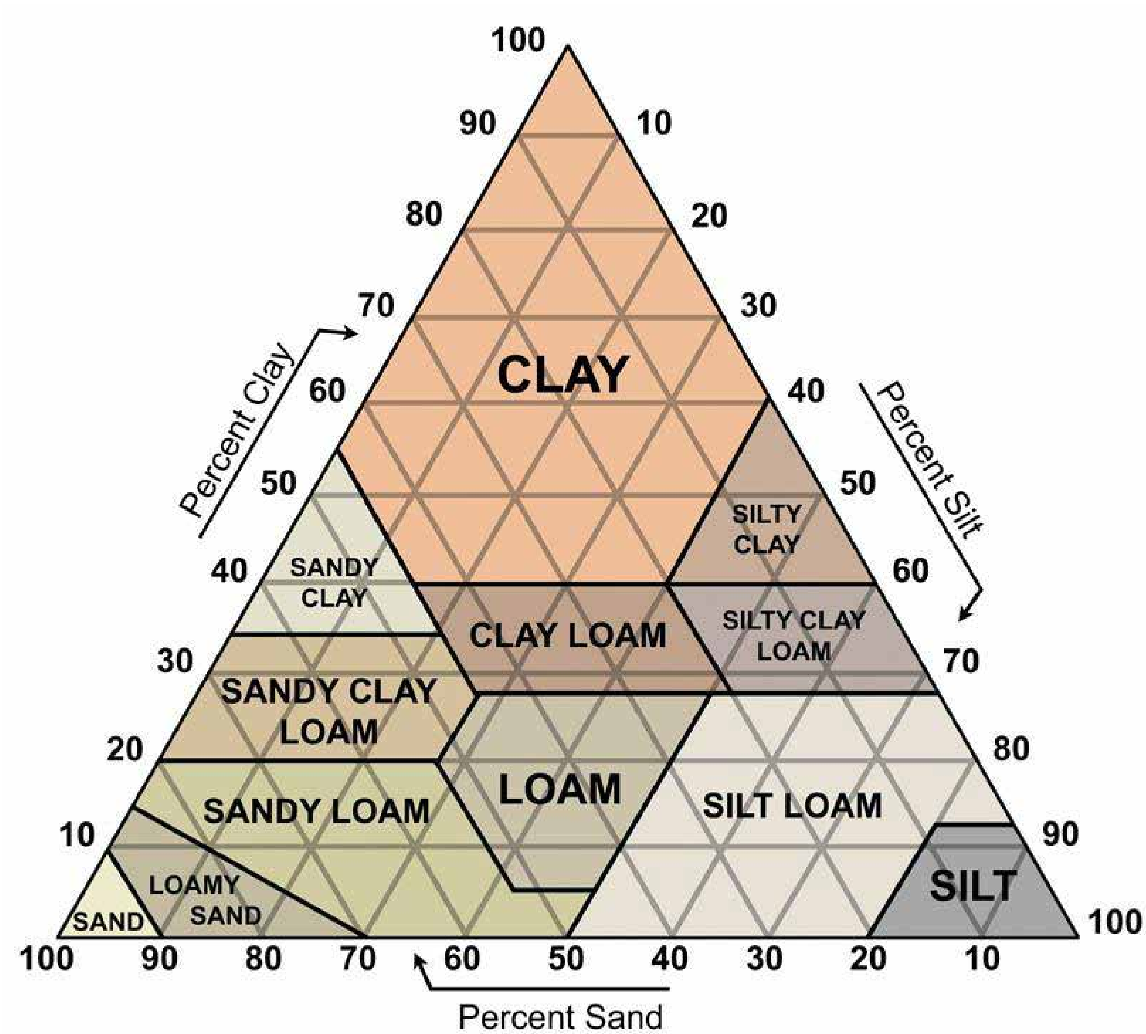


Figure 6. Soil Textural Triangle

Textural Class Names	%Sand	%Silt	%Clay
Sand	85 – 100	0 – 15	0 – 10
Loamy Sand	70 – 90	0 – 30	0 – 15
Sandy Loam	43 – 85	0 – 50	0 – 20
Loam	23 – 52	28 – 50	7 – 27
Silt Loam	0 – 50	50 – 87	0 – 27
Silt	0 – 20	80 – 100	0 – 12
Sandy Clay Loam	45 – 80	0 – 28	20 – 35
Clay Loam	20 – 45	15 – 53	27 – 40
Silty Clay Loam	0 – 20	40 – 73	27 – 40
Sandy Clay	45 – 65	0 – 20	35 – 65
Silty Clay	0 – 20	40 – 60	40 – 60
Clay	0 – 45	0 – 40	40 – 100

Figure 7. Soil Textural Names for Mineral Soils

Textural Subclasses
Coarse Sand
Fine Sand
Very Fine Sand
Loamy Coarse Sand
Loamy Fine Sand
Loamy Very Fine Sand
Coarse Sandy Loam
Fine Sandy Loam
Very Fine Sandy Loam

Selected Modifiers to Soil Textural Classes	
Gravelly	15 to 35% gravel
Fine Gravelly	15 to 35% fine gravel
Medium Gravelly	15 to 35% medium gravel
Coarse Gravelly	15 to 35% coarse gravel
Very Gravelly	35 to 60% gravel
Extremely Gravelly	60 to 90% gravel

Figure 8. Soil Textural Subclasses of Mineral Soils

OBTAINING A SOIL PARTICLE ANALYSIS

The simplest form of a particle size analysis is to determine the percent sand, silt, and clay. This is typically done in a laboratory by conducting a hydrometer test. The soil sample is mixed with water and phosphate and thoroughly shaken to separate the soil material into individual sand, silt, and clay particles. The solution is poured into a glass cylinder and the hydrometer is placed in the cylinder where it floats (Figure 9). The sand particles settle to the bottom in just a few seconds. The silt particles settle in several hours and the clay particles tend to stay in suspension. The hydrometer is read at specific time increments that correspond to the size of particles. The laboratory provides the percent total sand, silt, and clay. The laboratory should also provide the soil textural name for each sample using the USDA NRCS mineral soil textural classes.

Figure 9. Particle size analysis sedimentation cylinders for determining percent of sand, silt, and clay of soil sample

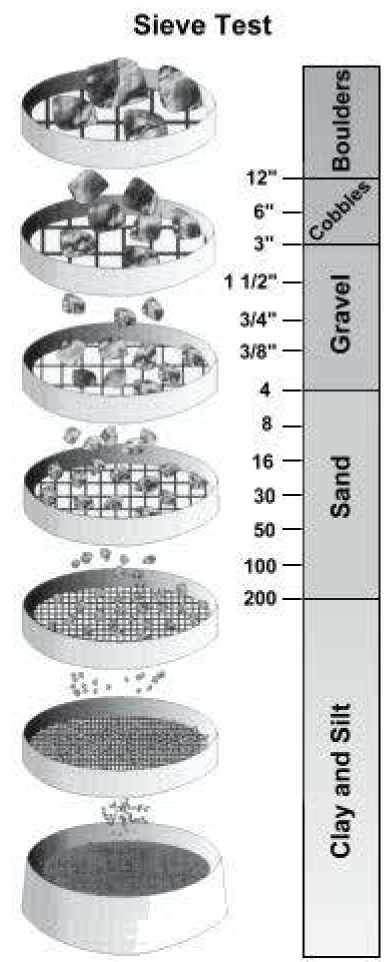


Figure 10. Particle size analysis sieves

OBTAINING A SAND PARTICLE ANALYSIS

A sand particle size analysis using a sieve analysis can be requested from a soil testing laboratory. The sand fraction of a soil sample is placed in a stack of sieves (Figure 10) to determine the amount by weight of very coarse sand, coarse sand, medium sand, fine sand, and very fine sand. The information is reported as either the amount passing through a given sieve size or the amount retained on a given sieve size. It is better to request the data as the percent (amount retained) by weight for each of the USDA sand sizes.

OBTAINING AN ORGANIC SOIL ANALYSIS

A landscape architect who needs an organic soil for wetland planting will need to request laboratory organic analytical determinations, usually from a university laboratory or a private laboratory. Classes of organic soil material are shown in Figure 11. The typical organic tests are:

- Percent soil organic matter
- Percent organic carbon
- Classification of organic soil material

Grassy	> 15% grassy fibers
Herbaceous	> 15% herbaceous fibers
Mossy	> 15% mossy fibers
Mucky	Mineral matter with >10% soil organic matter & < 17% fibers
Peaty	Mineral matter with >10% soil organic matter & <17% fibers
Woody	> 15% wood pieces or fibers

Figure 11. Classes of Organic Soil Material

Physiography:	Piedmont upland slope
Altitude:	129.5 m (425 ft.) above sea level
Relief:	Gently sloping – 5 to 8%
Drainage:	Well drained
Vegetation:	Fescue pasture
Scientific Classification:	Typic Kanhapludults, fine, kaolinitic, thermic, Cecil Series

A-horizon; 0 to 3 inches: Dark brown (7.5 YR 4/4) Coarse Gravelly Loam; brown (10 YR 4/3) dry; weak fine granular structure; loose (moist), non-sticky (wet); many fine and very fine continuous dendritic tubular and irregular interpedal pores; many very fine roots; clear wavy boundary.

AB-horizon; 3 to 17 inches: Yellowish red (5 YR 5/8) Very Gravelly Loam; yellowish red (5 YR 5/6) dry; moderate very fine subangular blocky structure; friable (moist), slightly sticky (wet); continuous vertical simple tubular transpedal pores; many fine discontinuous random irregular interpedal pores; common very fine roots; gradual wavy boundary.

B1-horizon; 17 to 24 inches: Red (2.5 YR 5/8) Extremely Gravelly Clay Loam; reddish yellow (5 YR 6/6) dry; moderate fine subangular blocky structure; friable (moist), slightly sticky (wet); common discontinuous clay skins; few fine to medium discontinuous vertical simple tubular transpedal pores; common fine to very fine discontinuous random irregular interpedal pores; common very fine roots; clear smooth boundary.

B2t-horizon; 24 to 32 inches: Red (2.5 YR 4/6) Coarse Gravelly Clay; light red (2.5 YR 6/8) dry; moderate medium subangular blocky structure; friable (moist), slightly sticky (wet); common continuous clay skins; common fine to very fine discontinuous random irregular interpedal pores; common very fine roots; gradual wavy boundary.

B3-horizon; 32 to 49 inches: Red (2.5 YR 4/6) Clay; light red (2.5 YR 6/8) dry; few fine prominent brownish yellow (10 YR 6/6) mottles; weak fine subangular blocky structure; friable (moist), slightly sticky (wet); common discontinuous clay skins; common fine to very fine discontinuous random irregular interpedal pores; few very fine roots.

Depth to Rock > 49 inches

Depth to Seasonally High Water Table > 49 inches

Described by: Dr. Barrett L. Kays, Licensed Soil Scientist

Note: This is an example of a soil profile description that would be included in a soil survey report for your site. The description should adhere to the standards contained in “Field Book for Describing and Sampling Soils”, Version 3.0, National Soil Survey Center, National Resources Conservation Service, USDA, 2012.

Figure 12. Profile Description for Schenck Site, Raleigh, NC

SOIL PROFILE DESCRIPTION

The soil textural names are included in a soil profile description which includes information on each soil horizon. The description includes a range of descriptive information (Figure 12) including depth, color, texture, structure, consistency, pores, roots, and boundary conditions. A soil survey report should also contain the laboratory data (Figure 13 and subsequent figures of laboratory data).

Hydrometer Test for Schenck Site

Depth	Horizon	OM	Sand	Silt	Clay	Texture	Total Fine Fraction[1]	Total Coarse Fraction[2]
in		%	%	%	%		%	%
0 – 3	A	8.6	45.2	33.8	21	Loam	70.6	29.4
3 – 17	AB	2.7	48.1	29.4	22.5	Loam	54.9	45.1
17 – 24	B1	1.6	33.8	27.5	38.7	Clay loam	33	67
24 – 32	B2	0.8	16.2	15.4	68.4	Clay	68.2	31.8

Sieve Analysis of Sand and Gravel for Schenck Site

		Sand[3]					*Gravel[4]*			
Depth	Horizon	VCS	CS	MS	FS	VFS	CG	MG	FG	Texture with Modifiers
in		%	%	%	%	%	%	%	%	
0 – 3	A	1.2	1.2	7.7	25.2	9.9	16	8.8	4.6	Coarse Gravelly Loam
3 – 17	AB	1.9	1.3	5.2	29.5	10.2	24.2	19.2	1.7	Very Gravelly Loam
17– 24	B1	1.3	1.1	4.1	18.9	8.4	23.1	14.6	29.3	Extremely Gravelly Clay Loam
24 – 32	B2	0.3	0.5	2.4	9.2	3.8	25.3	6.5	0	Coarse Gravelly Clay

[1] Fine Fraction– percent of sand, silt, and clay of total soil before gravel is removed.

[2] Coarse Fraction– percent of gravel in total soil before the sand, silt, and clay is removed.

[3] Sand is divided into very coarse sand, coarse sand, medium sand, fine sand, and very fine sand by sieving.

[4] Gravel is divided into fine gravel, medium gravel, and coarse gravel by sieving.

Soil Data, Courtesy of Author.

Figure 13. Example of Laboratory Particle Size Data

SOIL STRUCTURE

Soil structure is qualitative measure of the soil fabric and is used in field evaluations of soil horizons; it is the combination of primary soil particles into secondary units or peds. The secondary units are characterized on the basis of size, shape, and grade The names for different types of peds are: granular, angular blocky, subangular blocky, platy, prismatic, and columnar.

- Granular structure is a semi spheroidal shaped structure.
- Angular blocky structure has particles arranged around a point and bounded planes bounded by angular edges.
- Subangular blocky structure has particles arranged around a point and bounded mixed rounded and plane surfaces.
- Platy structure has particles arranged around a plane and generally horizontal.
- Prismatic structure has particles arranged around a vertical plane with relatively flat surfaces without rounded ends.
- Columnar structure has particles arranged around a vertical plane with relatively flat surfaces with rounded ends.

Soil pores located within the structural peds are referred to as interpedal pores, while pores that are on the surface or cross structural peds are referred to as transpedal pores (Figure 13).

BULK DENSITY

Bulk density refers to the density or weight per unit volume. The weight of soil is expressed in grams and volume is expressed in cubic centimeters[5]. Higher values are more dense; for example, the density of solid quartz rock is 2.65 g/cm$^{3.}$ The density of water is 1.00 g/ cm^3. A soil density of less than one means the soil is lighter than water (normally an organic soil). A soil density of between 1.0 to 1.65 cm^3 is common for mineral soils. A density of 1.65 cm^3 is considered sufficiently dense so that roots cannot penetrate the soil.

Different soil textures have different densities. Soil compaction will increase the bulk density. If a maximum bulk density of 1.40 g/cm^3, is desired the laboratory can blend the various bulk soil materials into a mix that, when compacted, will normally not exceed 1.40 g/cm^3. However, the maximum density of a soil is dependent upon the percent of moisture in the sample.

The bulk density is calculated from the weight of a given volume of soil after it has been completely dried in an oven for 24 hours. Soil samples should be delivered to the laboratory in a soil core so that there is a known volume. The soil in the metal core is shaved at the ends of the sample to create a smooth edge. Plastic caps are then placed on the ends to retain the field moisture content in the sample. The sample is weighed prior to drying so that the soil moisture content can be calculated by the laboratory. An example of bulk density and total porosity laboratory data is shown in Figure 14.

Bulk Density* and Total Porosity for Schenck Site

Depth	Horizon	Bulk Density	Total Porosity[1]
in		g/cm^3	%
0 – 3	A	1.23	52.6
3 – 17	AB	1.29	51.3
17 – 24	B1	1.53	42.2
24 – 32	B2	1.59	40

[1] Total Porosity – is calculated by (Density of Quartz – Bulk Density) / Density of Quartz; Porosity = (2.65 – 1.23) / 2.65
Soil Data, Courtesy of Author.

*This is an example of laboratory data where the bulk density of a soil core is determined by the dry weight of the soil. Total porosity is calculated from the bulk density. Another method is shown in Figure 20 where the porosity is determined by the volume of water that is drained out of the soil core.

Figure 14. Example of Bulk Density and Total Porosity Data

A cone penetrometer[6] can be calibrated using samples compacted in the laboratory to various densities. A cone penetrometer can then be used to estimate the bulk density of the soil on the

5 454 grams = 1 pound and 2.54 centimeters = 1 inch

6 Cone Penetrometer – is a hand held device for measuring the resistance of an in place soil; the bulk density can be estimated using a calibration curves for different moisture contents of the particular soil material.

job site. Care needs to be taken since the cone penetrometer values will vary for both the bulk density and the moisture content of a particular soil. Some practitioners also prefer the cone penetrometer for checking the estimated density of soil during the construction process.

SOIL POROSITY

Soil porosity is the quantity of voids in a soil sample. The porosity of a soil sample is calculated from the bulk density of the soil. A bulk density of 1.325 g/cm^3 is one half the density of solid quartz rock. Therefore, half the sample is solid and half the sample is porous and the soil has a porosity of 50%. Most mineral soils will have a porosity of around 50%. Organic soils will have a porosity of significantly more than 50% and a compacted mineral soil will have less porosity.

The most important concept about soil porosity is the size and type of voids in a soil. Total porosity is divided into macro-porosity, meso-porosity, and micro-porosity (Figure 15). The macro-pores are responsible for most of the water movement in soils when the soil is saturated with water. The meso-pores and micro-pores are responsible for most of the water movement in soils when the soil is unsaturated.

Classes of Pores	Subclasses	Pore Diameters	Pore Size Approximates the Size of:
Macro-pores	Coarse	> 5 mm	Medium gravel
	Medium	> 2 to 5 mm	Fine gravel
	Fine	> 1 to 2 mm	Very coarse sand
	Very Fine	> 0.075 to 1 mm	Very fine, Fine & Medium sand
Meso-pores		0.030 to 0.075 mm	Coarse silt
Micro-pores	Micro	> 0.005 to 0.03 mm	Fine & Medium silt
	Ultramicro	> 0.0001 to 0.005 mm	Clay

Figure 15. Soil Pore Classes and Pore Diameters

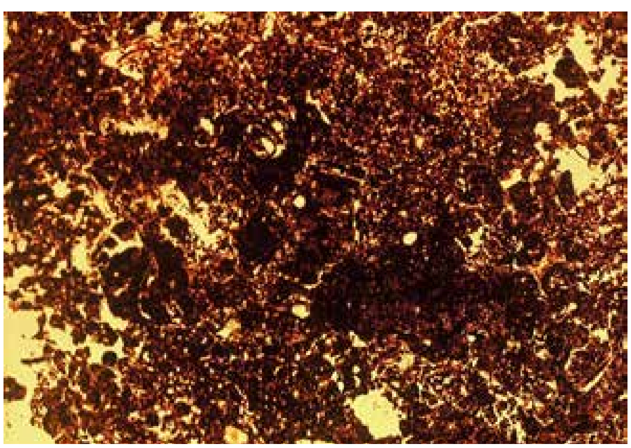


Figure 16. Porous Forest Loam Topsoil
Total Porosity = 63.9%
Macro-Porosity = 25.3%
Bulk Density = 0.957
Sugar Creek Watershed, Charlotte, NC

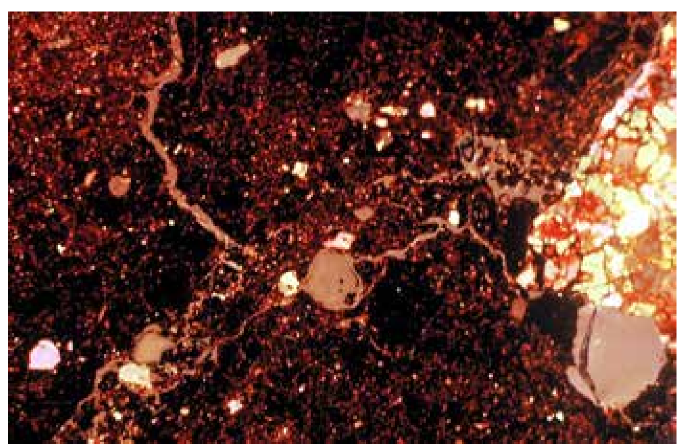


Figure 17. Porous Forest Clayey Subsoil
Total Porosity = 47.7%
Total Porosity = 47.7%
Bulk Density = 1.387
Sugar Creek Watershed, Charlotte, NC

Figure 18. Loamy over Clayey Fill
Total Porosity of Clay Layer = 42.3%
Macro-Porosity of Clay Layer = 4.1%
Bulk Density of Clay Layer = 1.529
National Mall, Washington, DC

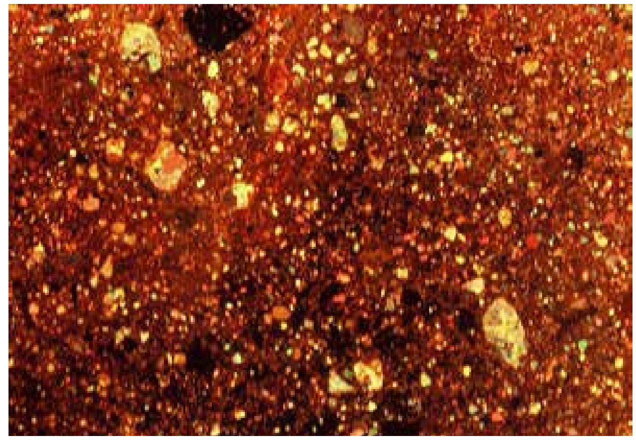


Figure 19. Compacted Clayey Fill
Total Porosity = 40.7%
Macro-Porosity = 3.8%
Bulk Density = 1.573
Sugar Creek Watershed, Charlotte, NC

OBTAINING A PORE SIZE DISTRIBUTION ANALYSIS

The pore size distribution is a specialty test, but it can be performed in many university soil physics laboratories (Figure 20). Saturated undisturbed soil cores are placed on a special pressure plate and allowed to drain under increasing soil moisture tensions. The water that drains at various soil moisture tensions can be used to determine the percent of macro-pores, meso-pores, and micro-pores.

