Soil Science

NATIONAL ENVIROTHON OBJECTIVES:

- Recognize soil as an important and dynamic resource.
- Recognize and understand the features of a soil profile.
- Describe basic soil properties and soil formation factors.
- Understand the origin of soil parent materials.
- Identify and list soil characteristics (e.g., texture, structure, etc.) and their relation to soil properties.
- Determine basic soil properties and limitations (e.g., mottling and permeability) by observing a soil pit or a soil profile.
- Recognize the characteristics of wetland (hydric) soils.
- Understand soil drainage classes and understand how wetlands are defined.
- Understand soil water, its movement, storage and uptake by plants.
- Understand the effects of land use on soils.
- In land use planning decisions, discuss how soil is a factor in or is impacted by non-point source pollution.
- Identify types of soil erosion and discuss methods for reducing erosion.
- Utilize soil information, including a soil survey.

BUT WHAT DO SOIL SCIENTISTS DO?

The terrestrial ecosystem relies on the soil as a foundation from which to build. Soil Scientists teach people what soil is and how it interacts with other components of our ecosystem. They study and research soil formation, classification and engage in soil mapping (i.e.; soil surveys). They investigate the chemical and biological properties of soil and how these support life above ground. They also strive to find sustainable management and usage guidelines which will benefit crop production, environmental quality, waste management, recycling and wildlife.

Soil Scientists often work for the federal government but also find work with non-profit environmental groups, consulting firms or private practice. In the government sector, soil scientists can work for the Natural Resources Conservation Service (NRCS) or a state's environmental agency. They work on comprehensive soil surveys and interact with the public, offering tips on the best management practices for land use, plant growth and erosion control. Soil Scientists often act as consultants working with engineers on construction projects or technicians on soil problems, and often they deal with waste management and groundwater issues. Soil Scientists spend much of their time outdoors, conducting soil testing and gathering information about the relationship between different soil properties and plant growth.

Soil Scientists require at least a four year bachelor's degree from an accredited university, and usually a master's degree or higher to work in research positions. Students will study a range of disciplines including biology, geology, chemistry and hydrology. Recent graduates often make between $30,000 and $50,000 per year. Soil Science is integral to understanding the world we live in and to supporting the health of our ecological community. The demand for Soil Scientists will be steady as our nation strives to live in sustainable harmony with our environment.

Introduction to Soils

Why should we know our soils?

First and foremost, soils perform important functions in our environment. Furthermore soils are variable, meaning their capability to perform these functions also varies. Soil distribution is related to geology and it plays an important role in determining land use. Soils can also be degraded through erosion, compaction and contamination, which can affect their ability to function. Knowledge of soil distribution patterns and soil properties can help us put our soils to their best use and maintain optimal quality and performance. Important environmental functions performed by soils include:

- Sustaining biological activity, diversity and productivity
- Regulating and portioning water and solute flow
- Filtering, buffering, composting, immobilizing and detoxifying organic and inorganic materials
- Storing and cycling nutrients and other elements
- Providing support for socio-economic structures
-

What is soil?

Soil is a naturally occurring mixture of mineral and organic matter, which forms on the surface of the earth, and which changes, or has changed, in response to climate and organisms. A natural soil is composed of:

- mineral material
- organic material
- air
- water

The proportion of each component can vary from one soil to another.

An "ideal" agricultural soil contains:

50% solid space &	**50% pore space**
45% mineral material	25% water
5% organic material	25% air

Mineral soil material

Derived from weathered rocks, this "fine earth" is composed of three particle sizes:

- *sand* —2 to 0.05 millimeters—gritty feel— can be seen with eye
- *silt* —0.05 to .002 millimeters—smooth feel—can be seen with microscope
- *clay* —less than .002 millimeters—sticky feel—need electron microscope to see

Sand and silt are relatively inert; they form the 'soil skeleton'. Clay particles have an electrical charge and a high surface area. These make it the active portion of the mineral soil—it has a high attraction for water, nutrients and other clay particles. The three sizes (sand, silt and clay) are commonly associated together in aggregates. Varying proportions of each size give the soil a 'texture'.

The upper size limit for soil material is 2mm; larger particles, or coarse fragments, do not behave entirely like soil, although they influence drainage, and can reduce the volume in soil for root growth, and water and nutrient storage.

Coarse fragments can be subdivided by size.

- *gravel* - 2 to 75mm (2mm to 3 inches)
- *cobbles* – 75 to 250mm (3 to 10 inches)
- *stones* – 250 to 600mm (10 to 24 inches)
- *boulders* - >600mm (>24 inches)

Common coarse fragments in the NYC area include:

- gneiss, schist, granite (from Manhattan & Bronx)
- red sandstone and shale, with associated igneous rocks such as diabase (coarse-grained) and basalt (fine-grained) (from Staten Island & NJ)
- serpentinite (green meta-igneous rock from Staten Island)
- quartz or chert (coastal plain deposits in Staten Island, Brooklyn, Queens)

human-made "artifacts" are also common in urban areas: glass, brick, wood, concrete, asphalt, etc.