Data for Schenck Site

Depth	Horz	Tension	Tension	Pore Dia.	Pore Dia.	Volume	Macro Porosity	Meso Porosity	Micro Porosity	Total Porosity
In		cm H_20	bars	mm	in	%	%	%	%	%
0–3	A	-3.8	-0.004	0.817	0.0322	0.57	6.67	6.46	39.47	52.6
		-10	-0.01	0.311	0.0122	1.02				
		-20	-0.019	0.155	0.0061	1.44				
		-30	-0.029	0.104	0.0041	1.73				
		-40	-0.038	0.078	0.0031	1.91				
		50	-0.048	0.062	0.0024	2.01				
		-60	-0.057	0.052	0.002	2.1				
		-100	-0.096	0.031	0.0012	2.35				
		-345	-0.33	0.009	0.0004	2.7				
17-24	B1	-3.8	-0.004	0.817	0.0322	0.07	2.31	2.58	37.31	42.2
		-10	-0.01	0.311	0.0122	0.34				
		-20	-0.019	0.155	0.0061	0.53				
		-30	-0.029	0.104	0.0041	0.64				
		-40	-0.038	0.078	0.0031	0.73				
		-50	-0.048	0.062	0.0024	0.81				
		-60	-0.057	0.052	0.002	0.85				
		-100	-0.096	0.031	0.0012	0.92				
		-345	-0.33	0.009	0.0004	1.05				

Note: This is an example of the amount of water that was drained from soil cores of these two horizons at various soil moisture tensions. This allows the soil scientist to calculate the volume of various pore diameters and determine the volume of macro-pores, meso-pores, micro-pores, and total porosity of the soil

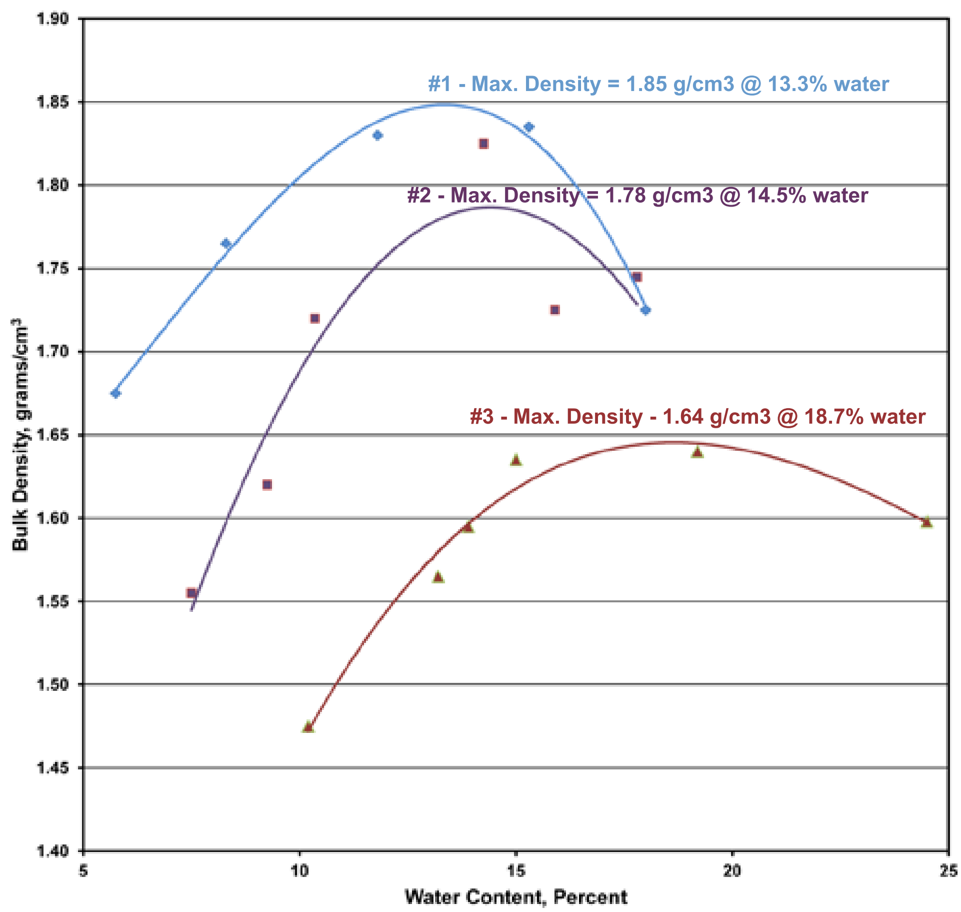
Soil Data, Courtesy of Author.

Figure 20. Example of Pore Size Distribution Data

SOIL MAXIMUM DENSITY

Soil engineers express the density of a soil in pounds per cubic foot. Soil scientists express bulk density in grams/cubic centimeter. Grams/cubic centimeter can be converted to pounds/cubic foot by multiplying grams/cubic centimeter by 62.328; a bulk density of 1.50 grams/cubic centimeter equals 93.64 pounds/cubic foot. Pounds/cubic foot can be converted to grams/cubic centimeter by dividing pounds/cubic feet by 62.328; 100 pounds/cubic foot equals 1.60 grams/cubic centimeter.

Soil engineers put soil into a compactor to determine the maximum density. Compaction tests are performed at different moisture contents so that the relationship between moisture content and maximum density can be determined. The percent of maximum density is referred to as the standard proctor density, for example 95% of maximum density. Figure 21 illustrates maximum density curves for three soils. Note that the curves do not always fit the data points. The maximum density is the density at the top of the curve. Also note that the maximum density is very dependent upon the water content of the soil.



Note: To determine maximum density, different amounts of water were added to five samples of each soil. Samples were mechanically compacted and the density was determined. After plotting the densities and moisture contents for each sample, a curve is drawn; the crest of the curve determines the maximum density.

Figure 21. Maximum Density Curves for Three Soils

The appropriate density of a planting soil is less than 1.60 grams/cubic centimeter or 100 pounds/cubic foot, which is considered the maximum density that roots can penetrate. Another measure of the appropriate density is to determine the hydraulic conductivity desired from a soil. The soil can be compacted, for example, to 85% maximum density and then the hydraulic conductivity can be measured in the laboratory at this density.

Compaction standards will typically require a minimum percent of maximum density to be achieved. The contractor understands how to achieve a minimum percent maximum density and if the contractor over compacts the soil it will have met the minimum standard. However, planting soil should be compacted so that it does not exceed a given density. It is easier for a contractor to exceed a given density when compacting, such as is necessary for a soil subgrade under a pavement, than it is for the contractor to avoid exceeding a maximum density, such as is critical for landscape planting soil. In the first case, it is beneficial to overly compact a subgrade for a pavement, but in the second case it is a major problem to exceed the maximum density for a landscape planting soil.

For example, in Figure 21, the maximum density of soil #3 is 1.64 g/cm3 and therefore 95% of maximum density is 1.56 g/cm3. If the water content is between 12.5% and 25%, it is more than likely that the soil is compacted more than 95% of maximum density. Since the soil material will likely have a moisture content in this range, it will be difficult for the contractor to avoid over compaction.

Layer 1 - Sieve Analysis of Sand Fraction

V. Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	V. Fine Sand	Grade of Sand	Sand D85	Sand D15
%	%	%	%	%	mm	mm	
12.3	18.2	24.8	28.7	16	Well	1.25	0.13[a]
0.3	46.4	52	1.2	0.1	Uniformly	0.75	0.50[b]

Layer 2 - Sieve Analysis of Very Coarse Sand Fraction – Choker Sand

Coarse Gravel	Medium Gravel	Fine Gravel	V.Co.Sand Sand	V.Co.Sand D90	V.Co.Sand D15
%	%	%	%	mm	mm
2.3	2.4	5.3	90.0	1.5	1.2

Layer 3 - Sieve Analysis of Fine Gravel Fraction

Coarse Gravel	Medium Gravel	Fine Gravel	V.Co.Sand Sand	Gravel D90	Gravel D15
%	%	%	%	mm	mm
0	3.1	92.3	4.6	3.5	2.20[c]

[a] Uniformity between layer #2 and layer #1 well graded sand = 1.50/0.13 = 11.5; fails uniformity standard. Bridging between layer #2 and layer #1 well graded sand = 1.20 < (0.13 x 8); no 1.2 > 1.04; which fails the uniformity standard and therefore the well graded sand will fall into the choker sand layer.

[b] Uniformity between layer #2 and layer #1 uniform sand = 1.50/0.50 = 3; meets uniformity standard .
Bridging between layer #2 and layer #1 uniform sand = 1.20 < (0.75 x 8) = 1.20 < 6.0, which means that the uniform sand will not fall into the sand choker layer and therefore no filter fabric is required.

[c] Uniformity between layer #3 and layer #2 = 3.50/1.20 = 2.9; meets uniformity standard.
Bridging between layer #3 and layer #2 = 2.20 < (1.50 x 8); yes 2.2 is < 12.0; meets bridging standard therefore no filter fabric is required.

Note: This is an analysis comparing the uniformity and bridging standard standards between adjoining soil layers. The landscape architect or soil scientist can perform this analysis to make sure that the soil particles in layer 1 will not fall into layer 2 and that layer 2 will not fall into layer 3. This elliminates the need for filter fabric, which tends to clog and is difficult to remove without serious damage to the landscape plantings.

Figure 22. Example of well and uniformly graded sand data

The correct size of sand or gravel particles needs to be determined for the soil mix. Sands are either described as "poorly graded" or as "well graded" based upon the mixture of different sizes of sand particles. Poorly graded sand contains a mixture of very coarse sand, coarse sand, medium sand, fine sand, and very fine sand.

Well-graded sand will have a mixture of most of these sand classes (Figure 22). Concrete sand or mortar sand consists of well-graded sands. The mixture of different sizes produces sand that has a higher bulk density due to the fact that the smaller diameter sands will fill in a portion of the voids in the coarser diameter sands, i.e. the sands will lock together when compacted. Well-graded sands have slower saturated hydraulic conductivities, less total porosity, and less macro-porosity.

Uniformly graded sand is produced by sieving out the coarser sand material and the finer sand material to leave a narrow range in sizes, e.g. medium and coarse sand with a range of 0.25 to 1.0 mm in diameter (Figure 22). The sand smaller than 0.25 mm and the sand larger than 1.0 mm have been removed. Uniformly graded sand will have a lower bulk density than the above poorly graded sand. Uniformly graded sand will typically have a higher saturated hydraulic conductivity, more total porosity, and more macro-porosity.

Uniformly Graded Sand Based Mix - Uniformly graded sand will maintain its total and macro-porosity regardless of how it is compacted. If the uniformly graded sand is mixed so that it is 80 to 90% sand and with 10 to 20% silt, clay, and soil organic matter, it cannot be overly compacted.

Well Graded Sand Based Mix - A mixture of 80 to 90% well graded sand with 10 to 20% silt, clay, and soil organic matter can easily be overly compacted because during the compaction process the particles are rearranged to achieve a density near that of concrete or brick. It is difficult for a contractor to avoid over compaction of a well-graded sand based soil.

One disadvantage of the uniformly graded sand is that it will have a lower content of plant available water vs. the poorly graded sand. Therefore, it is important to adjust the amount of silt, clay, and soil organic matter in the uniformly graded sand to increase the plant available water. Also, as is explained in a later chapter, uniformly graded sandy structural mixes can be placed in custom layers of soil to further increase the amount of plant available water.

A uniformly graded sand used as planting soil should have a total porosity of 35 to 60%. If the total porosity is 50%, then normally it should have 10 to 15% as macro-pores and meso-pores. During the compaction of a soil the macro-pores are first to be lost, next the meso-pores, and finally some of the micro-pores. The micro-pores are generally resistant to compaction unless it is excessive.

A loamy sand planting soil (using a well graded sand) should have a total porosity of 30 to 50% depending upon the degree of compaction. Due to the sand gradation, the soil will normally have a higher bulk density and thus less porosity than if uniformly graded sand was used.

WATER MOVEMENT

Infiltration is the rate that water flows into the surface of a soil. Infiltration occurs at atmospheric pressure and the flow of water is downward. The initial infiltration rate is typically fast; this is the time it takes the pores in the surface horizons to fill with water and expel air. Over time the infiltration rate decreases, typically due to the hydraulic limitations of subsurface horizons. The final constant infiltration rate is typically taken to be the rate after sixty minutes.

INFILTRATION – FIELD TEST USING DOUBLE RING INFILTROMETER

A double ring infiltrometer is used to measure the infiltration rate. Metal rings are driven into the soil to a depth of several inches into the subsoil. A small (0.5 inch) head of water is maintained over the soils surface. The flow rate in the middle ring is measured. The same small head of water is maintained in the outer ring. A constant head device should be used to maintain a constant head of water within the rings. The constant head device should be used to measure the flow rate in the middle ring every few minutes. Plotting an infiltration rate graph over sixty minutes will create a curve that is referred to as a decay curve in that the rate decreases over time. Normally at least three infiltration rate tests are conducted at any one location. The infiltration rate should first be measured when the soil is slightly moist, referred to as moist antecedent conditions; twenty-four hours later another set of tests are measured under wet antecedent conditions. Figure 23 illustrates infiltration curves for wet antecedent conditions.

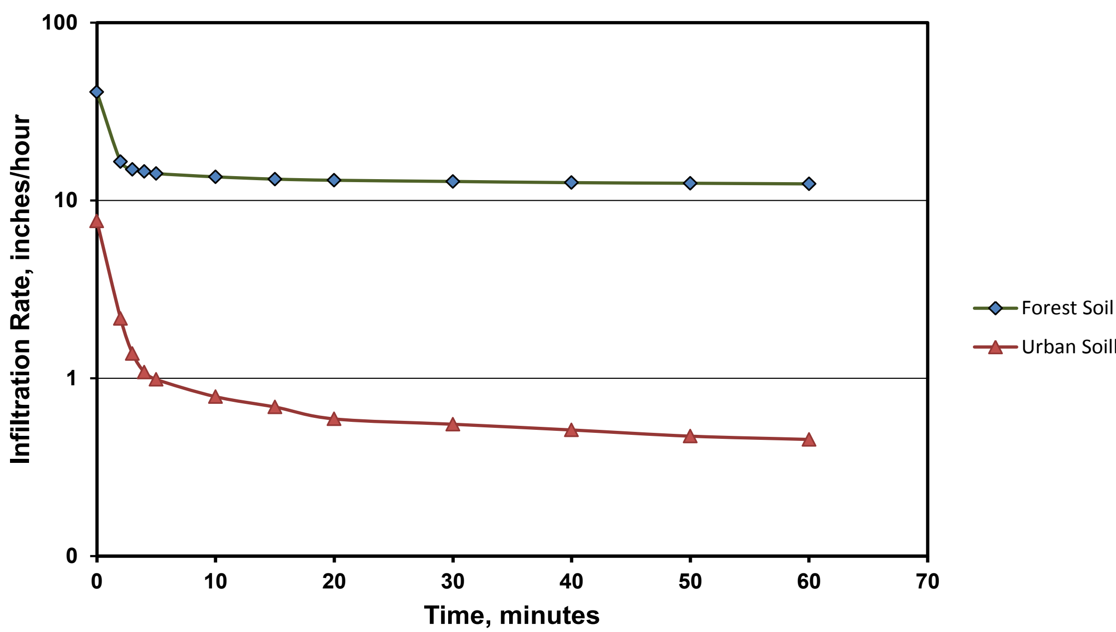


Figure 23. Wet Antecedent Infiltration Rate Curves for a Forest and Urban Soil

The final constant infiltration rate in a forest's soil profile is typically high as shown in the infiltration curve (Figure 23). The forest soil profile has an extremely porous humus layer and a small sample of the A-horizon contains thousands of macro pores (Figure 19). The A-horizon is in very good condition; it contains an abundance of roots and the soil is very loose and friable.

The A-horizon serves as the soil's reservoir for detention storage during a rainfall event. A healthy thick A-horizon might store two to four inches of rainfall or more, although somewhat less on slopes. Continued infiltration during large rainfall events occurs when there are macro-pores in the A-horizon that are well connected to tubular macro-pores and meso-pores in the subsoil. Therefore, water in the surface reservoir flows into the macro-pores and meso-pores in the subsoil. Water flows rapidly through continuous tubular macro-pores and meso-pores in the subsoil and then slowly flows into millions of micro-pores.

Soil macro-pores and meso-pores are fragile and can be easily disturbed or destroyed by grading and compaction. Think of the macro-pores, meso-pores, and micro-pores as a complex network, somewhat like the network of veins in human body. Blockage and disruption of the heart's veins can paralyze the heart's ability to pump blood. In a similar fashion, blockage and disruption of the soil pore network will cripple the infiltration process. Compaction significantly reduces porosity, blocking and tearing the pathways. The macro-pore network is the first casualty caused by introduction of motorized equipment in the forest as the first trees are cut.

Water flows faster through a soil that has a greater volume of macro-pores. Conversely, as the volume of macro-pores is reduced, the rate of water movement is severely restricted. The relationship between soil macro-porosity and flow of water is shown in Figure 24.

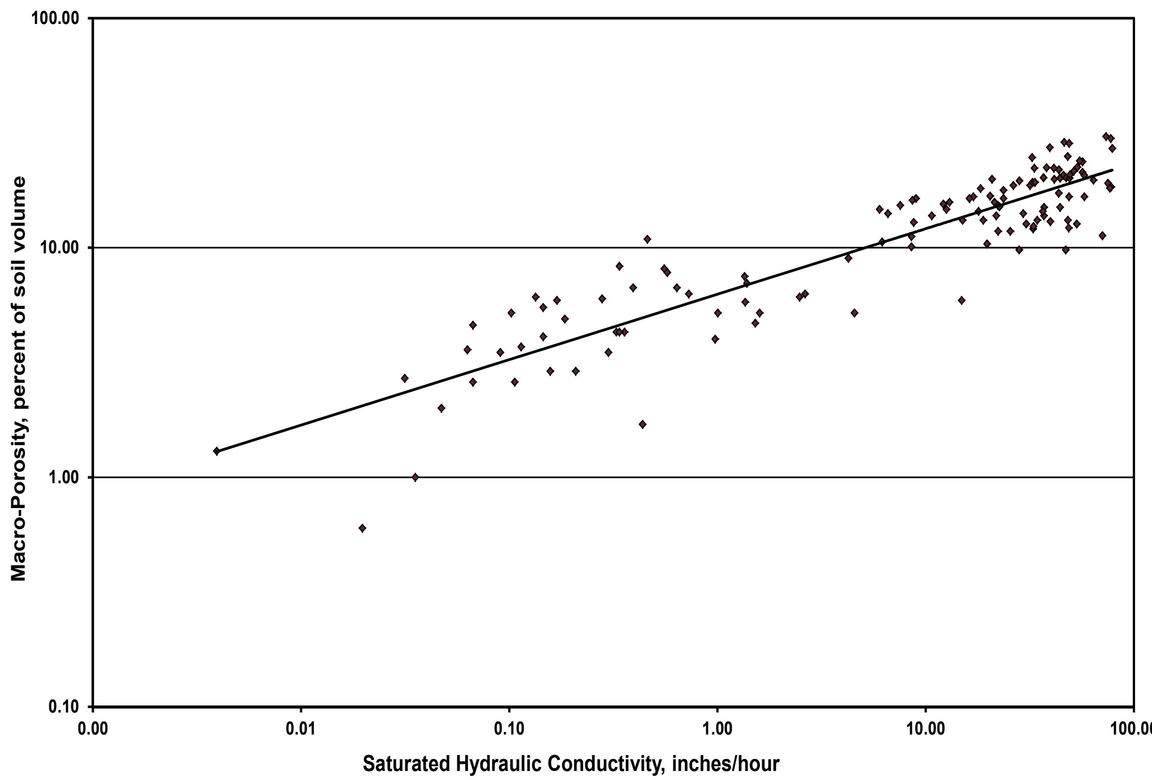


Figure 24. Macro-Porosity vs. Rate of Hydraulic Flow for Sugar Creek Watershed, Charlotte, NC

SATURATED HYDRAULIC CONDUCTIVITY – LABORATORY TEST

Hydraulic conductivity is a quantitative measurement of the rate that water flows through a soil. At least three undisturbed soil core samples should be collected for each horizon and type of soil for the laboratory measurement of the saturated hydraulic conductivity.

Hydraulic conductivity is calculated using Darcy's Law:

$$Q = KS(H+e)/e$$

Where:

- Q – is the volume of water that passes through the soil core in unit of time (inches/hour)
- K – is a coefficient based upon the soil media, K is proportional to the porosity of the soil material
- S – is the cross sectional area of the soil core (cubic inches)
- H – is the depth of the water (head) on top of the soil core
- e – is the thickness or height of the soil core (inches)

The above equation shows the relationship of the variables. In practice this equation is normally not used, since the actual hydraulic conductivity is best measured in-situ. The saturated hydraulic conductivity is the preferred measurement of water flow in subsurface horizons in a soil profile. Most landscape soils should be blended to achieve a hydraulic conductivity of 2 to 5 inches/hour. However, rates of 5 to 10 inches/hour or more are typical of structural soils and bioretention soils. If it is critical to the design, the landscape architect needs to specify that the hydraulic conductivity be measured after installation of the planting soil to assure that the soil will function properly.

Figure 25. Constant head permeameter, New York, NY

IN-SITU HYDRAULIC CONDUCTIVITY – FIELD TEST

The saturated hydraulic conductivity can also be measured in the field by using a constant head permeameter to accurately measure in-situ hydraulic conductivity (Figure 25 and 26). The permeameter will maintain a constant depth of water in an unlined bore hole that extends down into the horizon to be measured. The greater the volume of macro-pores then the greater the saturated hydraulic conductivity. Figure 24 illustrates data from many soils and shows the relationship between more large pores and higher conductivities.

Saturated Hydraulic Conductivity and Infiltration Rates for Schenck Site

Horizon	Saturated Hyd. Cond.[1]	Final Constant Infiltration Rate[2]
	in/hr	in/hr
A	13.9	3.74
AB	4.23	
B1	0.7	
B2	0.31	

[1] Saturated Hydraulic Conductivity– the mean laboratory values measured from soil cores; also known as Ksat.

[2] Final Constant Infiltration Rate – the rate of infiltration after one hour; note the rate is lower than Ksat for A-horizon; AB-horizon limits the flow after the initial filling of the soil pores.

Figure 26. Example of Hydraulic Data

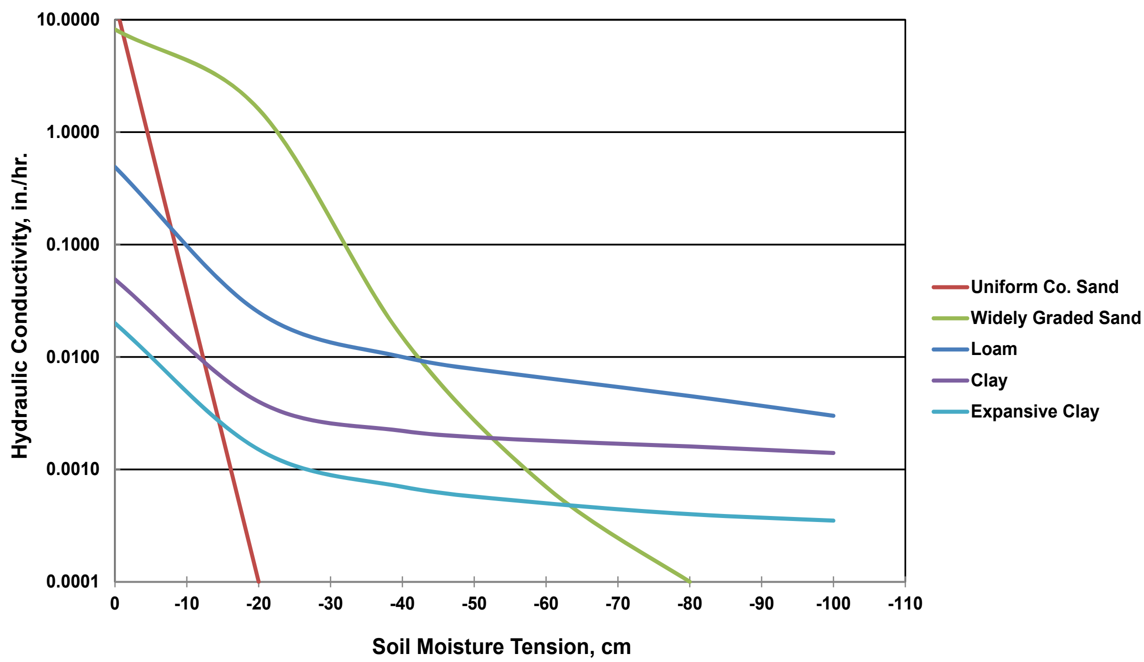


Figure 27. Hydraulic Conductivity vs. Soil Moisture Tension

UNSATURATED HYDRAULIC CONDUCTIVITY

In reality, most undisturbed soils are rarely saturated even during an intense rainstorm. When the soil is not totally saturated with water, the flow is referred to as unsaturated flow. Most of the time water moves in soils by unsaturated flow. In unsaturated flow water moves in the direction of greatest soil moisture tension or greatest negative tension. Figure 27 illustrates saturated flow (at zero soil moisture tension) and varying states of unsaturated flow for five different types of soil. The rate of water movement drops dramatically when the soil becomes unsaturated.

Unsaturated flow becomes interesting in layered soil systems. Looking at the graph in Figure 27, if a uniform coarse sand layer at -20 cm[7] of soil moisture tension is constructed on top of a well graded sand layer which is at -45 cm of soil moisture tension, which direction will water flow between the two sands? Since the flow is in the direction of the greater tension, the water will flow into the lower layer that is at -45 cm of tension. However, if a well graded sand layer at -45 cm of soil moisture tension is above a uniform coarse sand layer at -25 cm tension, then the water will not flow downward, but will flow upward in the direction of the greater soil moisture tension. The uniform coarse sand layer will cause water to be held in the upper sand layer.

PLANT AVAILABLE WATER

Traditionally, plant available water is the water that is held between soil moisture tension of 1/3 bar and 15 bars. A soil water characteristic calculator[8] can be used to estimate the amount of plant available water depending upon the soil texture, organic matter, and relative density. Some soil physical testing laboratories will provide testing of soils using pressure plates at various soil moisture tensions (-1/10, -1/3, -15 bars). Figure 28 illustrates typical amounts of plant available water.

Sand	Silt	Clay	Soil Texture	Organic Matter	Relative Density	PAM[1]	PAM
%	%	%		%		in./ft.	%
85	5	10	Loamy Sand	2.5	Normal	0.69	5.8
				2.5	Hard	0.41	3.4
				5	Normal	0.82	6.8
				5	Hard	0.58	4.8
				7.5	Normal	1.0	8.3
				7.5	Hard	0.81	6.8
65	20	15	Sandy Loam	2.5	Normal	1.14	9.5
				2.5	Hard	0.87	7.3
				5	Normal	1.31	10.9
				5	Hard	1.06	8.8
				7.5	Normal	1.49	12.4
				7.5	Hard	1.28	10.7
40	40	20	Loam	2.5	Normal	1.71	14.3
				2.5	Hard	1.44	12
				5	Normal	1.86	15.5
				5	Hard	1.63	13.6
				7.5	Normal	2.05	17.1
				7.5	Hard	1.93	16.1
20	65	15	Silt Loam	2.5	Normal	2.35	19.6
				2.5	Hard	2.07	17.3
				5	Normal	2.52	21.0
				5	Hard	2.31	19.3
				7.5	Normal	2.72	22.7
				7.5	Hard	2.55	21.3

[1] PAM– the Plant Available Water content of a soil.

Note: This table illustrates a range of plant available water estimates from various soil textures, % organic matter, and relative densities of the soil.

Figure 28. Plant Available Water Using Soil Water Characteristic Calculator

7 Soil moisture tension values are negative therefore -20 cm, represents a negative 20 centimeters.

8 Soil Water Characteristic Calculator – www.hydrolab.arsusda.gov/soilwater/Index.htm

Field capacity is a measure of the amount of water available in the soil after draining. Field capacity is dependent upon the type and arrangement of soil horizons in the soil profile, texture, porosity, saturated and unsaturated conductivities, and slope. To determine field capacity, a soil profile is completely saturated with water and the amount of water that remains in a soil profile after draining for either a one, two, or three day period is calculated.

The inverse of field capacity is the drainage porosity; it is sometimes erroneously referred to as field capacity. For example, a local agency indicates that the amount of irrigation cannot exceed field capacity. In some cases, the topsoil can be dry and the subsoil may be moist after drainage. Therefore, the local agency will not allow irrigation even though the rooting zone is dry. Ideally, you would want to irrigate an amount that is approximately equal to 25% of the drainage porosity.

SOIL ENGINEERING AND CLAY MINERALOGY

Soil engineers conduct a wide range of soil testing for civil and structural engineering. The Atterburg Limits[9] data is useful for landscape architects in that it indirectly deals with the liquid and plastic moisture contents when a soil is in a liquid or plastic state. The Atterburg data often correlates with the amount and mineralogy of the clay in the soil (Figure 29). A planting soil should have some clay in its composition, but not too much, and it should not contain expansive clays, such as montmorillonitic clays. Expansive clays are found in subsoils in the presence of certain types of geology. Know from experience if the region has expansive clay minerals, review the Atterburg data in a soil engineering report for the site, read the engineering or clay mineralogy data in the county soil survey, or review the Cation Exchange Capacity data from the samples to submit for laboratory testing.

Clay Mineralogy	Depth	Horizon	Clay	Plastic Limit[1]	Liquid Limit[2]	Plastic Index[3]	Total Soil CEC[4]	Clay CEC[5]	Clay CEC[6]
	in		%	%	%	%	@pH 7.0	@pH 8.2	@pH 7.0
Kaolinite	24 – 32	B2	68.4	27.7	39.9	12.2	12.2	18.6	17.8
Montmorillonite	24 – 30	B2	63.8	44	86	42	42.4		66.4

[1] Plastic Limit– an engineering measurement (Atterburg Limits) of the plasticity of soil; percent moisture content when soil is said to become plastic.

[2] Liquid Limit–an engineering measurement (Atterburg Limits) of the liquidity of soil; percent moisture content when soil is said to become liquid.

[3] Plastic Index– an engineering value (Atterburg Limits) of liquid limit minus the plastic limit; the smaller the value the easier the soil moves from plastic state to liquid state.

[4] CEC7.0 – the cation exchange capacity at pH 7.0 of the total fine earth fraction (sand, silt, and clay)

[5] CEC8.2 – the cation exchange capacity at pH 8.2 of the total fine earth fraction (sand, silt, and clay) and is used to determine if the clay minerals are not expansive (values of < 16), slight expansive (values of 16 to 35), highly expansive (values > 35)

[6] CEC7.0 – the cation exchange capacity at pH 7.0 of the clay fraction only; note that the CEC is much higher than the CEC for the total fine earth fraction (sand, silt, and clay)

Soil Data, Courtesy of Author and Floyd, Neal C., Jr. 1982. Evaluation of the Swelling Potential of Selected North Carolina Soils. Master's Thesis, Department of Soil Science, NC State University, Raleigh, NC

Figure 29. Plant Available Water Using Soil Water Characteristic Calculator

9 Atterburg Limits is a measure of the intrinsic ability of soil to move into a liquid or a plastic state at a given moisture content. The test method for liquid limit, plastic limit and plasticity index is at ASTM D-4318 and the results are used for classification of soils for engineering purposes at ASTM D-2487.

ORGANIC SOILS

Organic soils are often used for wetland restoration and creation, as well as in some aquatic landscapes. Bulk density, soil porosity, hydraulic conductivity, and moisture holding capacity tests can all be performed on organic soils. The particle size analysis and sand sieve analysis are not normally used for highly organic soils. Organic soils are typically evaluated based upon the organic content, density, and moisture holding capacity.

Organic Content - The amount of organic matter is one of the most important tests for organic soils. Organic humus provides for the retention of water and nutrients in the soil.

Bulk Density - The bulk density of organic soil with substantial amounts of visible organic fibers may be less than 0.50 g/cm3. Samples with little or no visible organic fibers may have bulk densities of 0.50 to 1.00 g/cm3. It is best to collect undisturbed soil cores for measurement of bulk density.

Plant Available Water - Disturbed samples of each type of the organic soil should be collected for laboratory pressure plate testing of -1/3 bar and -1/15 bar. The plant available water in organic soils is proportional to the percent of soil organic matter.

COMPOST TESTING

Compost testing is important because the products can vary widely in the percent of soil organic matter, organic carbon, degree of decomposition, and pH. Compost to be mixed with mineral soils should contain a minimum of at least twenty percent soil organic matter.

The pH of the organic matter is important and should preferably be 4.5 to 5.5. The lower the pH the more acidity will be created in the soil mix. The electrical conductivity (salt content) should be less than 5000 micro-mohs/cm. The compost must be screened and should pass through a screen with ¼-inch or ½-inch openings. The compost must be produced by a recognized member company of the US Composting Council and tested by approved laboratory using Test Methods for the Examination of Composting and Compost (TMECC). The compost should have received the USEPA Seal of Testing Assurance. The compost is measured on a cubic yard basis (volume rather than weight) for mixing with soil materials.

Highly decomposed and finely divided organic matter is referred to as humic matter. Most commercial certified composts are best suited for a mulch layer rather than mixing with soil due to the low percent of humic matter[10]. Compost with a high amount of humic matter is preferred for soil amendments because the humic matter is very stable and less likely to decompose in the soil. The humic matter is also the most chemically active portion of organic matter.

Soil Humic Matter Percent is a measure of the portion of organic matter that has fully decomposed, is microscopic, and coats soil particles. Humic matter represents the portion of organic matter that is chemically active.

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10 Humic Matter – formed by secondary synthesis reactions in soils including humic acid, fulvic acid, and humin; humic matter coats and colors soil particles and humic particles are not visible to the eye.

Soil Chemistry Concepts

Landscape architects should submit soil samples for laboratory testing of soil chemistry, fertility, and biology analysis. It is better to obtain this data early in the design process. It will help in making better decisions about amending the existing site soil or import native soils. It is impossible to prepare an adequate soil specification for planting soils without this data.

SOIL FERTILITY ANALYSIS

Samples from each soil horizon to be amended or imported should be collected for soil fertility analysis. Composite samples of the soil should be collected over each landscape management area. The fertility analysis should include the recommended amendments to the soil to be applied by the landscape contractor.

Soil pH is a measure of acidity v. alkalinity of the soil. Certain plants are adapted to low pH values and others to high pH values; however, most plants prefer a pH of 6.5 to 7.5 because nutrients are more available to plants at this pH range (Figure 30). At low pH (4.5 to 5.5) iron, aluminum, copper, and zinc can become toxic to most plants. At high pH (7.5 to 9.5) iron, aluminum, copper, and zinc become unavailable to most plants. In acidic regions, a pH of 6.5 to 7.0 is preferred, and in alkaline regions a pH of 7.0 to 7.5 is preferred. An acceptable range of pH for organic and mineral-organic soils is 5.0 to 5.5.

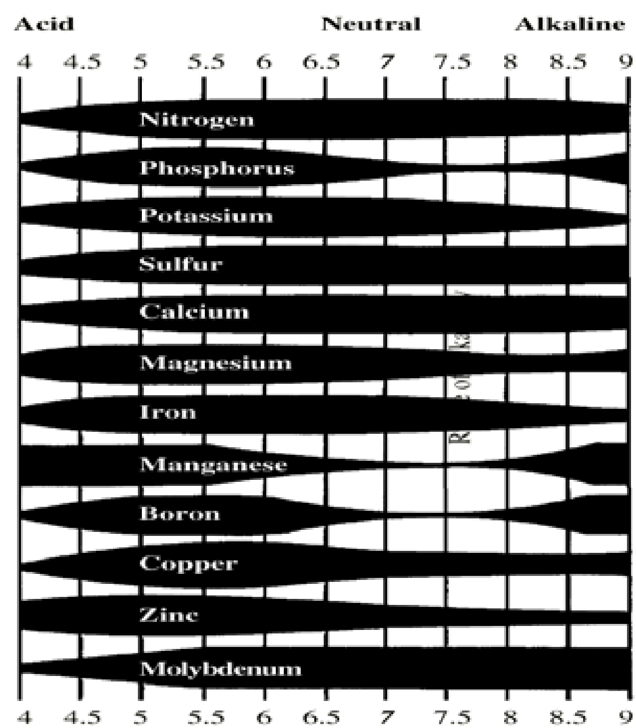

Figure 30. Effect of Soil pH on Plant Nutrient Availability

Figure 30 shows the availability of nutrients across the range of pH values. The thicker the bar, the greater the availability of the nutrient. Iron, magnesium, and manganese are higher in concentration at low pH, sometimes at toxic levels. Iron, magnesium, manganese, copper, and zinc are lower in concentration at pH of 7 to 8, sometimes causing deficiencies in plants.

Cation Exchange Capacity (CEC) is a measure of the amount of nutrient retention and exchange that can occur; it is measured as milliequivalent/100 grams of soil (meq/100g). The soil CEC value increases with increased amounts of clay in the soil and the type of clay mineral and organic material has a large effect on the CEC (Figure 31). Surface soils will have different CEC values due to the amount of clay, type of clay, and amount of organic material (Figure 32).

Type of Mineral/OM	Cation Exchange Capacity
	meq/100 grams
Kaolinite clay	3 to 15
Illite clay	15 to 40
Montmorillonite clay	40 to 80
Peat moss	100 to 250

Figure 31. Cation Exchange Capacity of Clay Minerals & Organic Matter

Texture	Cation Exchange Capacity
	meq/100 grams
Sand	2 to 3
Sandy loam	2 to 15
Loam	7 to 15
Silt loam	10 to 25
Clay	5 to 50

Figure 32. Cation Exchange Capacity of Surface Soils

Base Saturation Percent is the portion of the CEC that is occupied by nutrient cations, primarily calcium, magnesium, and potassium. Higher base saturation reduces acidity and increases the availability of other plant nutrients. A base saturation of 50% means that half of the cation exchange capacity is occupied by calcium, magnesium, and potassium cations and the other half of the capacity has hydrogen and/or aluminum. The positive charged cations are bonded to negative charges on the clay particles. A high percent of hydrogen/aluminum bonding means a low pH, while a low hydrogen/aluminum bonding means a high pH. A base saturation of 100% means that all of the CEC has the calcium, magnesium, and potassium cations bonded and there is no hydrogen or aluminum.

Exchangeable Acidity is a measure of the portion of CEC occupied by acidity factors, hydrogen, and aluminum. The acidity increases as the pH decreases.

Nitrogen Mineralization testing is provided only by a limited number of laboratories. It is a measure of the amount of nitrogen that will become available from soil organic matter as the soil temperature increases in the spring. Planting soils do not have an adequate supply of nitrogen from this source alone.

Nitrate Nitrogen is a measure of the amount of nitrogen in the soil that is available to plants. However, nitrate nitrogen readily leaches through the soil if it is not taken up by plant growth. Therefore, supplemental nitrogen is generally needed each year for the adequate growth of landscape plants.

Phosphorus Index is a quantitative value of plant available phosphorus; a range of 50 to 100 is acceptable for planting soils without supplemental fertilizer.

Potassium Index is a quantitative value of plant available potassium; a range of 50 to 100 is acceptable for planting soils without supplemental fertilizer.

Calcium Percent is a measure of the portion of the CEC occupied by calcium.

Magnesium Percent is a measure of the portion of the CEC occupied by magnesium. Low magnesium levels are typically associated with low pH soils. If supplemental magnesium is needed, it is usually applied in the form of dolomitic limestone, since liming is probably also needed to raise the soil pH.

Manganese Index is a quantitative value of plant available manganese; a range of 50 to 100 is acceptable for planting soils without supplemental fertilizer.

Zinc Index is a quantitative value of plant available zinc; a range of 50 to 100 is acceptable for planting soils without supplemental fertilizer.

Copper Index is a quantitative value of plant available copper; a range of 50 to 100 is acceptable for planting soils without supplemental fertilizer.