Organic soil material

This is composed of original and decomposed plant, animal and microbial components. It helps aggregate and loosen soil, provide nutrients and hold water and nutrients.

Organic material can accumulate in very wet or waterlogged conditions, where decomposition is slower. In a natural soil, the *topsoil* or *surface layer*, is usually darker in color because it contains more organic material than the *subsoil*.

Air, water & pore space

A natural soil contains pores space which is ideally half filled with air and half with water. Pore space is one way soil is differentiated from rock. It allows the soil to become a medium for plant, animal, and microbial growth.

In the natural environment, the soil exists as a *three-phase system*, containing:

- A *solid phase*, or soil matrix, including inorganic material with various chemical and mineralogical properties, and organic material in varying degrees of decomposition;
- A *liquid phase*, or soil solution; including soil water and its dissolved substances;
- A *gaseous phase*, or soil atmosphere, more variable in composition than the external atmosphere.

Soil Characteristics

Variability of Soils

Why are soils different? There are *5 Soil forming factors* that describe and control the variation:

- *Parent material* is the raw material or 'geologic substratum' from which soils form. It influences the physical, chemical and mineralogical properties and to a large extent, the rate at which soil formation takes place.
- *Landscape position or topography* influences erosion and deposition, water movement and micro-climate (e.g., north vs. south facing slope) and how effective precipitation is at infiltrating the surface.
- *Climate (*moisture and temperature) affects the rate and extent of physical, chemical and biological reactions in soils.
- *Organisms* affect soil through their activity add organic matter to the soil via decomposition of their wastes and residues. In urban areas, humans are the most influential organisms controlling soil formation.
- *Time* of development from parent material affects soil.

The interaction of these *5 factors* result in the *Soil forming processes*:

- *Additions* include organic matter accumulation and other surficial deposits such as dust or chemicals.
- *Losses* occur through "leaching" of soluble constituents downward through (and out of) the soil by water and the removal of soil material by erosion.
- *Translocations* involve redistribution of constituents from one place to another.
- *Transformations* are physical and chemical changes in minerals or organic compounds.

Processes create soil from a pile of unconsolidated rubble. As time passes, the soil begins to look less like the rubble it came from. The soil forming factors and the soil forming processes are expressed in variable soil properties: horizonation, texture, color, structure, consistence, mineralogy, pH, and nutrient supply. Similar soil forming factors (inputs) result in similar soils (outputs). This makes it possible to predict soil properties and easier for soil scientists to map soils.

Pedology is the study of soil as a natural body. In examining the soil profile, a soil scientist can interpret the processes and factors from the properties (e.g., they can see "mottled" color patterns as an indicator of a saturated soil, or estimate soil age from the extent of horizon development or mineral weathering.

A *soil profile* is a sequence of horizons. A *soil horizon* is a layer of soil that can be distinguished from the surrounding soil by features such as chemical composition, color, and texture.

Description of Master Horizons

O horizons

These are dominated by soil organic material (SOM). Raw organic matter such as plant tissue is decomposed by plants, animals (mainly insects) and microbes, turning it into SOM or humus. SOM improves soil quality as it helps aggregate and loosen soil, provides nutrients and holds water.

Definition: Organic horizon

Process: surface accumulation of slightly to highly decomposed plant & animal residues

ID: surface material, lighter in weight and darker in color than mineral material

Comment: not found in cultivated soils, as it is 'mixed' in when plowed

A horizons

These re mineral layers that formed at the surface or below an O horizon and exhibit an accumulation of highly decomposed soil organic matter intimately mixed with the mineral fraction.

Definition: organically enriched mineral horizon (topsoil)

Process: incorporation or mixing of organic material into mineral soil

ID: darker mineral horizon at the soil surface

E horizons

These are layers in which the main feature is loss of silicate clay, iron, manganese or aluminum or some combination of these, leaving a concentration of sand and silt particles.

Definition: horizon characterized by the loss of some component

Process: eluviation (washing out) of iron, clay, manganese or aluminum

ID: paler color or lighter texture than below, just below A

Comments: not found in all soil profiles

B horizons

These are layers that formed below an A, E or O horizon and show one or more of the following:

1. lighter, brighter or redder colors than above
2. more clay than above
3. Subangular blocky or prismatic structure

Definition: horizon of accumulation, transformation or development of structure or color

Process: development of structure or color through illuviation (moving in) of iron or clay

ID: more clay or iron than above, noticeable structure and brighter or redder color than above

C horizons

These are layers which are not bedrock and are little affected by soil forming processes and lack properties of O, A, E or B horizons.