Sodium Index is a measure of the portion of the CEC occupied by sodium; a sodium level of less than 15% is acceptable and levels of greater than 15% are excessive and harmful to plants not adapted to saline conditions.

Soluble Salt Index is a measure of the amount of soluble salts.

CEC	BS[1]	pH	Ac[2]	P-I[3]	K-I[4]	Ca[5]	Mg[6]	S-I[7]	Mn-I[8]	Zn-I[9]	Zn-Al[10]	Cu-I[11]	Na[12]
Meq/100g	%		meq/100g			%	%						meq/100g
3.6	54	6.1	1.5	125	31	49	5.4	23	56	33	55	50	0.1

Note: Laboratory's fertilizer recommendations based upon the above data – per acre and 6-inch depth (double for 12-inch tillage depth) Lime - 1.2 tons[13], Nitrogen - 50 lbs.[14], Phosphorus (P2O5) - 10 lbs.[15], and Potassium (K2O) – 80 lbs.[16] per acre, respectively[17].

[1] BS – base saturation
[2] Ac – exchangeable acidity
[3] P-I – phosphorus index
[4] K-I – potassium index
[5] Ca – abbreviation for calcium
[6] Mg – magnesium
[7] S-I – sulfur index
[8] Mn-I – manganese index
[9] Zn-I – zinc index
[10] Zn-Al – zinc aluminum index
[11] Cu-I – copper index
[12] Na – sodium

[13] Lime – agricultural lime which has been finely ground is useful to raise the pH in acidic soils. The lime contains calcium carbonate as well as other minerals; the label contains the percent of calcium carbonate equivalent or the percent purity.

[14] Nitrogen – an essential element for plant growth. The tag on a bag fertilizer indicates the amount of nitrogen, phosphorus, and potassium. The first number represents the amount of nitrogen in the fertilizer. A 10-20-10 fertilizer contains 10% nitrogen therefore it will take 500 lbs. of the fertilizer to yield 50 lbs. per acre of nitrogen.

[15] Phosphorus (P2O5) – phosphoric acid; Phosphorus is an essential element for plant growth. The tag on a bag fertilizer indicates the amount of nitrogen, phosphorus, and potassium. The second number represents the amount of phosphorus in the fertilizer. A 10-20-10 fertilizer contains 20% phosphorus therefore it will take 50 lbs. of the fertilizer to yield 10 lbs. per acre of phosphorus.

[16] Potassium (K2O) – potassium oxide; Potassium is an essential element for plant growth. The tag on a bag fertilizer indicates the amount of nitrogen, phosphorus, and potassium. The third number represents the amount of potassium in the fertilizer. A 10-20-10 fertilizer contains 10% potassium therefore it will take 800 lbs. of the fertilizer to yield 80 lbs. of potassium.

[17] Fertilizer consisting of 50-10-80 or equivalent ratio would require a special mix.

Figure 33. Example of Soil Fertility Data for Schenck Site Surface Soil

SOIL BIOLOGICAL ANALYSIS

Soil biological analysis is preferred by some landscape architects; however few laboratories provide biological analysis of soils. The types of biological analysis include nitrogen mineralization rates, soil organic matter analysis, and microbiological assay.

The soil biological function criterion in the Sustainable Sites Initiative™ (SITES™) requires a measurement of the potential mineralizable nitrogen (PMN) in the soil. The potential mineralizable nitrogen is a laboratory determination of the weekly rate of nitrogen that will be released from soil organic matter. The release of nitrogen typically occurs in a narrow window during approximately the first two weeks of the growing season. The nitrogen is released during the decomposition of organic matter in the spring as the soil warms sufficiently due to increased biological activity. The release period of several weeks takes place in March and April in the south and in May and June in the northern contemporaneous United States. Since the release is dependent upon the soil temperature in any given year, the release period of nitrogen will vary each year. The SITES standard requires that the biological release must equal or exceed 8.0 micrograms of nitrogen/gram/week for sandy soils, 8.5 for silty soils, and 11.5 for clayey soils.

1. Ammonium Production During Waterlogged Incubation Method – This method incubates the soil sample at 40°C temperature for seven days. The amount of nitrogen mineralization is measured for the week.

2. Inorganic Nitrogen Production During Long-Term Aerobic Incubation – This method incubates the soil sample at 35°C temperature and the nitrogen is leached from the soil sample four to six times over an eight to twelve week period. The SITES criterion does not indicate the use of the average for this period, or the maximum weekly value.

3. Other methods – Other testing procedures do not incubate the soil samples over time, which is essential in order to meet the SITES standard. For example, the Illinois Soil Nitrogen Test does not use either of above two methods.

Soil organic matter tests include carbon, organic matter, and humus matter. The carbon analysis testing is by wet or dry combustion of the soil organic matter. The organic matter analysis involves the oxidation with H_2O_2 or loss by ignition methods. Humic analysis involves chemical treatment with a caustic alkali and extraction with mineral acids. Testing should be performed according to laboratory methods described in *Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties* published by the Soil Science Society of America.

Microbiological assay is used to determine the abundance and balance of various types of biological organisms in the soil. The microbiological assay can typically involve determination of (a) Active Bacteria/Active Fungi Ratio, (b) Total Bacteria/Total Fungi Ratio, (c) Nematode Assay, (d) Protozoa Assay, (e) Mycorrhizal Fungi Assay, and (f) Micro Arthropod Assay. Testing should be performed according to laboratory methods described in *Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties* published by the Soil Science Society of America.

Restoring and Amending On-Site Soils

This chapter looks at ways to preserve native soils, restore previously damaged soils, and prevent damage to soils during the construction process. The goal of these approaches is to create high performing and sustainable landscapes.

It is important to identify early in the design process the soil problems on the project site. In order to identify the problems in sufficient detail, an on-site soil survey, and soil sampling and data will be needed. Whenever possible, landscape architects should strive to work with the existing because the results are likely to be more sustainable than if off-site native soils or manufactured soils are imported. However, there are instances when the project site has been previous disturbed to such an extent that it is difficult to amend the soils. Disturbed soils often require multiple types of amendments to the soil physical, chemical, and biological characteristics. Therefore, a detailed soil restoration plan will need to be prepared during the design phase. See a later chapter for more information on soil restoration plans.

Frequently soils are disturbed during the construction process, necessitating restoring and amending. The most common types of man-made disturbance are the compaction of soils, grading operations that exhume subsoils to the new land surface, and covering of native soils.

Identifying the Problems and Solutions

SOIL COMPACTION

Landscape architects can preserve existing native soils by prohibiting equipment from certain areas on the site, but fines or penalties are required to assure adherence to the preservation. Just one pass of large equipment across an area can create significant impacts.

After the grading and construction have been completed on the site, most soils will need physical amendment to reduce the compaction caused by construction activities. Soil compaction is the most common man-made problem. Contractors know how to compact soils and they are very good at it. Soil engineers have developed methods and tests to assure that compaction has been achieved. However, landscape architects do not have good ways to assure that soil will not be excessively compacted. If you want the soil compaction to be between 80 and 85% of maximum density, you will need to field test the number of passes of the compaction equipment at different moisture contents to properly advise the contractor.

Native topsoil is very effective at infiltration and storage of rainstorm events; however minor compaction can destroy much of the macro-porosity. Grading activities that strip topsoil frequently destroy the macro-porosity and some of the micro-porosity of the new surface.

Figure 34 illustrates how agricultural and urban alterations to the soil profile have impacted infiltration rates. Line #1 represents undisturbed native soil profiles; lines #2, 3, and 4 represent degrees of disturbance from agricultural cultivation; and lines #5, 6, and 7 represent disturbance from grading activities during development. The last column shows the percent reduction in the infiltration rate. The impact on infiltration rates is enormous.

Sugar Creek Watershed, Charlotte, NC [1][2]

	Pre-1960's Land Use	Pre-1960's Alteration	Post-1960's Alteration	Average Infiltration Rate Rate & Percent Reduction	
				Inches/Hour	% Reduction
1	Mature Forest	No alteration	No alteration	12.43	0
2	Cultivated field	Cultivation	No alteration	4.41	64.5
3	Cultivated field	Plow pan	No alteration	1.89	84.8
4	Cultivated field	Plow pan	Compaction	0.29	97.7
5	Mature Forest	No alteration	Cuts into subsoil	0.67	94.6
6	Mature Forest	No alteration	Fills with subsoil	0.49	96.1
7	Cultivated field	Cultivation	Heavy compaction	0.17	98.6

Infiltration rate measured after 1 hour and proceeded by wet antecedent conditions.

[1] Kays, Barrett L. 1980. "Relationship of Forest Destruction and Soil Disturbance to Increased Flooding in the Suburban North Carolina Piedmont". Proceeding of the Metropolitan Tree Improvement Alliance 3:118-125.

[2] Kays, Barrett L. and James C. Patterson. 1982. "Soil Drainage and Infiltration", Chapter 5, In Phillip J. Crawl (ed.) *Urban Forest Soils* , Syracuse, New York.

Figure 34. Example of Soil Fertility Data for Schenck Site Surface Soil

Figure 35 illustrates how the loss of macro-pores, meso-pores, and micro-pores has impacted the infiltration rates for the soils. The loss of macro-pores in the subsoil is most closely related to the reduction in infiltration rates. Although a fair amount of macro-pores are retained in disturbed subsoils (row #2 through #6) the pores are broken and not very continuous due to the machine cutting, filling, and compaction of the subsoils.

Sugar Creek Watershed, Charlotte, NC [1]

	Pre-1960's Land Use Macro-Pores	Topsoil Meso/Micro-Pores	Subsoil Macro-Pores	Average Meso/Micro-Pores	Average Infiltration Rate
	%	%	%	%	Inches/Hour
1	25.3	38.6	8.3	39.3	12.43
2	21.7	37.4	5.3	41.2	4.41
3	15.2	36.9	4.8	38.4	1.89
4	12.5	36.7	7.3	32.7	0.29
5	18.4	36.7	6	39.7	0.26
6	14.9	37	3.4	35.8	0.49
7	16.8	41.4	1.3	42.2	0.17

[1] Kays, Barrett L. 1979. *Relationship of Soil Morphology, Soil Disturbance and Infiltration to Stormwater Runoff in Suburban North Carolina Piedmont, Department of Soil Science, North Carolina State University*, Raleigh, NC, 348 pp.

Figure 35. Soil Porosity vs. Infiltration Rate of Cecil Soils

Professional soil scientists have proposed various ways to amend the effects of compaction and restore infiltration rates[1]. There is an extensive body of soil science research documenting that deep tillage and deep fertilization is effective in improving rooting depths and plant growth of many crops[2]. Only in recent years has deep tillage and deep fertilization research been

1 Pitt, R, et al. 2008. Compaction's Impacts on Urban Storm-Water Infiltration. Journal of Irrigation & Drainage, ASCE 134:652-658.

2 Fehrenbacher, J.B., et al. 1958. Deep tillage and deep fertilization experiments on a claypan soil. SSSAJ 22(6):553-557; Baumhardt, R.L., et al. 2008. Long-term effects of profile-modifying deep plowing on soil properties and crop yield. SSSAJ 72(3):677-682; Sumner, M.E., et al. 1986. Amelioration of an acid soil profile through deep liming and surface application of gypsum. SSSAJ 50(5):1254-1258.

extended to highly disturbed soils and compacted urban soils[3]. Urban research by soil scientists has shown this approach to be very effective. The approaches include mixing a high amount of organic matter into the soil, tillage of the soil, and fertilization of the soil. Recent research at North Carolina State University has studied how to alleviate the impacts of compaction[4]. Research plot studies were conducted at the Lake Wheeler Field Laboratory in Raleigh, NC, the Sandhills Experiment Station in Jackson Springs, NC, and the Mountain Horticultural Research Center near Asheville, NC. The soils studied included sandy subsoils in the Sandhills Region, fine-loamy subsoils in the Mountain Region, and clayey subsoils in the Piedmont Region.

Figure 36. Establishment of deep tillage enhanced infiltration research plots.

3 Dunker, R.E., et al. 1995. Deep tillage effects on compacted surface-mined land. SSSAJ 59(1):192-199; Brown, Virginia. 2012. Establishing and Maintaining Enhanced Infiltration on Compacted Construction Site Subsoils Through Shallow and Deep Tillage with Soil Amendments. Master's Thesis, Department of Soil Science, NC State University, Raleigh, NC; Patterson, James C. 1976. "Soil Compaction and Its Effects on Urban Vegetation, In Better Trees for Metropolitan Landscapes, USDA Forest Service, Gen. Tech. Report NE-22, p. 91 -102; Patterson, James C. and Donald L. Mader. 1982. "Soil Compaction: Causes and Control", Chapter 3, In Urban Forest Soils, Philip J. Crawl (ed.), Syracuse, New York.

4 McLaughlin, Richard. 2013. "Using Basic Agronomic Principles for Urban Soil Remediation", Paper to 56th Annual Meeting of Soil Science Society of North Carolina, Raleigh, NC; Brown, Virginia. 2012. Establishing and Maintaining Enhanced Infiltration on Compacted Construction Site Subsoils Through Shallow and Deep Tillage with Soil Amendments. Master's Thesis, Department of Soil Science, NC State University, Raleigh, NC; Kays, Barrett L., William E. Wenk, and Thomas Tavella. 2012. "Bold Concepts in Stormwater Infiltration and Principles That Drive Success", Seminar Presentation to 2012 Annual Meeting, American Society of Landscape Architects, Phoenix, AZ; Kays, Barrett L. 2010. "Enhanced Infiltration of Stormwater on Development Sites in North Carolina Piedmont", Paper to 53rd Annual Meeting of Soil Science Society of North Carolina, Raleigh, NC.

Deep tillage and deep fertilization were found to significantly increase infiltration, substantially reduce runoff, and substantially improve the quality of stormwater runoff for all the soils studied at all three locations. The study developed and quantified methods for implementing enhanced infiltration to the extent that infiltration could be a useful innovative stormwater management system on construction sites and other disturbed soils in urban areas. Figure 37 shows and enhanced infiltration soil profile; the red dye marks the path of water from an infiltration rate test. The amended sites were found to be reasonably resistant to compaction from normal landscape mowing and maintenance activities.

Triplicate research plots were established for each of the treatments and at each of the sites that included graded and compacted soils similar to construction sites, shallow tillage and fertilizer amendments to a depth of 6 inches, and deep tillage and fertilizer amendments to a depth of 12 inches. All plots were seeded with either fescue or Bermuda grass and were then covered with straw and erosion control netting.

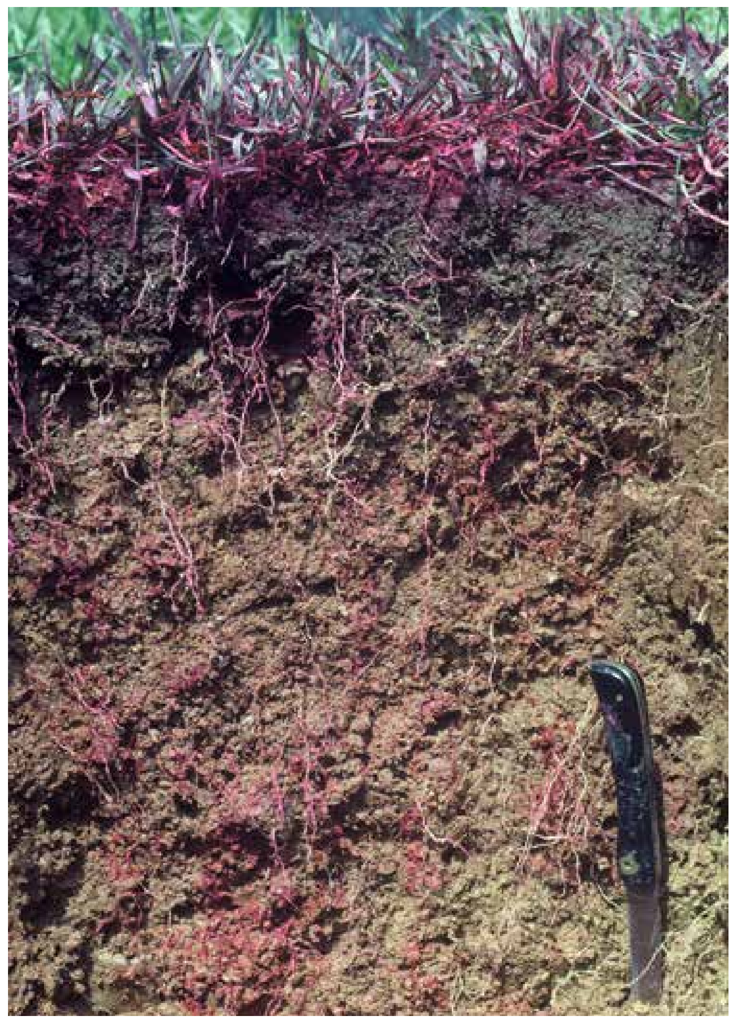

Figure 37. Enhanced infiltration soil profile showing deep rooting.

Research Results on Sandy Soils in Sandhills Region: Simulated rainfalls had an averaged infiltration of 1% for compacted plots, 95% for shallow, and 98% for deep tillage plots. Simulated rainfalls had an average runoff of 99% for compacted plots, 5% for shallow, and 2% for deep tillage plots. Soil densities averaged 87.4 lbs./cubic foot (1.4 g/cm^3) for compacted plots and 62.4 lbs./

cubic foot (1.0 g/cm^3) for both shallow and deep tillage plots. The soils on this site contained on average 96% sand, 6% silt, and 2% clay. Organic matter treatments did not produce a significant increase in infiltration rates over that achieved with tillage and fertilization.

Research Results on Fine-Loamy Soils in Mountain Region: Simulated rainfalls had an averaged infiltration of 2% for compacted plots, 90% for shallow, and 97% deep tillage plots. Simulated rainfalls had an averaged runoff of 98% for compacted plots and 10% for shallow, and 3% for deep tillage plots. Soil densities averaged 112.4 lbs./cubic foot (1.8 g/cm^3) for compacted plots and 93.6 lbs./cubic foot (1.5 g/cm^3) for shallow and deep tillage plots. The soils on this site contained on average 48% sand, 22% silt, and 30% clay.

Research Results on Clayey Soils in Piedmont Region: Simulated rainfalls had an average infiltration of 6% for compacted plots and 72% for both shallow and deep tillage plots. Simulated rainfalls had an averaged runoff of 94% for compacted plots and 18% for both shallow and deep tillage plots. Soil densities averaged 93.6 lbs./cubic foot (1.5 g/cm^3) for compacted plots and 68.7 lbs./cubic foot (1.1 g/cm^3) for both shallow and deep tillage plots. The soils on this site contained on average 48% sand, 12% silt, and 40% clay.

Rainfall and runoff was monitored for 12 storm events at the Piedmont site. The rainfall amounts ranged from 0.35 to 2.01 inches. Nine of the storm events were low intensity storms and three were high intensity storms. Low intensity storm events produced an average of 20.6% runoff for compacted plots, while the shallow tilled plots averaged 5.6% runoff and the deep tilled plots averaged 1.7% runoff. High intensity storm events produced an average of 64.7% runoff for compacted plots, while the shallow tilled plots averaged 9.3% runoff and the deep tilled plots averaged 3.0% runoff.

Figure 38. Deep tillage and fertilization installation.

Providing adequate deep tillage requires breaking up the soil with a v-ripper or a subsoiler, followed by four to six passes with a rotary tiller; its effectiveness depends upon the soil texture, moisture content, and other factors. The example in Figure 38 is an installation with vigorous rooting depth of greater than 9 inches after second month following planting in clayey soil. The types of tillage equipment and their effective depth of tillage are shown in Figure 42.

Types	Blade Diameter	Shank Height	Effective Tillage Depth [1]
	Inches	Inches	Inches
Disks	16 – 24 [2]		4 – 6
Rotary Tillers	12 – 18 [3]		6 – 10
Chisel Plows		20 – 30	8 – 18
Subsoilers		20 – 30	12 – 18
V-Rippers		20 – 30	16 – 20

[1] Effective tillage depth depends upon the equipment model, horse power, soil texture, soil moisture, and number of tillage passes. Chisel plows typically have an effective depth of 8 to 12 inches, while some can achieve 18 inches. Chisel plows, subsoilers, and rippers all require about 30 Hp per shank to achieve deep effective tillage.

[2] Agricultural disks commonly have 16 to 20 inch diameter blades.

[3] Large rotary tillers typical have 12 to 16 inch diameter tines.

Information courtesy of Dr. George C. Naderman, Emeritus Professor, Department of Soil Science, North Carolina State University, Raleigh, NC, 2010.

Figure 39. Types of Tillage Equipment

EXHUMED SOILS

Exhumed soils typically lack adequate soil biology and/or soil organic matter. When a soil profile has been cut into the subsurface, it exposes soil material that is normally not found at the ground surface. The exhumed soil material likely has more clay, is denser, is lower in soil organic matter, lower in fertility, and lower in the number of micro-organisms. Thus, the exhumed soil material is a poorer soil material for production of vibrant soil biology. Many landscape architects prefer to increase the organic matter and incorporate it through tillage. After incorporating the amendments, the site is planted with trees and shrubs, and the surface is covered with a thick layer of organic compost.

Extreme caution should be used when adding organic matter to a soil that has a seasonally high water table within twelve inches below the planting depth. Organic amendments are not advised in these soils because organic matter in wet soils will produce anaerobic[5] soil gases that will stress or kill non-wetland plants. Normally, an aerobic[6] soil environment is preferred for all non-wetland plantings.

When organic matter is added to soil it is important to add a nitrogen fertilizer in order to maintain a good carbon/nitrogen ratio. If there is insufficient nitrogen in amended soil, the organic matter will use all of the nitrogen for the decomposition. An alternate approach is to add humic matter that is already fully decomposed and is finely divided. The soil structural peds are then coated with the humic matter; this helps in preventing cementation of the peds.

5 Anaerobic soil– a soil that is absence of oxygen and usually produces methane and sulfuric odors.

6 Aerobic soil– a soil that contains a high concentration of oxygen.

EXHUMED ACIDIC SOILS

While some plants prefer acidic soils, most do not. Therefore, practitioners face the decision to plant exclusively acidic loving plants or to amend the soil pH. Chemical and biological amendments are important especially in reducing the acidity and raising the pH of acidic (low pH) subsoils[7]. Organic amendments are valuable in most soils, but are not recommended for low pH soils since the amendments will tend to further lower the pH. Acidic soils need to be amended to achieve a pH in the range of 6.5 to 7.0. Low pH have a pH less than 7; less than pH 5.5 is very low, pH 5.5 to 6.5 is moderately low, and pH 6.5 to 7 is slightly low pH.

Low pH soils have increased solubility of aluminum, cooper, iron, manganese, and zinc. The concentration of aluminum and manganese can reach toxic levels and thereby inhibit root growth. Clayey acidic subsoils frequently have toxic levels of either aluminum or manganese. Some clayey acidic subsoils fix and immobilize phosphorous so that it is not available for plant growth. Many clayey acidic subsoils are also deficient in phosphorous or potassium. Therefore, a soil fertility analysis needs to be conducted in order to determine the correct amendments to the soil.

In order to change the soil pH, the entire soil mass to the desired depth of rooting will need to be physically amended by tillage and thorough pulverization. After tillage the finely ground limestone and, if needed, super phosphate amendments should be spread across the soil surface, and then the entire soil mass needs to be tilled again to uniformly incorporate the lime and super phosphate. Thorough mixing of the lime and super phosphate is critical because the materials do not move in the soil. They will only amend those particles of soil that they come into contact with.

When planning to amend extensive areas of acidic soils, conduct an incubation bench test. The soil fertility laboratory can assist in conducting this type of specialty test. The incubation test allows for increasing amounts of the amendments to be added to duplicate soil samples and additional time for the amendments to react with the soil for a month or two prior to laboratory fertility testing. In some problem soils the incubation test will provide a more reliable reading of the amount of amendments to add to the soil.

EXHUMED ALKALINE SOILS

As with acidic soils, practitioners must decide whether to address alkaline (high pH) soils through plant selection or through soil amendment. Again, there is the option to plant strictly alkaline loving plants. If not, then chemical and organic amendments are important especially in amending the soil to lower the alkalinity and lowering the pH alkaline subsoils[8]. Organic amendments are recommended for high pH soils since the amendments will tend to further lower the pH. Alkaline (high pH) soils need to be amended to achieve a pH in the range of 6.5 to 7.0. High pH soils or alkaline soils have pH greater than 7; greater than pH 8.5 is very high, pH 7.5 to 8.5 is moderately high, and pH 7 to 7.5 is slightly high.

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7 Kays, Barrett L. 2008. "Strategies for Clay Soils", Landscape Architecture Magazine, May 2008, pp. 66 – 74.

8 Ibid.

Soil alkalinity is one of the largest factors limiting growth of plants and soil biota throughout North America. High pH (greater than 7.5) soils typically have copper, iron, and/or zinc deficiencies. These deficiencies are most pronounced in clayey alkaline subsoils. Clayey alkaline subsoils are deficient in essential nutrients due to the excessive amount of calcium in the soil.

Certain plants are highly susceptible to metal chlorosis due to the deficiency of metals in the soil solution. An alternative to lowering the pH is to add chelated copper, iron, and/or zinc fertilizers to the soil to increase the availability of these metal ions in the soil solution and make them available to the plants.

Amending soil pH is done in the same manner as described for low pH soils, except finely ground sulfur is incorporated into the soil to lower the pH. The incubation test can also be used to determine the amount of sulfur to add to problem soils. Add organic matter or humic matter to soil samples separately or along with the sulfur in increasing amounts to determine if organic amendments alone can solve the problems or if sulfur is also needed.

SOILS LACKING SUFFICIENT SOIL MOISTURE

Soils vary across the landscape and these variations must be understood in order to select the proper plants for the landscape. The drainage class and the depth to seasonally high water table of the soils often vary considerably both across regions, even within a site. Certain plants are adapted to poorly drained soils and other plants are adapted to well-drained soils. A frequent problem in the hot, dry, urban landscape is that limited soil areas cannot support large landscape plants without very frequent irrigation. This is due to the limited volume of soil as well as the lack of sufficient water holding capacity.

One of the most basic questions for landscape architects to determine is how much soil and water are needed for trees, especially in urban landscapes. This is a critical issue, since the trees will suffer, never achieve the desired size, and be short-lived if the volume of soil and amount of plant available water is insufficient. The landscape architect will need to determine the following factors: how much water will be needed for certain size and spacing of trees and how much plant available water can be stored in the soil in order to determine how much soil volume will be needed. One approach to addressing this type of question is illustrated in Example A.

NORMAL SOIL MOISTURE FLUCTUATIONS

There is a relatively new system called the Soil Climate Analysis Network (SCAN) , from the NRCS National Water and Climate Center, which reports soil moisture for various soil depths at locations across the United States. Their website publishes the SCAN climatic data where you can choose from the many different reporting stations[9]. Both the historic and real-time soil moisture data is reported for depths of 2, 4, 8, 20, and 40 inches below the surface. See Example B for a description of accessing and interpreting the data. Review data for various years and periods of droughts and study the change in moisture levels. The data can be presented as a chart or in a table format using historical data and can be accessed in real time.

9 Soil Climate Analysis Network - http://www.wcc.nrcs.usda.gov/scan/

EXAMPLE A

The late Professor Thomas O. Perry, an international forestry expert, studied the half-life of urban trees across much of eastern United States. He proposed a method for determining the area needed for open grown trees along streets and urban landscapes that includes a calculation of water demand. The following tables are from Dr. Perry's research[1].

Sample Question: What volume of soil is needed for sufficient moisture so that irrigation is not needed except for drought conditions?

Spacing Required for Open Grown Trees of Various Diameters

DBH	Trees/ Acre	Sq.Ft./ Tree	Spacing Between Trees
Inches		*Sq.Ft.*	*Feet*
1	2209	19.7	5.01
5	365	119.3	12.3
10	120	362	21.4
15	59	736	30.6
20	35	1241	39.8
25	23	1878	48.9
30	16	2647	58.0
35	12	3546	67.2
40	10	4577	76.3

Water Consumed Per Day by Open Grown Trees

DBH	Low Moisture Gal/Day/Tree	Mod. Moisture Gal/Day/Tree	High Moisture Gal/Day/Tree
Inches	*@0.1 Acre/In./Day*	*@0.25 Acre/In./Day*	*@1.0 Acre/In./Day*
1	1.85	4.63	18.5
5	9.94	24.9	99.4
10	29.7	74.3	297
15	64.7	162	647
20	103.3	258	1033
25	156.5	390	1565
30	214.8	536	2148
35	287	717	2870
40	366	915	3660

Assume: Tree Caliper = 10-inch

Ground Area = 362 SF/Tree

Water Needed = 74.3 Gal/Day/Tree – based upon above moderate moisture

Therefore: Plant Available Water (PAW) = 1.2 inches/foot for sandy loam soil or PAW = 10% of soil volume; see calculation of soil volumes and water below:

Depth of Soil	Vol. of Soil[a]	Water in Soil Vol.[b]	Water Capacity w/o Rain[c]
Feet	*Cubic Feet/Tree*	*Gallons/Tree*	*Days*
2	724	541.6	7.3
3	1,086	812.3	10.9
4	1,448	1,083.1	14.6
5	1,810	1,353.9	18.2

[a]Ground Area x Depth = Cubic Feet/Tree

[b]Soil Vol. x 10% x 7.48 Gal/CF = Gallons/Tree

[c]Water in Soil / 74.3 Gal/Day/Tree = Days of PAW

Answer: If the local climatic records show that during the summer months it typically takes about 2.5 weeks to obtain 1.75-inches of rain (amount to add 1.2 inches/foot of water into the soil) , a 5-foot depth of sandy loam soil is recommended.

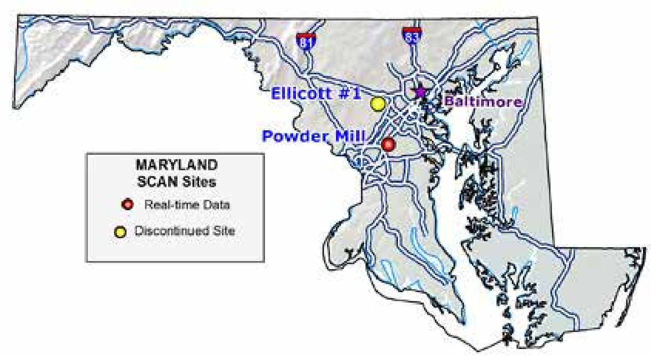
[1]Thomas O. Perry, "The Size, Design, and Management of Planting Sites Required for Healthy Tree Growth", Metropolitan Tree Improvement Alliance Proceedings 3:1-14.

WET SOILS

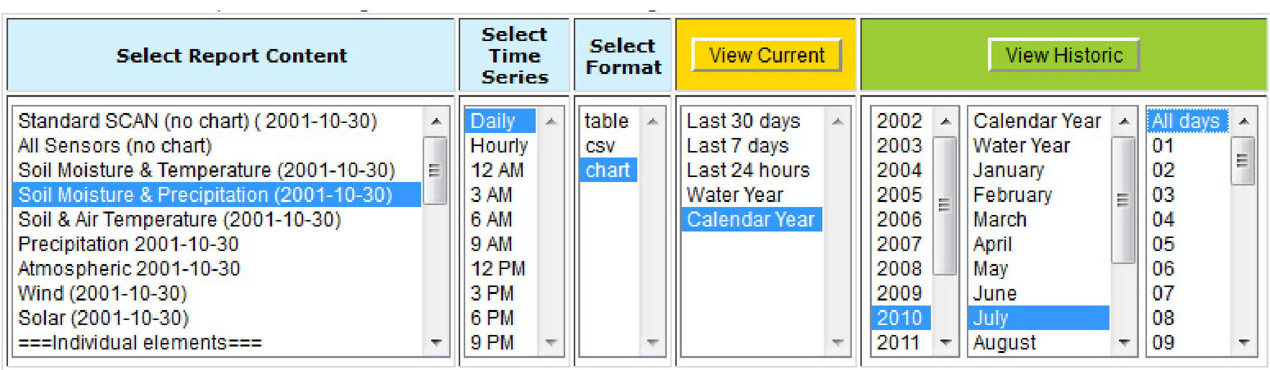
Some soils are excessively wet because of a rising water table or a perched water table. Typically, rising water tables occur in areas that have a history of a seasonal or normal high water table within the rooting zone. Occasionally, when fill is placed over a poorly drained soil, the water table rises in the fill. This phenomenon occurred in various areas in Central Park where the marsh was filled in during the nineteenth century and in areas of the National Mall in Washington, DC.

When a subgrade is compacted and then covered with topsoil, a perched water table frequently occurs in areas lacking sufficient lateral gradient for water movement through the adjacent soils. Roads, parking lots, and buildings all serve as dams to subsurface water movement and

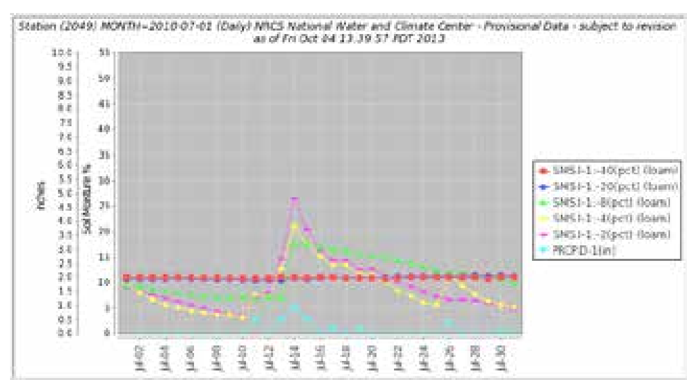
EXAMPLE B



Maryland's Powder Mill site outside of Washington, DC., will be used for sample data. Navigate to the site by selecting the correct state, then choosing the station.



Choose the variables that display the Soil Moisture & Incremental Precipitation Daily series for July, 2010 and click the "View Historic" button for the chart.



This chart shows the rainfall and percent moisture at 2, 4, 8, 20, and 40 inches below the surface. Note the percent moisture at 2, 4, and 8 inches quickly declines when there is no rain, but increases after a large rainfall event. Also note that the percent moisture at the 20 and 40-inch depths is rather constant.

USDA, Natural REsources Conservation Service. SCAN Site. http://www.wcc.nrcs.usda.gov/scan/

help create these problems. Surface drainage inlets normally do not alleviate these types of problems. However a system of drainage inlets and slotted drain lines can be an appropriate solution. This solution works only when the compaction has been corrected sufficiently so that the subgrade soils will be able to adequately conduct water to the slotted drain lines[10]. Many disturbed and compacted soils will require special soil survey methods and testing of hydraulic conductivity of the soil in order to determine the correct spacing of drain lines that will adequately drain the perched water table in these soils[11].

Soils that are poorly, somewhat poorly, or very poorly drained will generally need subsurface drainage for most types of plantings. In these soils the wetness is not normally due to a perched water table, but rather is due to an area wide water table that rises under the site during wet periods of the year. A subsurface drainage system is used on such sites to lower the water table to a specific design depth. Such a system is used when there is an inadequate aerobic rooting depth. Surface and subsurface drainage systems are covered in detail in the NRCS National Engineering Field Manual[12].

The depth of the slotted subsurface drainage lines and the spacing between the drainage lines must be determined in relationship to the actual soils and drainage conditions on the site. The depth of the lines will need to be lower than the rooting depth, since the water table will rise closer to the surface between two parallel slotted drain lines. The distance between the slotted subsurface drain lines depends upon permeability of the soil and thus how easily the water can horizontally migrate to the drain lines.

The following equations are used to determine the depth and spacing of the lines:

S = square root of (4P (b2 – a2)) / Qd

Where:

S = Spacing between the slotted drain lines in feet,

P = Coefficient of permeability (inches/hour),

b = Distance between the desired water table depth and a lower impermeable horizon (feet),

a = Distance between the drain lines and the lower impermeable horizon (feet), and

Qd = Drainage coefficient (soil permeability of horizon to be drained) (inches/hour).

The drainage coefficient of 10% of the permeability or the saturated hydraulic conductivity of the soil horizon, as listed in the county soil survey, should be used for the design, unless the hydraulic conductivity is measured for the site soils in the specific soil horizons to be drained. Also, lateral drainage for dense clay loam, silty clay, sandy clay, and clay textured soils can be approximately 10% of the vertical permeability.

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10 Kays, Barrett L. and James C. Patterson. 1982. Soil Drainage and Infiltration, Chapter 5, In Phillip J. Craul (ed.) Urban Forest Soils, Syracuse, New York.

11 Kays, Barrett L. and James C. Patterson. 1982. Methodology for On-Site Soil Analysis, Chapter 7, In Phillip J. Craul (ed.) Urban Forest Soils, Syracuse, New York.

12 National Engineering Manual: Part 530 – Hydrology Chapters: http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?&cid=stelprdb1043063

However, the best approach is to obtain lateral saturated hydraulic conductivity measurement from undisturbed horizon soil core sample from the site. The current approach to design of subsurface drainage and irrigation systems is to determine the daily fluctuation in water table and/or irrigation using the DRAINMOD Computer Simulation Model[13]. The model allows the designer to simulate the infiltration, runoff, soil drainage, depth to water table, and irrigation on a daily basis for the entire period of climatic records from the nearest weather station. This model has been used for restoration of wetland sites, restoration of site soils, and design of imported native and manufactured soil systems. The model is data intensive so it is normally only used with field and / or laboratory physical analysis of the site soils. A few samples of DRAINMOD data are seen in Figures 40 - ##. These graphs are for loamy soil in Norfolk, VA. The horizontal axis shows the Julian days in the year.

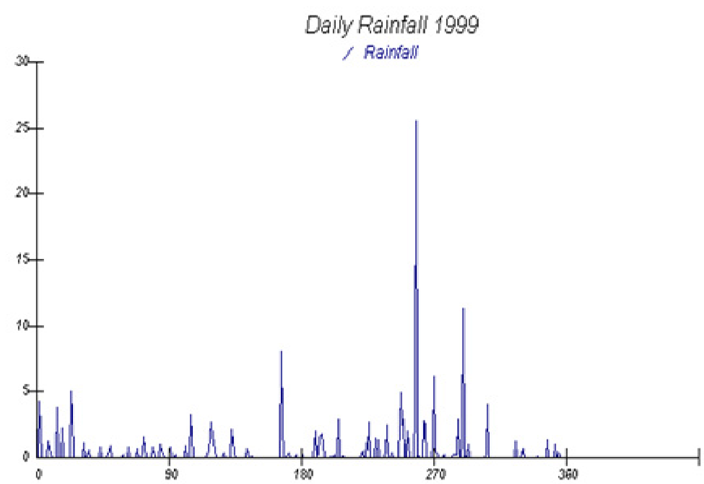

Figure 40. DRAINMOD rainfall plot in cenitmeters for 1999

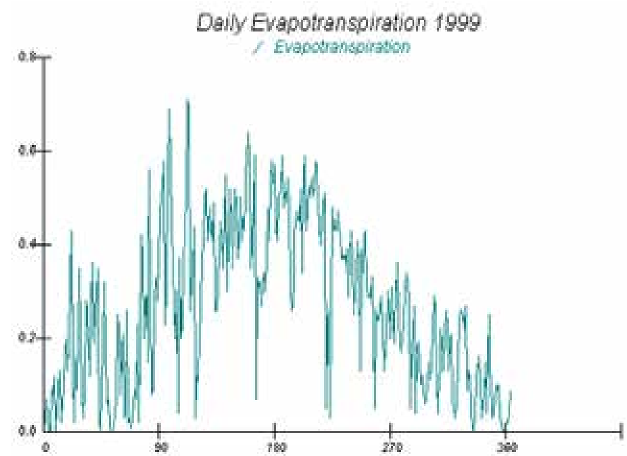

Figure 41. DRAINMOD evapotranspiration plot in centimeters for 1999

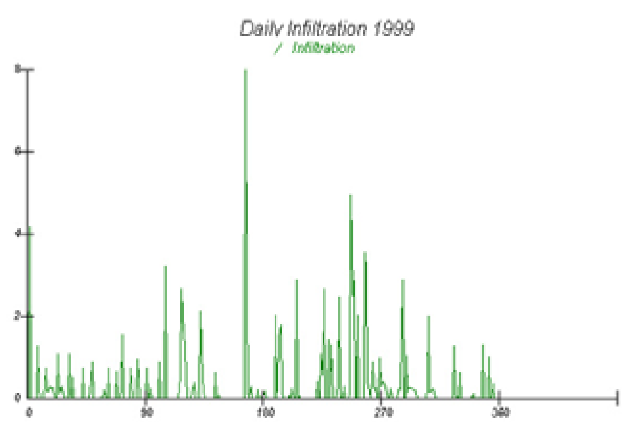

Figure 42. DRAINMOD infiltration plot in centimeters for 1999

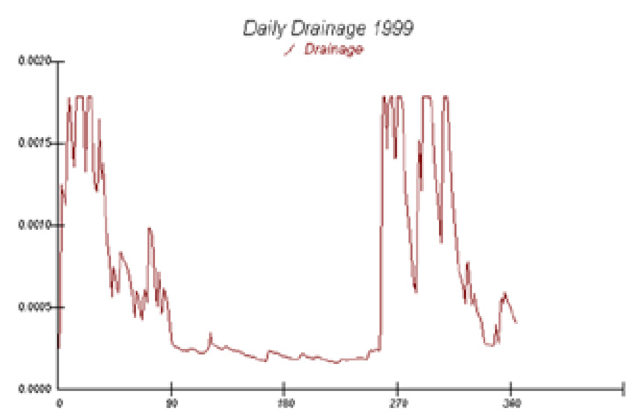

Figure 43. DRAINMOD subsurface drainage plot in centimeters for 1999

13 DRAINMOD Computer Simulation Model, Agricultural & Biological Engineering Department, North Carolina State University, Raleigh, NC http://www.bae.ncsu.edu/soil_water/drainmod/