Definition: largely unaltered parent material

Process: no evidence of soil forming processes (can have weathering, redox features)

ID: unconsolidated material below B; no illuviation, no structure in at least half the volume

R horizons

These are layers of hard bedrock.

Definition: hard bedrock

Process: no soil forming processes, little evidence of weathering

ID: hard, consolidated bedrock

Comment: Not found in all soil profiles

Topsoil: A horizon

Solum: A, E, and B horizons

Subsoil: B horizon

Substratum: beneath the solum (C and R horizons)

Soil Color

Important coloring agents in soil include:

1) *Organic matter* darkens the soil depending on the content and the extent of decomposition;
2) *Iron* gives soil a brown, yellow, or red color, even shades of blue or green depending upon its amount, oxidation state and hydration state. When soil is saturated, iron can become soluble and easily removed, leaving the soil witj "mottled" brown and gray colors. Complete removal of iron leaves the soil with a basic gray color.

Other factors affecting soil color include:

- The parent material
- Soil wetness
- Extent of leaching in the soil

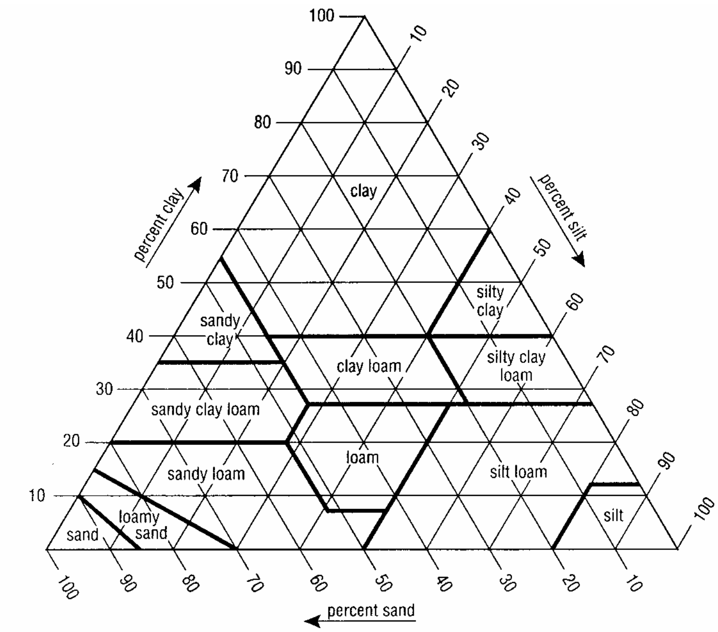
Soil color is described with the *Munsell system*:

- *Hue* is the dominant spectral wavelength. Pages in the Munsell system color book are arranged by hue.
- *Value* is the degree of darkness/lightness. Columns range from black, 0, at the bottom of the page, to white 10, at the top.
- *Chroma* is the purity of spectral color. Rows range from neutral, 0 on the left, to bright colors, 8 on the right. A low chroma (<2) color and a high value (>/= 4) indicates soil wetness.

Soil color for each horizon is matched to a color chip. Soil moisture status affects color and should be recorded (moist or dry). Some horizons may have more than one color present and the percentage of each color should be recorded as well. In this case the dominant color is known as the *matrix color*.

Soil Texture

Soil texture refers to the proportion of various particle sizes (sand, silt and clay) in a given soil. A USDA textural triangle, soil textural classes and a process called ribboning (see page 96) are used to describe soil texture.



Soil Textural Classes

Texture Class	*The*	*% in Soil*	*Type*
	Sand	*Silt*	*Clay*
Sand	>85	<15	<10
Loamy sand	70-90	<30	<15
Sandy loam	43-85	<50	<20
Loam	23-52	28-50	7-27
Silt loam	20-50	50-80	12-27
Silt	<20	>80	<12
Sandy clay loam	45-80	<28	20-35
Clay loam	20-45	15-53	27-40
Silty clay loam	<20	40-73	27-40
Sandy clay	45-65	<20	35-55
Clay	<55	<40	>40
Silty clay	<20	40-60	40-60

Sand particles in soil range from 2mm to .05mm and silt particles range from .05mm to .002mm.

Silt and sand, composed dominantly of quartz, form the relatively inactive soil "skeleton." Clay particles are less than 0.002mm, or 2 microns. Their small size and sheet like structure give them a great amount of surface area per unit mass and their surface charge attracts ions and water. Because of these properties, clay particles are known the "active" portion of the soil matrix.

In describing soil texture, the percent volume of coarse fragments in the soil is also estimated. In addition to influencing the physical properties of a soil, coarse fragments can provide information on parent material or origin.