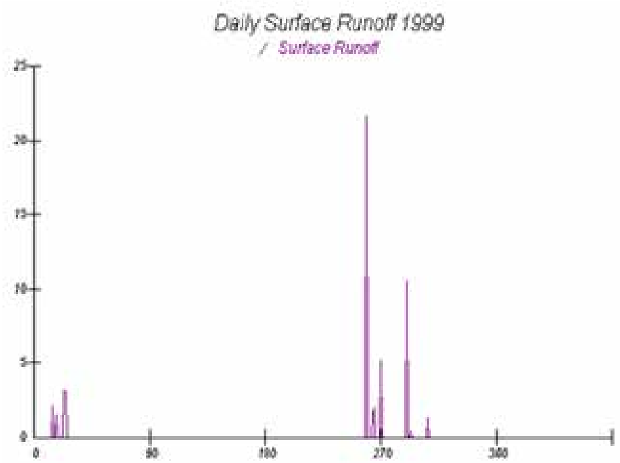

Figure 44. DRAINMOD runoff plot in centimeters for 1999

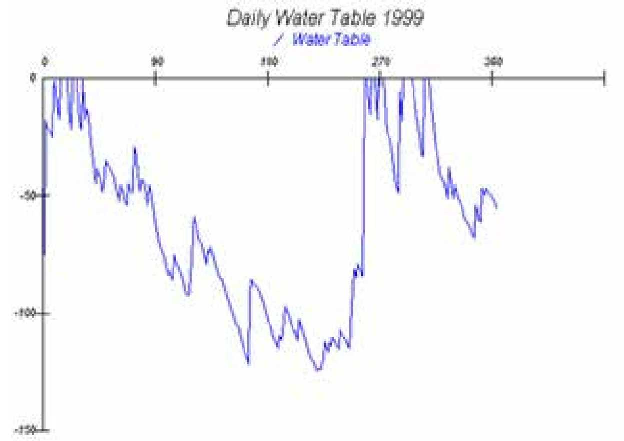

Figure 45. DRAINMOD water table depth plot in centimeters below the surface for 1999

Severe compaction, especially on urban sites, can make the soils exceedingly difficult and expensive to drain, to say nothing about the other problems associated with plant growth. With this type of soil take special note of lithologic discontinuities[14], which could seriously impair water movement[15]. It is also important to consider that lateral drainage through heavy loam, clay loam, heavy silt loam, and clayey soils may be on the order of 1/10 of the vertical water movement rates for the same soil. If laboratory hydraulic conductivity tests are to be performed the soil core samples are taken in the lateral rather than vertical position. Samples must be taken from all important soil horizons and spatially to determine the soil variability (seek out the most limiting horizons and locations). Prior to completing the site's drainage design, determine to what extent construction compaction will alter the soils.

14 Lithologic discontinuities are abrupt vertical changes in soils such as compacted pans, or in urban areas where different soils have been filled where certain compacted layers limits water movement.

15 Kays, Barrett L. and James C. Patterson. 1982. Methodology for On-Site Soil Analysis, Chapter 7, In Phillip J. Craul (ed.) Urban Forest Soils, Syracuse, New York.

Designing Soils to Solve Difficult Problems

Landscape architects will find that amending and restoring existing on-site soils is the most cost effective solution for most landscape projects. However, not all problems can be solved with the approaches outlined in the previous chapter. Designing soils to address specific issues should be reserved for difficult problems and be implemented by experienced landscape architects in conjunction with their soil consultants[1]. Successfully designing soils for a project first requires that the landscape architect fully understands the limitations of the existing soils on the site and the complexities in designing and implementing an appropriate solution. In addition, the design project may require different solutions for various areas of the site due to soil conditions and proposed design elements. This chapter will introduce four of the most common approaches: importing native soils, structural soil systems, layered soil systems, and creation of wetland/or rain garden soils.

Importing and Blending Native Soils

Native soils are imported to provide a surface soil layer conducive to plant growth when the existing site soils cannot be adequately amended or restored. The landscape architect's soil specification should include, at minimum, the amendments to the existing site soil as subgrade soil material, a detailed description of the soil to be imported, soil testing requirements, approval and placement of the soil material, and inspection and testing of the installed soil materials after placement. Sometimes it is important to inspect the native soil material site, collect representative samples, and approve the soil material prior to excavation.

Too often native soil is imported and placed over unamended subsoil which has been compacted during construction. This can create several serious problems. First, the plants cannot root down into the subsoil due to its density. Second, the compacted subsoil can cause a perched water table to occur above the subsoil and cause excessive wetness in the imported soil material. The imported soil material will become excessively wet during rainy periods, and excessively dry in other periods because the plants cannot root down to sufficient soil moisture. The solution is to amend the subgrade material, using one of the strategies in the previous chapter, immediately before placement of the imported soil.

The sandy group of soils includes sand and loamy sand textured soils. These textures are normally selected for sites where a soil is well to excessively well-drained. In many cases, a considerable amount of organic matter needs to be added to these soils to increase the amount of plant available water and to reduce the use of irrigation.

The loamy group of soils includes sandy loam, loam, sandy clay loam, and clay loam textured soils. The sandy loam, loam, and silt loam textures are normally selected as some of the best soil textures for a wide variety of landscape plants. Loam soils have higher amounts of plant available water than sandy loam textures. Sandy clay loam and clay loam textures have more clay and are used when a higher cation exchange capacity is desired; e.g. bioretention soils.

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1 Sloan, John, et al. 2012. Addressing the Need for Soil Blends and Amendments for the Highly Modified Urban Landscape. Soil Sci. Soc. Amer. Journal 76:1133-1141.

The silty group of soils includes silt, silt loam, and silt clay loam textured soils. These textures are normally used for sites when it is important to retain the maximum amount of plant available water when irrigation is not provided.

The clayey group of soils includes sandy clay, silty clay, and clay textured soils. Clayey soils are normally considered to be problem soils for landscape plantings. If the site contains these textures, consider amending the soils to improve drainage. Soils with higher amounts of clay are commonly used for prairie establishment. Clayey soils are selected for special purposes including pond liners, layers to create a perched water table near the surface, wetland liners, or the core of pond dams. In these instances the clay is intended to reduce the movement of water out of the water containment area or to create a perched water table for wetland plantings.

BLENDED SOILS

Many landscape architects prefer to blend planting soils. They import a sandy soil, a loamy soil, and organic matter compost. They obtain particle size analysis, cation exchange capacity, and moisture retention laboratory data to aid in determining a mix of the three soil materials. Some landscape architects have blended planting bed soils to provide various amount of moisture retention for different portions of the landscape. They will blend a mix of the sandy soil, loamy soil, and organic compost for various purposes.

The following slope soil blends illustrate the concept for the upper, mid, and lower slopes of a high sloping landscape bed. The purpose is to retain more moisture in the upper portions of the slope that would otherwise be the driest, and to provide better drainage in the lower slopes where water will accumulate during rainstorm events. The actual portions in the mix should be based upon the laboratory data.

i. Planting bed soil for upper slopes – Use a mix of 1 part sandy soil, 6 parts loamy soil, and 3 parts of organic compost.

ii. Planting bed soil for mid slopes – Use a mix of 2 parts sandy soil, 6 parts of loamy soil, and 2 parts of organic compost.

iii. Planting bed soil for lower slopes – Use a mix of 3 parts sandy soil, 6 parts of loamy soil, and 1 part of organic compost.

The following aquatic soil blends illustrate the concept for a wetland fringe with fluctuating water table, shallow water marsh, deeper water marsh, and deep open water soil. The concept is to use the wetland fringe and shallow marsh to create a denitrifying environment and thus a higher content of organic matter as a food source for the microbes. Only limited denitrification will occur in the deep water marsh so the organic matter is not included. The deep water marsh and deep open water has a higher percent of sand and a preferred media for aquatic organisms.

i. Planting bed soil for wetland fringe with fluctuating water table – Use a mix of 3 parts of sandy soil, 3 parts of loamy soil, and 4 parts of organic compost, placed over top of a clay textured soil.

ii. Planting bed soil for shallow water marsh – Use a mix of 2 parts of sandy soil, 4 parts of loamy soil, and 4 parts of organic compost.

iii. Planting bed soil for deep water marsh – Use a mix of 3 parts of sandy soil and 7 parts of loamy soil.

iv. Planting bed soil for deep open water – Use a mix of 5 parts of sandy soil and 5 parts of loamy soil.

The following upland and wetland soil blends illustrate the concept for a sandy hummocky landscape typical to some barrier islands where there is a wetland area between steep sandy dunes. The purpose is to mimic the natural soil sequence across the dunes and swales for restoration of the maritime forest. There will be an organic soil at the bottom of the swale where the elevation will be about one to three feet above the normal sea level.

i. Sandy dune ridge – Use 8 parts of sandy soil and 2 parts of organic compost.

ii. Sandy dune forest slope – Use 7 parts of sandy soil and 3 parts of organic compost.

iii. Sandy dune toe slope – Use 6 parts of sandy soil and 4 parts of organic compost.

iv. Sandy dune bottom swale – Use 2 parts of sandy soil, 2 parts of loamy soil, and 6 parts of organic compost.

Figure 46. On-site grinding and blending of a planting soil material

DEPTH OF SOILS

The depth of an urban landscape planting soil was discussed in the previous chapter. The basic concept also applies to any other type of landscape where the amount of plant available water based upon the texture of the planting soil, the depth of the planting soil, and the area of the planting. From these three factors calculate the amount of water the planting soil will hold from a rainfall event and after drainage of the macro-pores. All three of these factors can be adjusted to alter the volume of stored soil water.

Also, as discussed in the previous chapter, the Soil Climate Analysis Network can be used to determine the normal moisture levels at various depths at the monitoring station nearest to the site. The concept is to match the moisture retention that represents the geographic area or to match the moisture retention that represents the geographic area of the ecosystem of the plant species.

SOIL TESTING OF IMPORTED SOILS

The following types of soil testing are normally included in specifications for imported soil materials. While other types of soil testing may be needed for special situations, the following basic parameters are most commonly used.

i. Particle Size Analysis – sand, silt, and clay content using Hydrometer Method.

ii. Bulk Density – bulk density of the soil after compaction.

iii. Water Movement – saturated hydraulic conductivity: desirable range for clayey soils is 0.5 to 2 inches/hour, 1 to 3 inches/hour for loamy soils, and 3 to 5 inches/hour for sandy soils.

iv. Plant Available Water – soil moisture content at -1/3 and -15 bars. Adjust soil mix to achieve the desired PAW.

v. Soil Organic Matter – organic matter content.

vi. Fertility – soil pH, Cation Exchange Capacity, Base Saturation, nutrients, and salinity of fine earth fraction of the soil.

vii. Compost Analysis – testing requirements and standards of US Composting Council.

Figure 47. Spreading structural soil at Great Lawn in Central Park, New York, NY

Designing Structural Soils

Structural soils are designed to be compacted to as much as 95% maximum density and still support vigorous plant growth. Structural soils use gravel or sand as the structural support[2]. Whether gravel or sand is used, it must have a high degree of uniformity. Gravel based structural soils are used for street tree plantings and planting where the roots will extend under pavement. The gravel size is typically 1 to 1.5 inches in diameter. A loamy soil material is mixed with the gravel in a ratio of approximately 2.5 parts of loamy soil and 7.5 parts of gravel[3].

Sand based structural soils are used for planting beds, sports fields, and lawns which will receive considerable foot traffic. Sand based systems use medium to coarse sand and a range of silt and clay depending upon the desired amount of plant available water to be retained. The sand based soil mix includes 1 to 2.5 parts of silt and clay, and 7.5 to 9 parts of uniform sand. This mix can be placed over a highly uniform, very coarse sand/fine gravel material without the use of filter fabric, provided that the uniformity and bridging standards are met as described in the previous chapter.

Figure 48. Structural lawn soil at Millennium Park, Chicago, IL

2 Grabosky, Jason, Nina Bassuk, Peter Trowbridge. 2005. Using CU-Structural Soil™ in the Urban Environment. Urban Horticulture Institute, Cornell University. Ithaca, NY.

3 Grabosky, Jason and Nina Bassuk. 1995. A New Urban Tree Soil to Safely Increase Rooting Volumes Under Sidewalks, Journal of Arboriculture, 21:197-201; Grabosky, Jason and Nina Bassuk. 1996. Testing of Structural Urban Tree Soil Materials for Use Under Pavement to Increase Street Tree Rooting Volumes, 22:255-263.

EXAMPLE C

The following are two examples of layers designed for different purposes.

The Saturated Water Flow is designed to promote downward water movement when the upper layer is completely saturated. The water drips into the gravel lower layer because the soil moisture tension in the upper layer is saturated and is at 0 soil moisture tension. The lower gravel layer is at a positive atmospheric pressure. As soon as the upper layer is not saturated the soil moisture tension becomes negative and the flow of water into the gravel stops. The downward flow when saturated is logical to most landscape architects and engineers, but the reason that the water flow into the gravel stops seems counter-intuitive.

Example of Layer System for Saturated Water Flow

Upper Layer–uniformly graded medium to coarse sand with silt

- Medium sand 27.2%, coarse sand 61.8%, and 11.0% silt
- Saturated hydraulic conductivity – 6.431 in./hr.

Lower Layer–uniformly graded fine gravel

- Fine gravel – 2.0 to 3.0 mm in diameter
- Saturated hydraulic conductivity – 15.610 in./hr.

Example of Layer System for Unsaturated Water Flow

Upper Layer–uniformly graded medium to coarse sand with silt

- Medium sand 27.2%, coarse sand 61.8%, and 11.0% silt
- Hydraulic conductivity:
- 6.431 in./hr. at 0 cm soil moisture tension,
- 0.055 in./hr. at -20 cm soil moisture tension,
- 0.056 in./hr. at -50 cm soil moisture tension, and
- 0.003 in./hr. at -100 cm soil moisture tension

Lower Layer–uniformly graded fine gravel

- Fine gravel – 2.0 to 3.0 mm in diameter
- Hydraulic conductivity:
- 15.610 in./hr. at 0 cm soil moisture tension
- When vented the gravel layer is at atmospheric pressure.

In the Unsaturated Water Flow, when the upper layer's soil moisture tension becomes slightly negative the water will stop moving into the gravel. Therefore, the gravel layer is impeding the downward flow of water. In the unsaturated state, water flow is always in the direction of the greatest soil moisture tension. The greatest tension is upward or lateral into the drier portions of the upper layer. The upward or lateral flow is referred to as redistribution and this phenomenon is counter-intuitive to most landscape architects and engineers. The use of this phenomenon by precisely designing soil layers allows the designer to control soil moisture, hold moisture in the rooting zone, and create a water efficient landscape. At -20 cm soil moisture tension the water in upper layer stops dripping into the lower layer, because the upper layer has a greater soil moisture tension. Water is captured in the upper layer and begins to redistribute in the direction of those portions of the upper layer that are drier and therefore have the greatest soil moisture tension.

Data courtesy of Author

Designing Layered Soils

Natural soil profiles have layers that are referred to as soil horizons. Layered soil systems are being used to construct new man-made soil profiles that mimic the natural layering in a native soil. This approach has been used in a number of landscape restoration projects[4]. It is has also been used to restore urban floodplains where water is stored in the subsurface, then allowed to laterally seep into a stream, thus increasing the low flows.

4 Bill Wenk, Personal Communication, 2012. Constructs soil profiles designed to hold water in the subsurface of floodplains and implemented with the day lighting and restoration of urban streams and floodplains in Denver, Colorado. Wenk & Associates, Denver, Colorado.

Layered soils are also being used to construct man-made soil profiles that precisely control the saturated and unsaturated movement of water. These layered soils serve as both a growing medium and a water management system across the entire landscape.

Soil water movement is controlled by different soil moisture tensions in each of the layers. Unsaturated water movement can consequently be controlled through the precise soil moisture tensions in adjoining layers of soil. Unsaturated water always moves in the direction of the highest soil moisture tension (tension values are negative so the higher tension is more negative). Unsaturated water will flow from a loam textured layer into the underlying clay loam textured layer. However if the clay loam textured layer is located above the loam textured layer, unsaturated water will flow upward in the profile. Refer to Example C for two examples.

Designing Wetland and Rain Garden Soils

Wetland and rain garden soils are normally designed to capture and/or impede water movement sufficient to create saturated soils at, or near, the surface of the ground. This naturally occurs when the elevation of the wetland soil is at, or below, the elevation of the normal water table. However, wetland hydrology can be created even when the normal water table is considerably deeper than the ground surface by diverting additional runoff into the rain garden, shallow flooding of the rain garden, and/or creating a perched water table in the rain garden.

A perched water table can be created by compaction of the subgrade to limit the downward flow of water. A loam textured soil material can be installed over top of the compacted soil which will serve as wetland planting soil. In large systems it is complicated to determine how much water needs to be diverted into the wetland area, what the saturated conductivity needs to be in the compacted subgrade, and how to determine the height of the perched water table in both wet and dry periods. The watershed scale of DRAINMOD computer simulation model[5] is very useful in determining all of these factors in the design of a wetland hydrologic system.

Figure 49. Rain garden in Portland, OR

Figure 50. Planting the marsh soils around Belvedere Lake in Central Park, NY, NY

5 Watershed Scale Version of Drainmod – http://www.bae.ncsu.edu/soil_water/drainmod/

Preparing the Soil Plans

Landscape architects are now using a variety of custom soils across a site whether they use amended, imported, or manufactured soils. Therefore a complete construction documents package should include soil plans and details showing the location of soils across the site and the depth of the various soil layers.

Each of the soil areas should be described in detail explaining what soil work is to be conducted. A cross section and details of each area should be shown on the plans. All areas on the site for the protection of trees or undamaged soils will need to be shown in bold on the plans. The method of protecting these areas should be specified and limitations to work in these areas should be clearly stated on the plans and violation penalties enumerated.

Each soil, soil layer, and drainage layer should be described in detail in the specifications. The following is an example of what should be included in the soil specifications.

Approval of Laboratories and Subcontractors

LABORATORY QUALIFICATION DATA

Qualification data is needed to assure that the contractor will use the appropriate soil testing laboratories. Not all soil testing laboratories are the same, therefore request laboratories based upon previous experience. At minimum, the specifications should require that the contractor provides the laboratory names, contact persons, addresses, telephone numbers, e-mails, and web sites for each of the following:

i. The certified soil physical analysis testing laboratory shall use SSSA testing procedures.

ii. The certified soil fertility analysis testing laboratory shall use NAPT[1] analytical procedures.

iii. The certified soil chemical and biological analysis testing laboratory shall use SSSA testing procedures.

iv. The certified RCRA[2] analytical testing laboratory shall use EPA procedures

SUBCONTRACTOR QUALIFICATION DATA

Qualification data is needed to assure that the subcontractors have sufficient experience in the type of soil work that is needed for the project. Most grading contractors are not experienced in amending and restoring soils and most are not familiar with the installation of manufactured soils. Verify that the manufactured soils are prepared by an experienced company that has the appropriate size of soil screens to process the soil materials.

1 The North American Proficiency Testing (NAPT) Program (a program of the Soil Science Society of America) assists soil, plant, and water testing laboratories in their performance through inter-laboratory sample exchanges and a statistical evaluation of the analytical data.

2 RCRA (Resources Conservation and Recovery Act) includes minimum concentration standards for hazardous metals and other contaminants in soils.

Figure 51. Analytical laboratory mass spectrometry equipment for chemical testing

The following information should be obtained:

i. Company name, contact persons, addresses, telephone numbers, e-mails, and web sites for subcontractors, including but not limited to the soil scientist who will conduct the sampling and quality control submittals, the soil scientist who will conduct of testing of soil during the installation, and the soil scientist who will conduct the testing of in-place soils after installation.

ii. Experience narrative, names of similar projects, addresses, and photographs.

iii. Narrative of the company's understanding of the project.

MATERIAL CERTIFICATES

The contractor shall submit certificates for each type of soil amendment, product, compost, and fertilizer and shall comply with the following:

i. Manufacturer's qualified testing agency's certified analysis of standard products.

ii. Analysis of fertilizers by a qualified testing agency made according to AAPFCO methods for testing and labeling and according to AAPFCOs SUIP #25 (The Heavy Metal Rule).

iii. Analysis of nonstandard materials by a qualified testing agency made according to SSSA methods, where applicable.