Soil Density

Soil is composed of mineral (sand, silt, clay, etc) and organic (plant tissue, etc) material. The average *particle density* of soil mineral material is 2.65 grams/cubic centimeter, which approximates the density of quartz. The average *particle density* of soil organic material is 1.25 grams/cubic centimeter

The *bulk density* of a soil is the density for an undisturbed volume of soil, including pore space and organic material. The bulk density of a soil with 50% pore space and 50% solid matter is:

- With 50% mineral material—
  1.325 grams/cubic centimeter.
- With 45% mineral and 5% organic material—
  1.26 grams/cubic centimeter.

Bulk density in soils is inversely related to the amount of pore space. The following equation gives pore space:

Pore space = 1 – (bulk density/particle density)

At a bulk density of 1.06 grams/cm^3, the pore space would be .60 or 60% (this is assuming that all the solid space is mineral material, which has a particle density of 2.65 grams/cm^3).

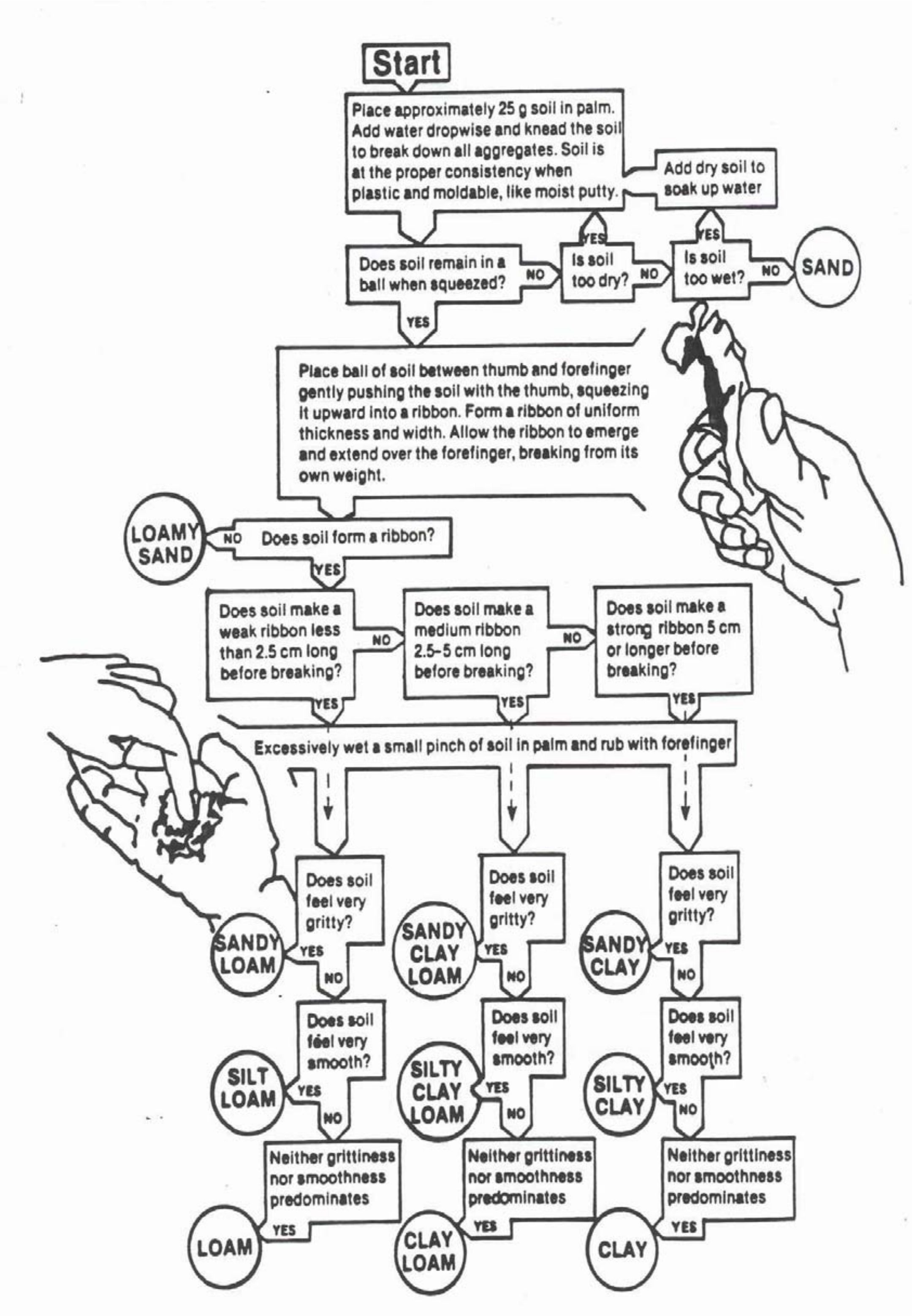
Pore Space and Water Movement

Pore space varies with soil texture:

- Sandy soils have smaller amounts of total pore space, but larger sized pores.
- Clayey soils have more total pore space, but smaller sized pores. As a result, clayey soils will generally have lower bulk densities than sandy soils.

Water movement through a soil's pore space takes place in response to a force, or potential. The *rate of flow* (how fast the water is moving) is affected by the geometric properties of the soil pores, or the

Ribboning is a technique used by soil scientists to determine soil texture. It helps soil scientists determine soil texture class by eliminating soil classes which do not match the characteristics of the soil sample being ribboned. The following diagram demonstrates the process.



hydraulic conductivity of the soil, as well as the amount of moisture in the soil. Several types of forces can act on water in soils: *positive forces* such as gravity and pressure and *negative forces* such as suction and osmosis.

Two types of water movement in soils:

1**. Saturated Flow** – all the soi's pores are filled with water and the driving force is a positive pressure. Since rate of flows are greatest through large connective pores, saturated flow is higher in sandy soils.

2**. Unsaturated Flow** – the soil has pores not filled with water and the driving force is suction. Under unsaturated conditions, the larger pores are filled with air, while the smaller pores retain and conduct water even at low levels of soil water. More flow is likely in clayey soils.

Soil Consistence

Soil Consistence is the feel of the soil and the ease with which a lump can be crushed by the fingers. Soil consistence depends on soil moisture content. Terms commonly used to describe consistence are:

Moist Soil

- *Loose* —noncoherent**,** when dry or moist; does not hold together in a mass.
- *Friable* —when moist, crushed easily under gentle pressure between thumb and forefinger and can be pressed together into a lump.
- Firm— when moist**,** crushed under moderate pressure between thumb and forefinger, but resistance is distinctly noticeable.

Wet Soil

- *Plastic* —when wet, readily deformed by moderate pressure but can be pressed into a lump; will form a "wire" when rolled between thumb and forefinger.
- *Sticky*—when wet, adheres to other material and tends to stretch somewhat and pull apart rather than to pull free from other material.

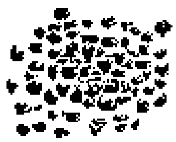
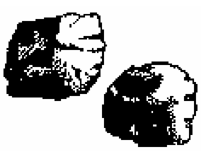
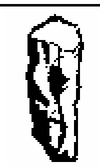
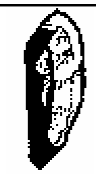
Dry Soil

- *Hard* – when dry, moderately resistant to pressure; can be broken with difficulty between thumb and forefinger.
- *Soft* – when dry, breaks into powder or individual grains under very slight pressure.
- *Cemented*—hard; little affected by moistening.

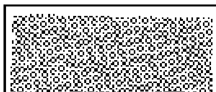
Soil Structure

Soil Structure is the combination or arrangement of primary soil particles into secondary units or aggregates. Organic materials and clay are important binding agents.

Types of Soil Structure

	**Granular** – roughly spherical, like grape nuts. Usually 1-10 mm in diameter. Most common in A horizons, where plant roots, microorganisms, and sticky products of organic matter decomposition bind soil grains into granular aggregates.
	**Platy** – flat peds that lie horizontally in the soil. Platy structure can be found in A, B and C horizons. It commonly occurs in an A horizon as the result of compaction.
	**Blocky** – roughly cube-shaped, with more or less flat surfaces. If edges and corners remain sharp, we call it *angular blocky*. If they are rounded, we call it *subangular blocky*. Sizes commonly range from 5-50 mm across. Blocky structures are typical of B horizons, especially those with a high clay content. They form by repeated expansion and contraction of clay minerals.
	**Prismatic** – larger, vertically elongated blocks, often with five sides. Sizes are commonly 10-100mm across. Prismatic structures commonly occur in fragipans.
	**Columnar** – the units are similar to prisms and are bounded by flat or slightly rounded vertical faces. The tops of columns, in contrast to those of prisms, are very distinct and normally rounded.

Structureless Soil Types

	**Massive** – compact, coherent soil not separated into peds of any kind. Massive structures in clayey soils usually have very small pores, slow permeability, and poor aeration.
	**Single grain** – in some very sandy soils, every grain acts independently, and there is no binding agent to hold the grains together into peds. Permeability is rapid, but fertility and water holding capacity are low.