Soil Sampling Procedures

The use of correct sampling procedures, number of samples, location of samples, depth of samples, and other factors must be taken into account.

QUALITY CONTROL

The following soil samples and number of samples need to be collected in order to properly assess the soil materials.

Provide a minimum of one quality control report for each type of soil and each soil layer in the existing and proposed soil profiles that consist of less than 500 cubic yards (CY), or provide one quality control report for every 500 CY of soil material and including the number of samples for the following tests:

i. Soil physical data of whole earth fraction for triplicate random samples including:

   a. Particle size analysis using hydrometer method and report for each of the three analyses on the percent of fine earth fraction that consists of sand, silt, and clay.

   b. Particle size analysis of sand using the sieve method and report for each of three analyses on the percent of fine earth fraction that consists of very coarse sand, coarse sand, medium sand, fine sand, and very fine sand.

   c. Gravel size analysis of gravel using sieve method and report for each of three analyses on the percent of coarse earth fraction that consists of coarse gravel, medium gravel, and fine gravel.

   d. Bulk density tests using the core method with the soil material compacted to 95% CBR (California Bearing Ratio) and report for each of three cores on the bulk density of the fine earth fraction in grams per cubic centimeter.

   e. Bulk density tests using the core method with the soil material compacted to 85% CBR and report for each of three cores on the bulk density of the coarse earth fraction in grams per cubic centimeter.

   f. Saturated hydraulic conductivity tests using the core method with the soil material compacted to 95% CBR and report on the conductivity in centimeters per hour.

   g. Water retention analysis data at 0, -1/10, -1/3, and 15 bars of soil moisture tension and report on the volumetric percent of water at each tension.

ii. Soil chemical and biological data of fine earth fraction for duplicate random samples including:

   a. CEC tests using sodium saturation method at pH 7.0.

   b. Base saturation.

   c. Soluble salt content.

   d. Soil pH.

   e. Chemical ammonium saturation test for determination of clay mineralogy.

   f. Humus content analysis and report of the percent of humus.

iii. Soil chemical analysis data of whole earth fraction for duplicate samples for the following:

   a. RCRA metals analysis test.

   b. Phytotoxicity analysis test.

iv. Soil fertility data for the fine earth fraction for single samples and recommendations for adjusting the pH and nutrient levels in pounds per cubic yard of soil material.

Soil Testing Procedures

Soil testing procedures are important to make sure that soil samples are tested using the appropriate field and laboratory methods. The landscape architect needs to make sure that the laboratory selected for the soil testing will be following each of the applicable methods noted below.

PHYSICAL TESTING OF SOIL

i. Soil-particle size-distribution analysis by the following methods according to Methods of Soil Analysis: Part 1 - Physical and Mineralogical Methods by the Soil Science Society of America's (SSSA)

ii. Sieving Method: Report sand-gradation percentages for very coarse sand, coarse sand, medium sand, fine sand, and very fine sand, according to USDA sand sizes.

iii. Hydrometer Method: Report percentages of sand, silt, and clay.

iv. Bulk Density: Calculate using Laboratory Core Method according to Methods of Soil Analysis: Part 1 - Physical and Mineralogical Methods, SSSA with samples compacted to 85% and 95% maximum density.

v. Total Porosity: Calculate using the bulk density according to Methods of Soil Analysis: Part 1 - Physical and Mineralogical Methods, SSSA with samples compacted to 85% and 95% maximum density.

vi. Micro, Meso and Macro-Porosity: Calculate using Laboratory Desorption Method according to Methods of Soil Analysis: Part 1 - Physical and Mineralogical Methods, SSSA with samples compacted to 85% and 95% maximum density.

vii. Physical Testing for Hydraulic Conductivity: Calculate using Laboratory Core Constant Head Method according to Methods of Soil Analysis: Part 1 - Physical and Mineralogical Methods, SSSA with samples compacted to 85% and 95% maximum density.

viii. Physical Testing for Water Retention: Calculate using Pressure Plate Method According to Methods of Soil Analysis: Part 1 - Physical and Mineralogical Methods, SSSA with samples compacted to 85% and 95% maximum density.

CHEMICAL TESTING OF SOIL

i. Chemical Testing for CEC: Analysis by Sodium Saturation Method at pH 7 according to Methods of Soil Analysis, SSSA.

ii. Chemical Testing for Base Saturation: Analysis by Total Exchangeable Bases: Summation of Bases Method according to Methods of Soil Analysis, SSSA.

iii. Chemical Testing for Soluble Salt Content: Analysis by Electrical Conductivity Method according to Methods of Soil Analysis, SSSA.

iv. Chemical Testing for pH: Analysis according to Methods of Soil Analysis, SSSA.

v. Chemical Testing of Clay Mineralogy: Analysis and estimated percentage of expandable clay minerals using CEC by ammonium saturation at pH 7 according to Methods of Soil Analysis: Part 2 - Microbiological and Biochemical Properties, SSSA.

vi. Chemical Testing for Hazardous Metals for Human Health: Test for presence and quantities of RCRA metals including aluminum, arsenic, barium, copper, cadmium, chromium, cobalt, lead, lithium, and vanadium. If RCRA metals are present, include recommendations for corrective action.

vii. Chemical Testing for Phytotoxicity: Test for plant-available concentrations of phytotoxic minerals including aluminum, arsenic, barium, cadmium, chlorides, chromium, cobalt, copper, lead, lithium, mercury, nickel, selenium, silver, sodium, strontium, tin, titanium, vanadium, and zinc.

viii. Fertility Testing: Soil fertility analysis according to standard laboratory protocol of SSSA NAPT SERA-6, including the following:

a. Percentage of humus.

b. Cation exchange capacity (CEC), calcium percent of CEC, and magnesium percent of CEC.

c. Base saturation percent.

d. Soil reaction (acidity/alkalinity pH value).

e. Buffered acidity or alkalinity.

f. Phosphorous index.

g. Potassium index.

h. Manganese index.

i. Manganese-availability index.

j. Zinc index.

k. Zinc availability index.

l. Copper index.

m. Soluble salts index.

n. Humus Content: Analysis of Humus Content according to Methods of Soil Analysis, SSSA.

Recommendations: Based upon the test results, state recommendations for soil treatments and soil amendments are to be incorporated to produce satisfactory landscape soil suitable for healthy, viable plants indicated. Include, as a minimum, recommendations for amending the soil to achieve desired pH, for nitrogen, phosphorous and potassium fertilization, and for micro-nutrients.

i. State fertilizer recommendations for fertilizers and soil amendments in weight per Cubic Yard (CY) and per 1,000 Square Feet.

ii. State recommended liming rates for raising pH or sulfur for lowering pH according to the buffered acidity or buffered alkalinity in weight per Cubic Yard (CY) and per 1,000 Square Feet.

Soil Performance Standards

The contractor shall submit a laboratory report from each laboratory to the landscape architect for approval provided the submittal meets the specifications. Some landscape architects have not carefully reviewed the laboratory submittals and have therefore made some serious and costly errors. Some laboratories do not use USDA standard sieves, but use engineering standard sieves and it can make a big difference. It is critically important to make sure that the laboratory qualifications show adherence to the specifications. Slight differences in sand, silt, and clay percentages can create a soil that compacts like concrete or a soil that meets the performance requirements. Therefore, soil performance standards are essential in getting the right soils for the project.

Landscape architects are now using many different types of soils, blends, or mixes. Therefore, it is necessary to go through the following requirements for each type of soil and for each soil layer that is shown on the plans and details. Not all of the soil requirements listed below may be necessary for every project, but the list provides the standard requirements that will likely be sufficient for even complex projects.

SOIL PHYSICAL REQUIREMENTS

Each soil or layer of soil shall meet requirements below based upon testing according to the above test methods. The soil texture can be specified by one of the following three different approaches, with the desired soil texture or percentage makeup dependent on the design intent concerning soil moisture, hydraulic conductivity, etc.

i. Provide the soil textural class e.g. sandy loam,

ii. Specify the percent range of sand, silt, and clay by weight, or

iii. Specify a specific percent range by weight of all of the textural constituents, including the various gradations of sand.

Other physical requirements to be specified include:

i. Fragment Size Distribution:

  a. Aggregates: Zero percent greater than (insert)[3] mm in diameter.

  b. Sticks, Debris, and other Foreign Materials: less than 1 percent by weight

  c. The soil shall all be screened and only the material that passes through a screen with ½-inch openings shall be acceptable.

ii. Total Porosity: Minimum (insert) percent

iii. Macro Porosity: Minimum (insert) percent

3 The landscape architect will have to make an independent judgement to the value; the values vary depending upon the type of soil and the intended application in the landscape.

iv. Saturated Hydraulic Conductivity: > (insert) inches/hour

v. Moistuire Holding Capacity:

a. Water Holding Capacity at atmospheric pressure (0 bars soil moisture tension): > (insert) by volume

b. Water Holding Capacity at -1/10 bar soil moisture tension: > (insert) by volume.

c. Water Holding Capacity at –1/3 bar soil moisture tension: > (insert) % by volume

d. Water Holding Capacity at –15 bar soil moisture tension: > (insert) by volume

SOIL CHEMICAL REQUIREMENTS

Each soil or layer of soil shall meet the requirements below based upon testing according to the specified test methods:

i. Cation Exchange Capacity: < (insert) meq/100 grams of fine earth

ii. Soluble Salt Content: < (insert) mmho./cm at 25oC

iii. Soil Reaction: (insert) to (insert) pH

iv. RCRA Metals: Shall be below maximum limits established by EPA

v. Phytotoxicity: Below phytotoxicity limits established by SSSA

vi. Compost Humus: Finely divided fine particulate or fine granular, with a pH range of 5 to 7.5, composed of partially decomposed organic matter. The compost shall be of uniform quality, free from toxins, ashes, construction debris, cement, bricks, concrete, boulders, tar residues, tarred paper, boards, chips, plastic, glass, or any other undesirable material. No compost shall be delivered in a frozen or muddy condition. The compost shall have a minimum of 25% humus content. The electrical conductivity (salt content) shall be less than 5000 micro-mohs/cm. The compost shall all be screened and all must pass through a screen with ½-inch openings. The compost shall be produced by a recognized member company of US Composting Council. The compost shall been tested by an approved laboratory using Test Methods for the Examination of Composting and Compost (TMECC) and has received USEPA Seal of Testing Assurance. The compost shall be measured on a cubic yard basis for mixing with soil materials.

ADDITIONAL PROPERTIES

Any imported, blended, or manufactured soil before amending should be cleaned so that the soil does not contain any of the following:

i. Stones and gravel larger than ½-inch in any dimension,

ii. Bullets, metal fragments, glass, plastic, or other similar debris,

iii. Roots, living plants, and sod,

iv. Clods, clay lumps, pockets of sand, or gravel,

v. Paint, paint washout, concrete slurry, concrete layers or chunks, cement, plaster, building debris, or other types of debris,

vi. Oils, gasoline, diesel fuel, paint thinner, turpentine, tar, roofing compound, acid, and other extraneous materials emitting a petroleum odor and which might be harmful to plant growth,

vii. Noxious weeds and invasive plants including quack grass, Johnson grass, poison ivy, nut sedge, nimble will, Canada thistle, bindweed, bent grass, wild garlic, ground ivy, perennial sorrel, and brome grass, or

viii. Grubs, nematodes, or other pests, pest eggs, or other undesirable organisms and disease-causing plant pathogens.

FINAL SCREENING

After amending the soil it shall be screened again and only the soil material that passes through a screen containing ½-inch openings shall be shipped to the construction site. Gravel based structural soils shall be screened and approved by the landscape architect prior to adding the structural gravel.

Soil Physical Amendments for Restoration

Soil restoration includes amending compacted soil, removing fill material that has buried the original soil, replacing soil material from old exhumed soils to rebuilt soil profiles, and other types of soil restoration work. The areas for each type of restoration should be shown on the plans and described in details, along with the performance standards that specify the restoration work.

Reference soils are natural undisturbed soil profiles, typically on the same site, which are thought to be similar to currently damaged soil profiles prior to their disturbance. The reference soils are tested to determine the correct soil standards (horizons, depths, textures, bulk densities, etc.) that will need to be achieved to successfully restore the damaged soils. An on-site soil survey is essential in determining the extent of both undamaged and damaged soils as well as the types and degrees of damage. Soil restoration is required for treating unhealthy or damaged soils pursuant to the Sustainable Sites Initiative.

REFERENCE SOIL PROFILES

i. Select and characterize the reference undisturbed soil profile(s),

ii. Compare the disturbed soil profile(s) to the reference soil profile(s),

iii. Determine the methods to restore the disturbed soil profile(s) to match or mimic the reference soil profile(s):

    a. Tillage of soil to eliminate compaction, adjust the soil pH, enhance infiltration, and/or increase the soil organic matter,

    b. Excavation of over burden on buried soils, and

    c. Filling surface soil material over exhumed soils.

TILLAGE PERFORMANCE STANDARDS

i. Chisel or subsoiler plow

a. Chisel plow with sufficient passes to rip the soil horizontally every (insert 6, 9, or 12-inches)[4].

b. Chisel plow in one direction then chisel plow at ninety degrees to the initial direction.

c. Achieve an effective tillage depth of (insert 15, 18, or 21-inches). Note: Select the appropriate width and depth depending upon the soil texture, density, and moisture content.

ii. Rotary tillage

a. Rotary tillage to an effective depth of (insert 6, 8, 10, or 12-inches).

b. Rotary till in one direction and then rotary till at ninety degrees to the initial direction.

c. Achieve sufficient tillage of soil so that 35% of soil particles pass a #4 sieve with openings of 5-mm (0.2-inch), 70% of soil particles pass a ½-inch sieve with openings of 12.7-mm (0.5-inch), and 90% of soil particles pass a 1-inch sieve with opening of 25.4-mm (1-inch).

iii. Hand tillage

a. Hand till to an effective depth of (insert 6, 8, 10, or 12-inches).

b. Achieve sufficient tillage of soil so that 35% of soil particles pass a 1-inch sieve with opening of 25.4-mm (1-inch), 70% of soil particles pass a 2-inch sieve with opening of 50.8-mm (2-inch), and 90% of soil particles pass a 4-inch sieve with opening of 101.6-mm (4-inch).

EXCAVATION OF UNSUITABLE SOIL MATERIAL

i. Buried Surface Soil Horizons – Soils filled over top of buried surface soil horizons should be carefully removed to expose the original soil surface.

ii. Buried Subsurface Soil Horizons – Soils filled over top of buried subsurface soil horizons can be difficult to distinguish, however the filled material should be removed and the upper portion of the soil profile should be reconstructed using one of the reference soil profiles to determine the missing horizons, textures, etc.

FILLING WITH SUITABLE SOIL MATERIAL

i. Filling of Surface Soil Horizons – surface soil material similar to one of the reference soil profiles should be excavated and stockpiled from areas of new development. The surface soils should be carefully stripped in order to not mix in any subsoil materials.

ii. Filling of Subsurface Soil Horizons – subsurface soil material similar to one of the reference soil profiles should be excavated and stockpiled from areas of new development. The subsoils should be carefully stripped to preserve as much of the soil structure as possible.

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4 The landscape architect will need to select a depth value depending upon the type of tillage equipment that should be used; refer to Figure 39 for tillage depths for various types of equipment.

Soil Inorganic Amendments

LIME

ASTM C 602, agricultural liming material containing a minimum of 80 percent calcium carbonate equivalent and as follows:

i. Class: T, with a minimum of 99 percent passing through No. 8 (2.36-mm) sieve and a minimum of 75 percent passing through No. 60 (0.25-mm) sieve.

ii. Form: Provide lime in form of finely ground dolomitic limestone.

iii. Rate of lime shall be based upon soil test report. Lime shall be mixed into the soil materials prior to final screening and prior to delivery to the project site.

FERTILIZER

Fertilizer rates are based upon the soil fertility laboratory test report. The fertilizer shall be added to Type 1, 2, 3, and 4 soil mixes prior to final screening and prior to delivery to the project site.

i. Bonemeal: Commercial, raw or steamed, finely ground; a minimum of 4 percent nitrogen and10 percent phosphoric acid.

ii. Superphosphate: Commercial, phosphate mixture, soluble; a minimum of 46 percent available phosphoric acid.

iii. Commercial Fertilizer: Commercial-grade complete fertilizer of neutral character, consisting of fast- and slow-release nitrogen, 50 percent derived from natural organic sources of urea formaldehyde, phosphorous, and potassium in the following composition:

    a. Slow-Release Fertilizer: Granular or pelleted fertilizer consisting of 50 percent water-insoluble nitrogen, phosphorus, and potassium in the following composition.

    b. Composition: 20 percent nitrogen, 10 percent phosphorous, and 10 percent potassium by weight, or composition of nitrogen, phosphorous, and potassium in amounts recommended in soil reports from a qualified testing agency.

Soil Organic Amendments

ORGANIC COMPOST

Suitable organic compost to blend with soil material consists of finely divided compost with a pH range of 5 to 7.5, and is composed of highly decomposed (75% with no visible plant fibers) organic matter. The organic compost material shall be ground so that 90% or more passes a ½-inch screen. The compost shall be of uniform quality, free from toxins, ashes, construction debris, cement, bricks, concrete, boulders, tar residues, tarred paper, boards, chips, plastic, glass, or any other undesirable material. No compost shall be delivered in a frozen or muddy condition. The compost shall have a minimum of 25% humic matter. The electrical conductivity (based upon salt content) shall be less than 5000 micro-mohs/cm. The compost shall be produced by recognized member company of US Composting Council. The compost shall been tested by approved laboratory using Test Methods for the Examination of Composting and Compost (TMECC) and has received USEPA Seal of Testing Assurance. The compost shall be measured on a cubic yard basis for mixing with soil materials.

Note: The requirements for 25% humic matter and 90% passing a ½-inch screen exceed the US Composing Council standards. Organic compost mulch need not meet these additional requirements, but the material should not be used to mix with soil materials.

ORGANIC HUMIC MATERIAL

Humic matter (used in the above standard for organic compost) shall consist of finely divided compost or granular textured humic matter with a pH range of 5 to 7.5, composed of fully decomposed (no visible plant fibers) organic matter. The organic humic material shall be ground so that 75% of the volume of particles are not visible and passes a #140 screen and 100% of the volume passes a #60 screen. The organic humic material shall have a minimum of 75% humic matter content. The electrical conductivity (based upon salt content) shall be less than 5000 micro-mohs/cm. The organic humic material shall be measured on a cubic yard basis for mixing with soil materials.

FIBROUS ORGANIC MATERIAL

A mix of fibrous organic material and uniformly graded sand produces a filter soil material that is used to absorb metals and organic chemicals in bioretention systems. Organic material (compost or other fibrous organic material) is primarily finely divided individual fibers of approximately ½-inch to ¾-inch in length that can be added to medium or coarse sandy soil media and will not wash out of the media.

GLUCOSE SUGAR

Glucose sugar consists of common granular glucose sugar that is used to amend soils and provide an immediate source of food for soil micro-organisms.

Installation Requirements for Imported Soils

The landscape architect can either specify the requirements for the imported soils needed for the project discussed previously, or can specify three or more base soil materials (e.g., sandy soil, loamy soil, and organic compost) that will be blended together to create a number of different types of soils or soil layers for the project. The performance standards for the different base soil material will cover most of the parameters. The ratio of base soil materials needed for the mix of different types of soils are estimated and the laboratory is asked to determine the recommended ratios to meet certain variable parameters, such as different percentages of plant available moisture and/or different hydraulic conductivities, etc.

Imported soils may require special installation and field testing procedures to avoid over compaction during placement. In some cases, imported soils can be placed using conveyors to avoid use of heavy equipment in their placement. In many cases, the use of small track type box graders can be used to spread soil material with limited soil compaction. No soil material should be delivered, blended, mixed, or installed in a wet, frozen, or muddy condition, or with a moisture content that is not optimum for achieving the desired percent compaction.

Imported soil material used for fill is typically placed in lifts of 4 to 6-inches. A percent of maximum density should be stated for each type of soil and soil layers. A small area on the site should be tested by the contractor to determine if the type of compaction equipment, number of passes, and moisture content of the soil needs to adjust so that the bulk density standard is not exceeded.

No soil material should be delivered to the site until the landscape architect approves the testing data and proposed soils. The soil should be field inspected upon delivery to the job site prior to approval to off load the soil materials. The landscape architect reserves the right to reject any soil materials that on delivery appear to not meet the specifications. The contractor should have the right to demonstrate that the soil material meets all of the specifications. If the specifications require testing of the in-place soil material (e.g. for bulk density) the landscape architect should allow for the soil material to be amended to correct any discrepancies (e.g. bulk density amended by tillage).