Ion Exchange in Soil

Some *plant nutrients* and *metals* exist as positively charged ions, or ***cations***, in the soil environment. Among the more common cations found in soils are hydrogen (H^+), aluminum (Al^{+3}), calcium (Ca^{+2}), magnesium (Mg^{+2}) and potassium (K^+). Most heavy metals also exist as cations in the soil environment. *Clay* and *organic matter* particles are predominantly negatively charged, ***anions***, and have the ability to attract cations and keep them from being washed away or *leached*. The adsorbed (*adsorption is the attachment of one substance to the surface of another*) cations are subject to replacement by other cations in a rapid, reversible process known as ***cation exchange***. Cations leaving the exchange sites enter the soil, where they can be taken up by plants, react with other soil constituents or be carried away with drainage water.

The ***cation exchange capacity*** (CEC) of a soil is a measurement of the magnitude of the negative charge per unit weight of soil. Simply it is the amount of cations a particular sample of soil can hold in an exchangeable form. The greater a soil's clay and organic matter content, the greater the CEC should be. However, different types of clay minerals and organic matter can affect CEC.

Cation exchange is an important mechanism in soils for retaining and supplying plants with nutrients and for adsorbing contaminants. It plays an important role in wastewater treatment in soils. Sandy soils with a low CEC have little adsorptive ability. They are generally unsuited for septic systems because the potential for groundwater contamination is high. *Septic systems* are domestic wastewater treatment systems (consisting of a septic tank and a soil absorption system) into which wastes are piped directly from the home. Bacteria decompose the waste, sludge settles to the bottom of the tank and the treated effluent flows out into the ground through drainage pipes. These systems are found in suburban and rural areas which have no connections to municipal sewers.

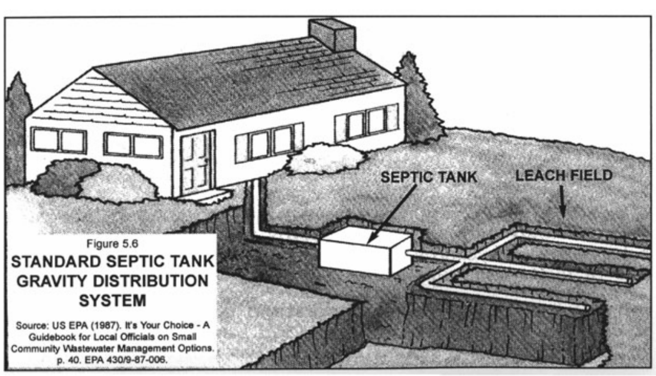


Figure 5.6
STANDARD SEPTIC TANK GRAVITY DISTRIBUTION SYSTEM
Source: US EPA (1987). It's Your Choice - A Guidebook for Local Officials on Small Community Wastewater Management Options. p. 40. EPA 430/9-87-006.

pH

By definition, *pH* is a measure of the active hydrogen ion (H^+) concentration. It is an indication of the acidity or alkalinity of a soil, also known as soil reaction. The *pH scale* ranges from 0 to 14. Values below 7.0 are acidic and values above 7.0 are alkaline (basic). A pH value of 7 is considered neutral; where H^+ and OH^- are equal, both at a concentration of 10^{-7} moles/liter. Values for pH are measured on a log scale meaning that a pH of 4.0 is ten times more acidic than a pH of 5.0.

The most important effect of soil pH is on ion solubility, which in turn affects microbial and plant growth. A pH range of 6.0 to 6.8 is ideal for most crops because it coincides with the optimum solubility for most important plant nutrients. Most of the micronutrients for plant growth and most heavy metals are more soluble at lower a pH. This makes pH management important in controlling movement of heavy metals (and potential groundwater contamination) in soil. In soils with pHs maintained at neutral (7) or near neutral, the movement of heavy metals such as lead, cadmium and mercury through the soil into the ground water is inhibited. These neutral soils also limit the uptake of heavy metals by plants.

In acidic soils, hydrogen and aluminum are the dominant exchangeable cations. The latter is soluble under acidic conditions, and its reactivity with water (hydrolysis) produces hydrogen ions. Calcium, magnesium and potassium are basic cations; as their amounts increase, the relative amount of acidic cations will decrease.

Factors that affect soil pH include parent material, vegetation and climate. Some rocks and sediments produce soils that are more acidic than others:

quartz-rich sandstone is acidic; limestone is alkaline. Some types of vegetation, particularly conifers, produce organic acids, which can contribute to lower soil pH values. In humid areas such as the eastern US, soils tend to become more acidic over time because rainfall washes away basic cations and replaces them with hydrogen. The addition of certain fertilizers to the soil can also produce hydrogen ions. Liming the soil adds calcium, which replaces exchangeable as well as solution H^+ and raises the soil pH.

Lime requirement, or the amount of liming material needed to raise the soil pH to a certain level, increases with CEC. To decrease the soil pH, sulfur can be added, which produces sulfuric acid.

Hydric Soils

Hydric soils are defined as soils which formed because they remained under conditions of saturation, flooding or ponding long enough during the growing season to develop *anaerobic (the absence of oxygen)* conditions in the upper part of the soil. Prolonged saturation during the growing season results in a depletion of oxygen by the plants and microorganisms in the soil. This lack of oxygen in the soil restricts aerobic (*'with oxygen"*) root respiration and aerobic microbial reactions and promotes several biogeochemical processes: 1) a transformation of several elements from oxidized to reduced chemical forms; and 2) an accumulation of organic matter. Evidence of these processes is useful in identifying hydric soils.

The microbial breakdown of soil organic matter is an oxidation-reduction process. Under aerobic conditions, organic matter is *oxidized (looses electrons*), and oxygen (O_2) is *reduced (gains electrons)* and combines with hydrogen to form water. The ultimate product of aerobic degradation is CO_2. When the soil is flooded, the amount of oxygen is decreased. As organic matter continues to breakdown the oxygen can be all used up and the soil becomes anaerobic. Biodegradation of organic matter now continues under different conditions (anaerobic conditions); different groups of microbes go to work using different electron acceptors instead of oxygen. These decomposition processes are not as efficient or as complete as the aerobic ones. A sequence of oxidation-reduction (electron transfer) reactions takes place. Nitrates, manganese oxides, iron oxides and sulfates are soil compounds that are used as electron acceptors in anaerobic microbial reactions, in a specific order. After the removal of oxygen, nitrate is the first soil component to be reduced, then manganese, then iron and eventually sulfate. These transformations bring about the translocation and/or accumulation of these elements (nitrogen, manganese and iron), which can result in morphological features useful in the identification of saturated zones in soil.

Nitrogen transformations in hydric soils can make the nutrient less available for plant uptake. However, excessive amounts of nitrate, the mobile form of nitrogen, can be reduced which can prevent its loss by leaching.

Oxidized or ferric (Fe^{+3}) iron compounds are responsible for the brown, yellow and red colors in soil. When iron is reduced to the ferrous (Fe^{+2}) form, it becomes mobile, and can be removed from certain areas of the soil. When the iron is removed, a gray color remains or the reduced iron color persists in shades of green or blue. Upon aeration, reduced iron can be re-oxidized and re-deposited, sometimes in the same horizon which results in a variegated or mottled color pattern. These soil color patterns, resulting from saturation, are known as *redoximorphic features* and can indicate the duration of the anaerobic state. They can range from brown with a few mottles, to complete gray or *gleization* of the soil. Soils that are dominantly gray with brown or yellow mottles immediately below the surface horizon are usually hydric.

Manganese transformations are similar to iron in that manganic (Mn^{+4}) compounds are reduced to more soluble manganous (Mn^{+2}) forms. Re-oxidized and re-deposited manganic oxides appear as black films or coats on soil particles.

Sulfates in soils are reduced to sulfides when soils are nearly permanently saturated. The presence of hydrogen sulfide can be detected by the "rotten egg" odor, which is used as a hydric soil indicator. Sulfides can be toxic to microbes and plants, and upon re-oxidation, can lead to extremely acidic conditions in soils when sulfuric acid is formed. Sulfides are more common in coastal wetlands than freshwater because of higher amounts of sulfate in seawater.

Certain bacteria can use CO_2 as an electron acceptor, resulting in the formation of methane (CH_4), or "swamp gas." Methane production is generally higher in freshwater environments.

Even though the decomposition of organic residues proceeds in a very inefficient and slow manner when the soil surface is saturated, eventually the amount of organic matter can accumulate significantly. Nearly all soils have some organic matter, but when the content exceeds 20 to 35% (on a dry weight basis), it is considered organic soil material. Organic soil materials have a lower bulk density and a higher water and nutrient holding capacity than mineral soils. The term *peat (or fibric organic material)* has been used to refer to organic material in which the plant parts are still recognizable, and *muck* (*sapric organic material*) is organic material that is more decomposed, with no recognizable plant parts. *Mucky peat (or hemic organic material*) is an intermediate between the two. As decomposition increases, organic material decreases both in water holding capacity and bulk density and becomes darker in color. If 16 inches or more of the upper 32 inches of a soil is organic material, the soil is considered an *organic soil or histosol*. Wet mineral soils that do not have a sufficient thickness of organic materials to be classified as histosols, can have an organic surface horizon 8 inches or more thick called a *histic epipedon.*

Soil wetness can result from either a perched or a regional water table. A *perched water table* is caused by a hydraulically restrictive horizon (such as impermeable hard rock), usually underlain by a more permeable horizon. A *regional water table* extends vertically without interruption and is usually located in a low-lying area of the landscape.