Processing Requirements for Manufactured Soils

On many landscape projects, large grading equipment can be used to install structural soils since the soils are resistant to over compaction. The soils are designed to be compacted to 85 to 95% maximum density and at the same time to be sufficiently porous to allow for the vigorous root growth. Some projects cannot be easily constructed without the use of large earth moving equipment and may require the use of as much as 100,000 cubic yards of manufactured structural soils.

Gravel based structural soils are used for urban street trees, compacted base for concrete, and other applications needing a dense soil that is also porous. Sand based structural soils are used for sports fields, event venues, and other landscapes that will receive considerable use compaction after completion of construction.

Execution of Work

GENERAL

i. Install landscape soils according to requirements in the various landscape planting specification sections.

ii. Verify that no foreign or deleterious material or liquid such as paint, paint washout, concrete slurry, concrete layers or chunks, cement, plaster, oils, gasoline, diesel fuel, paint thinner, turpentine, tar, roofing compound, or acid has been deposited in landscape soil.

iii. Proceed with installation only after final approval has been received by the Project Soil Scientist and/or Landscape Architect.

Field Quality Control

Field testing is typically required prior to off-loading of soil materials and field performance testing is conducted during or after construction and prior to approval of the work.

TESTING AGENCY

Contractor shall engage a qualified soil science testing firm to perform tests and inspections.

PERFORM FIELD TESTS

The following in-place tests and inspections shall be performed:

i. Soil Layers – Perform tests at top of soil layer before adding the next soil layer or pavement on top.

   a. Perform triplicate saturated hydraulic conductivity test using in-situ content head permeameter method at 6-inch, 12-inch, 18-inch, and 24-inch depths; one test for every 5,000 SF of surface area; conducted and approved prior to construction of paving areas.

   b. Geometric mean of saturated hydraulic conductivity test shall exceed 5-inches per hour and no test shall be less than 2.5-inches per hour.

ii. Drainage Layers – Sand Aggregate and Gravel Aggregate Layers – Perform tests of soil materials and confirm results before adding the next soil layers.

   a. Perform triplicate sieve analysis tests to confirm that soil material complies with the standards.

   b. Compare data of sand and gravel layers to determine if the layers meet the USGA uniformity and bridging standards.

   c. Tests shall conform to all of the methods and performance standards in this specification.

iii. Soil and aggregate materials will be considered defective if they do not pass tests and inspections. Failed soil materials will need to be corrected by amending the in-place soil or by removal and replacement of soil material that passes the tests.

iv. General Contractor shall be responsible for assuring that the in-place soil materials are protected and are not impacted from work by other subcontractors. If equipment must be located where damage to the in-place soil material might occur, the General Contractor shall require sufficient matting or boarding to be first placed over the in-place soil material.

v. Other Requirements:

   a. Restrict construction vehicles and pedestrian traffic from access to all soil layers during and after installation.

   b. Protection - Protect landscape soil from contamination. Keep adjacent paving and construction areas clean, and work areas in an orderly condition.

c. Contamination - If landscape soil or subgrade is contaminated by foreign or deleterious materials or liquids, remove the landscape soil and contamination; restore the subgrade as directed by soil scientist and replace contaminated landscape soil with new landscape soil.

d. Removals - Remove surplus soil and waste material including excess subsoil, unsuitable soil, trash, and debris and legally dispose of them off owner's property.

Appendix: Soil Science Terminology

Acidic Soils – soils that have pH values of < 7.0 and are typically found in humid regions.

Aerobic Soil – a soil that contains a high concentration of oxygen.

Alkaline Soils – soils that have pH values of > 8.5 and are typically found in semi-arid to arid regions. These soils contain sufficient sodium to interfere with the growth of most plants.

Alluvial Soil – a soil developed from recently deposited sediment in a floodplain.

Anaerobic Soil – a soil that has an absence of oxygen and usually produces methane and sulfuric gases harmful to most plants.

Apparent Water Table – the water table in the bore hole at the end of drilling when the water level may not be stabilized. Contrast with the normal water table depth which is measured twenty-four hours after drilling.

Available Water Capacity – the amount of water released to plants between field capacity and permanent wilting point.

Base Saturation – the ratio of quantity of exchangeable bases to cation exchange capacity. It is a measure of the amount of electron charges that are occupied by the cations: primarily calcium, magnesium, and potassium vs. aluminum and hydrogen. A high base saturation reduces soil acidity and increases supply of other plant nutrients.

Bulk Density – the density per unit volume; expressed in units of grams/cubic centimeter.

Cation Exchange Capacity (CEC) – the sum of the exchangeable bases plus acidity of the soil. The CEC is a measure of the available electron charges on clay or soil organic matter particles; express in milliequivalents/100 grams of soil.

Chroma –the relative purity, strength, or saturation of a color; its chroma is inversely related to the grayness of the soil.

Clay – a soil particle < 0.002 mm in diameter.

Claypan – a dense, compact, slowly permeable layer in the subsoil having much higher clay content than the overlying soil material.

Clod - refers to a compact coherent mass of soil varying in size, usually produced by plowing, digging, etc., especially when these operation are performed on compacted soils or soils that are too wet or too dry. The clod is usually formed by compression or breaking off from a larger unit, as opposed to natural soil forming processes that produce various types of soil structure.

Coarse Earth Fraction – total of soil particles in a mineral soil that are greater than 2.0 mm in diameter.

Coarse Textured Soils – a broad class of textures consisting of, or containing, large quantities of sand; includes sand and loamy sand textural classes.

Compost – organic residues or a mixture of organic residues, and soil, that has been mixed, piled, moistened, and has generally undergone thermophilic decomposition until the original materials have been substantially altered or decomposed.

Composting – a controlled biological process which converts organic materials into humus-like material suitable for use as a soil amendment or organic fertilizer.

Cone Penetrometer – a hand-held device for measuring the resistance of an in-place soil; the bulk density can be estimated using a calibration curves for different moisture contents of the particular soil material.

Consistency – the manifestation of the forces of cohesion and adhesion acting with the soil at various water contents, as expressed by the relative ease with which a soil can be deformed or ruptured.

Delineation – an individual polygon shown by a closed boundary on a soil map that defines the area, shape, and location of a soil mapping unit with a landscape.

Drainage Class – a group of soils defined as having a specific range in relative wetness due to a water table; occurrence is a product of development of the soil.

Duripan – a subsurface soil horizon that is cemented by illuvial silica.

Eluviation – the removal of soil material in suspension (or in solution) from a layer or layers of soil; usually the loss of material in solution is described as leaching.

Evapotranspiration – the loss of water from the soil due to evaporation from the soil surface and by transpiration from plants.

Expandable Clay Minerals – clay minerals that shrink and swell and in very small amounts can cause wicking of water upward through the soil profile. Their presence can produce upward movement of water causing prolonged saturation.

Fertilizer – any organic or inorganic material of natural or synthetic origin (other than liming materials) that is added to a soil to supply one or more plant nutrients essential for growth. See also Inorganic Fertilizer and Organic Fertilizer.

Field Capacity – the content of water remaining in a soil 2 or 3 days after having been saturated to the ground surface and after free drainage through the soil has become negligible.

Final Constant Infiltration Rate – the rate of infiltration after one hour; note that the rate is lower than Ksat for A-horizon; AB-horizon limits the flow after the initial filling of the soil pores.

Fine Earth Fraction – the total of the soil particles in a mineral soil that are equal to or less than 2.0 mm in diameter, thus not including the gravel and stone portion of the soil; portion of the soil that is normally used for soil testing. See also Coarse Earth Fraction and Whole Earth Fraction.

Fine Textured Soil – a broad class of textures consisting of or containing large quantities of silt and clay. It includes sandy clay, silty clay and clay textural classes.

Fixation Capacity – the amount of a given plant nutrient that is bound to the soil and organic particles and are therefore are not readily available to plants. Clay particles will bind phosphorous and phosphorous will not be available to plants until the fixation capacity has been exceeded.

Fragments – rocks larger than 2 millimeters in diameter including fine gravel (>2 to 5 mm), medium gravel (>5 to 20 mm), coarse gravel (>20 to 76 mm), cobbles (>76 to 250 mm), stones (>250 to 600 mm), and boulders (>600 mm); note 1-foot equals 304.8 mm.

Fragipan – a natural subsurface horizon that is dense, hard, and impermeable, which appears to be but is not cemented; horizon is typically associated with a water table.

Gypsum – the common name for calcium sulfate, which is used to supply calcium to ameliorate soils with a high exchangeable sodium fraction;exchangeable sodium is that portion of cation exchange capacity that is occupied by sodium.

Hardpan – a soil layer with physical characteristics that limit root penetration and restricts water movement.

Heavy Metals – Consists of the elements cadmium, cobalt, chromium, copper, iron, manganese, molybdenum, nickel, lead, and zinc in sufficient concentration that these metals are considered hazardous.

Horizontal Core – the core sample taken perpendicular to the ground surface.

Hue – a measure of the chromatic color of soil. see also Munsell Color System, Chroma, and Value.

Humic Matter – Humic substances formed by secondary synthesis reactions in soils including humic acid, fulvic acid, and humin; coats and colors soil particles, but not visible to the eye.

Hydraulic Conductivity – the measurement of tviscous flow of water in soil; typically used in Darcy's law of fluid dynamics. The measurement can be of saturated hydraulic conductivity or varying degrees of unsaturation (unsaturated hydraulic conductivity) based upon the soil moisture tension.

Hydric Soils – soils that are wet long enough to periodically produce anaerobic conditions harmful to plants that are not suited for wetland conditions.

Hydrometer – a method of measuring the sand, silt, and clay fractions in a soil using the principle of sedimentation.

Illuviation – the process of deposition of soil material removed from one horizon to; usually from an upper to a lower horizon in the soil profile; compare with eluviation.

Inclusions – minor soils within a soil mapping unit that are so small or the pattern is so complex that they cannot be reasonably delineated based upon the scale of the map.

Incubation – the process of adding soil amendments, then allowing sufficient time for soil reactions to occur before the laboratory testing of the soil.

Infiltration – entry of water into a soil.

Infiltration Capacity – volume of water entry into a soil; usually taken after 1 or 2 hours after the start of infiltration test.

Infiltration Rate – rate of water entry into a soil; volume of water entered a specified cross sectional area per unit of time; final constant infiltration rate is the rate after the decay curve has receded and equilibrium has taken place; usually taken as the rate after 1 to 2 hours.

Infiltrometer – a device for measuring the volume or rate of water entry downward into a soil.

Inorganic Fertilizer – a fertilizer material in which carbon is not an essential component.

Iron Pan – a hardpan in which iron oxide is the principal cementing agent.

K_2O (potassium oxide) – designation on the fertilizer label that denotes the percentage of available potassium reported as K_2O. See the definition for potassium.

Lime – agricultural lime which has been finely ground; used to raise the pH in acidic soils; contains calcium carbonate as well as other minerals; the label contains the percent of calcium carbonate equivalent or the percent purity.

Liquid Limit – an engineering measurement (Atterburg Limits) of the liquidity of soil; percent moisture content when soil is said to become liquid.

Lithologic discontinuities – abrupt vertical changes in soils such as compacted pans, or in urban areas where different soils have been filled where certain compacted layers limit water movement.

Loamy Textured Soil – a broad class of soil textures which consists of sandy loam, loam, silt loam, silt, clay loam, and sandy clay loam.

Macronutrient – a plant nutrient found at relatively high concentrations; usually refers to nitrogen, phosphorus, and potassium, but may include calcium, magnesium, and sulfur.

Macro-Pore – a pore that drains at tensions of less than -40 from pore diameters greater than 0.075 mm; macro-porosity is the total volume of all of the macro-pores in the sample.

Meso-Pore – a pore that drains at tensions -40 to -100 and thus from pore diameters between 0.03 to 0.075 mm. The meso-porosity is the total volume of all of the meso-pores in the sample.

Micro-Pore – Is a pore that drains at tensions of greater than -100 and thus from pore diameters less than 0.03 mm. The micro-porosity is the total volume of all of the micro-pores in the sample.

Matrix Color – Is the dominant or co-dominant color of the soil.

Medium Textured Soil – Is a textural group consisting of sandy loam, loam, silt loam, and silt textures.

Microbes – term for all microscopic organisms.

Micronutrient – a plant nutrient found in relatively small amounts in plants; such as boron, chloride, copper, iron, manganese, molybdenum, nickel, cobalt, and zinc.

Micro-pore – small diameter soil pores that are equivalent in size to the diameter of silt and clay particles; size range of 0.001 to 0.05 mm;hold plant available water in the soil.

Mineral Soil Profile – a soil consisting of predominately mineral matter, but may contain an organic surface layer of up to 30 cm (12 inches) thick.

Mineral Soil Material – a soil that has 10 percent or less of humus or soil organic matter.

Mottles – Spots or blotches of different color or shades interspersed with the dominant or matrix color.

Muck – an organic soil material in which the original plant parts are not recognizable; contains more mineral matter and is usually darker in color than peat.

Munsell Color System – a color designation system that specifies the relative degrees of color: hue, value, and chroma.

Mycorrhiza – literally refers to "fungus root"; an association of symbiotic fungi with the roots of plants.

Neutral Soil – a soil in which the surface layer, at least the tillage zone, is in the pH 6.6 to 7.3 range.

Nitrogen – an essential element for plant growth. The tag on a bag fertilizer indicates the amount of nitrogen, phosphorus, and potassium. The first number represents the amount of nitrogen in the fertilizer. A 10-20-10 fertilizer contains 10% nitrogen therefore it will take 500 lbs. of the fertilizer to yield 50 lbs. of nitrogen.

Nitrogen Mineralization – the microbial process of conversion of organic form of nitrogen to an inorganic form that can be utilized by plants.

Organic Fertilizer – a fertilizer material containing carbon and one or more plant nutrients in addition to hydrogen and/or oxygen; a by-product from the processing of animals or vegetable substances that contain sufficient plant nutrients to be of value as fertilizers.

Organic Soil Material – a soil which has 10 percent or more of humus or soil organic matter.

Organic Soil Profile – a soil where the sum of the thicknesses of layers dominated by organic matter is greater than the sum of the thicknesses of layers dominated by mineral matter.

P_2O_5 (phosphoric acid) - designation on the fertilizer label that denotes the percentage of available phosphorus reported as P_2O_5; see the definition for phosphorus.

Phosphorus – an essential element for plant growth. The tag on a bag fertilizer indicates the amount of nitrogen, phosphorus, and potassium. The second number represents the amount of phosphorus in the fertilizer. A 10-20-10 fertilizer contains 20% phosphorus therefore it will take 250 lbs. of the fertilizer to yield 50 lbs. of phosphorus. See also P_2O_5 (phosphoric acid).

Potassium – an essential element for plant growth. The tag on a bag fertilizer indicates the amount of nitrogen, phosphorus, and potassium. The third number represents the amount of potassium in the fertilizer. A 10-20-10 fertilizer contains 10% potassium therefore it will take 500 lbs. of the fertilizer to yield 50 lbs. of potassium. See also K_2O (potassium oxide).

Parent Material – the unconsolidated and chemically weathered mineral or organic matter from which soils are developed by soil forming processes.

Particle Size Analysis – the determination of the various amounts of sand, silt, and clay particles by their size through sedimentation or sieving.

Peat – organic soil material in which the original plants parts are recognizable.

Ped – a unit of soil structure such as a block, column, granule, plate, or prism formed by natural processes (in contrast to a clod which is formed artificially).

Penetrometer – Is an instrument for measuring the penetration resistance of a soil; used to calculate the density of a soil. A cone penetrometer uses a cylindrical rod with a cone-shaped tip designed for penetrating soil and for measuring the penetration resistance.

Perched Water Table – saturated layer of soil that is separated from any underlying saturated layers by an unsaturated layer; perched water tables typically occur above dense layers or hardpans.

Permeability –the ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil; usually expressed as permeability coefficient, which is a unit-less value.

Permeameter – a device for measuring the hydraulic conductivity of a soil; the preferred device is a constant head permeameter.

pH – a measure of the proportion of hydrogen ions vs. hydroxyl ions (ions with OH such as $Al-OH_3$ ion). Greater concentration of hydrogen ions creates low pH and greater concentration of hydroxyl ions creates high pH. The pH scale is logarithmic, so that pH 5 is ten times more acid than pH 6. High pH soils are alkaline soils and have pH greater than 7; greater than pH 8.5 is very high, pH 7.5 to 8.5 is moderately high, and pH 7 to 7.5 is slightly high. Low pH soils are acidic soils and have pH less than 7; less than pH 5.5 is very low, pH 5.5 to 6.5 is moderately low, and pH 6.5 to 7 is slightly low pH. Neutral pH soils are soils that have pH of 7, which is neither acidic nor alkaline.

Plant Available Water Content – the percent of water volume released between in-situ field capacity (after a saturated soil drains for 24 hours) and the permanent wilting point (-15 bars of tension) in relationship to the total volume of soil.

Plastic Index – an engineering value (Atterburg Limits) of liquid limit minus the plastic limit; the smaller the value the easier the soil moves from plastic state to liquid state.

Plastic Limit – an engineering measurement (Atterburg Limits) of the plasticity of soil; percent moisture content when soil is said to become plastic.

Porosity – the volume of pores in a soil; it is usually expressed as a percent of the soil volume.

Redoximorphic Features – soil features associated with wetness that result from the reduction and oxidation of iron and managanese compounds in the soil after saturation with water and desaturation, respectively.

Restrictive Horizon – a horizon of various types that are dense and/or cemented sufficient to restrict the movement of water and gas. In humid climates the types include: fragipans, iron pans, plinthite, and spodic horizons. In arid climates the types include: caliche, duripans, petrocalcic, petroferric, and petrogypsic horizons.

Runoff – the portion of precipitation or irrigation on an area that does not infiltrate, but instead is discharged from the area.

Saline Soils – soils that contain sodium that occupies more than 15% of CEC; these are problem soils that are difficult to manage unless plants are adapted to a high sodium concentration.

Salinity – the amount of soluble salts in a soil; conventional measure is the electrical conductivity of a saturated extract. Saline soils are difficult to manage unless plants are adapted to a high salt concentration or excess salt is leached from the soils.

Seasonally High Water Table – depth to water table during typical year as determined by redoximorphic features in the soil profile by a Professional Soil Scientist.

Soil – the unconsolidated mineral and organic material on the surface of the earth that serves as a natural medium for the growth of plants and other landscape uses.

Soil Amendment – any material such as lime, gypsum, compost, plant residues, or synthetic soil conditioners that when worked into the soil or applied on the surface enhances plant growth.

Soil Colors – specifically named and numeric colors which are defined by the Munsell Color System.

Soil Mapping Unit – polygon identified by name in NRCS (Natural Resources Conservation Service) soil surveys.

Soil Organic Matter – the organic fraction of the soil excluding undecayed plant and animal residue; soil organic matter is primarily finely divided and fully decomposed particles that cannot be seen by eye.

Soil Horizon – a layer of soil approximately parallel to the land surface and differing from adjacent layers in physical, chemical, and biological properties or characteristics such as color, structure, texture, consistency, organism present, degree of acidity or alkalinity, etc.

Soil Profile – a vertical section of the soil through all its horizons and extending downward to the extent of weathering or deposition. A soil profile typically extends downward for one to two meters or more.

Soil Series – official names of major soils by the USDA's Natural Resources Conservation Service (NRCS); each series has an official soil series description and geographic extent.

Soil Structure – combination or arrangement of primary soil particles into secondary units or peds. The secondary units are characterized on the basis of size, shape, and grade.

Soil Survey – the systematic examination, description, classification, and mapping of soils in an area.

Soil Taxonomic Classification – a highly technical procedure for classifying soils into scientific names bases upon the genesis, morphology, and other physical, chemical, biological, and mineralogical characteristics of soils. Soils are classified into orders, subgroups, great groups, subgroups, families, and finally soil series.

Sulfur – sulfur which has been finely ground; used to lower the pH in alkaline soils.

Super Phosphate – phosphorus oxide which has been finely ground; used to overcome phosphorus fixation capacity of certain clayey soils. Certain clays will bind phosphorous tightly so that it is not available to plants, therefore it is necessary to have sufficient phosphorus in the soil to exceed the fixation capacity so that the excess is available to plants.

Texture – the relative proportion of sand, silt, and clay particles grouped into textural classes having one of the following names: sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, or clay.

Total Porosity – the total volume of the macro-porosity, meso-porosity, and micro-porosity in the sample.

Undisturbed Soil Core – a core of soil dug using a specially design soil core sampler Typically the samplers extract a core with a diameter of 1.5, 2, 2.5, or 3-inches. The diameter needs to match the size needed for the laboratory's testing equipment.

Water Table – upper surface of ground water or level in the ground where the water is at atmospheric pressure.

Whole Earth Fraction – total soil particles in a mineral soil consisting of the fine earth and coarse earth fraction of the soil.