NRCS hydric soils website

http://soils.usda.gov/

Follow the Soil use link to Hydric soils. This includes most current info, including hydric soil lists and Field Indicators of Hydric Soils in the US, A Guide for Identifying and Delineating Hydric Soils.

Soil Drainage

Soil Drainage is a reflection of the rate at which water is removed from the soil by both runoff and percolation (downward water movement). Soil drainage classes were designed for agricultural purposes. Landscape position, slope, infiltration rate, surface runoff, permeability and depth to mottles (redoximorphic features) should all be considered in evaluating the soil drainage class. The upper depth to redoximorphic features for different drainage classes will be used for description purposes.

Soil Drainage Classes:

- ***Excessively and Somewhat Excessively Drained:*** Water is removed very rapidly. The occurrence of water throughout the profile is very rare or very deep. No evidence of wetness occurs within 100cm of the soil surface and textures are coarser than loamy fine sand. Most of these soils are sandy or sandy skeletal.
- ***Well Drained:*** Water is removed from the soil readily but not rapidly. The occurrence of free water is commonly deep or very deep. Wetness does not inhibit any root growth during growing seasons. Redoximorphic features occur at a deep depth, if present. Redox features with a chroma of less than or equal to 2 occur at a depth deeper than 75cm.
- ***Moderately Well Drained:*** Water is removed from the soil somewhat slowly during some periods of the year. The occurrence of free water is commonly moderately deep. These soils are wet for short periods of the growing season and some species of vegetation may therefore be affected. Redox features with chromas of 2 or less usually occur within the B horizon and/or C layers at a depth between 50cm and 75cm.
- ***Somewhat Poorly Drained:*** Water is removed from the soil slowly and occurs at a shallow depth. The occurrence of free water is commonly shallow to moderately deep. These soils are wet for significant periods of the growing season and vegetation growth is affected. Redox features with values greater then or equal to 4 and chromas less than or equal to 2, occur within 50cm of the soil surface. B horizons have a dominant color with chromas of 3 or more.
- ***Poorly Drained:*** Water is removed slowly from the soil so that it is wet at shallow depths for long periods of time. The occurrence of free water is shallow or very shallow. These soils are wet for significant periods of the growing season and vegetation growth is therefore affected. Poorly drained soils usually have dark surface horizons. Dominant colors immediately below the A horizon have chromas of less than or equal to 2.
- ***Very Poorly Drained:*** Water removal is so slow that the soil is wet at or near the ground surface during a large part of the growing season. The occurrence of free water is very shallow. These soils commonly occur within depression and frequently flooded areas. Very poorly drained soils usually have thick black surfaces and have a strong grey color directly below the A horizon. Dominant colors immediately below the A horizon include chromas of 2 or less and values of 4 or more.

Soil Survey Site Evaluation

Check soil map and/or geologic map beforehand.

Examine site relationship to surroundings with topographic map.

When at the soil survey site describe:

- land use
- vegetation, types and amounts
- Slope: expressed as % change in elevation over lateral distance
- Aspect: direction of the (down) slope facing direction

Soil Surveys

Soil surveys contain three basic parts: soil maps, soil descriptions and soil interpretations or ratings.

- The soil map is usually made by placing soil boundaries on an aerial photograph. Accompanying the map is a legend, which lists the map unit symbol and the name of the map unit:
  RdA*: Riverhead sandy loam, 0 to 3 percent slopes.*
- A description of the map unit is given. A map unit can be composed of more than one soil:

  Ex: *Included in this map unit are small areas of Plymouth soils and Montauk soils.*

  The percent composition of each soil is usually given, along with a description of the soil and its properties.
- The suitability of the mapped soils are rated for various uses.

  Ex: *Riverhead sandy loam, 0 to 3 percent slopes, has severe restrictions for septic absorption fields because the sandy substratum acts as a poor filter.*

Some soil surveys (text only) are available online at: http://soils.usda.gov/ , Follow the Soil Survey link.

New York state is usually divided into twelve physiographic areas, each with its own landscape and rock type. Some of these areas are valleys or lowlands and some are highlands or mountainous areas. In general, the lowlands have the most favorable soils and topography for agriculture. Bedrock types across the state include granitic rocks, limestones, shales, and sandstones.

New York City lies in three different physiographic areas. Southwestern Staten Island is part of the Triassic Lowland, which is characterized by relatively soft red sandstones, siltstones and shales, and harder igneous rocks; Manhattan, the Bronx and northwestern Staten Island belong to the New England Upland, which is comprised of northeast trending ridges of resistant gneiss and schist; and Brooklyn, Queens and southeastern Staten Island are part of the Long Island Coastal Plain lowland area, in which the bedrock is buried beneath thick deposits of sand and gravel.

New York has a great diversity of soils, largely a result of the variety in the parent material. In general, soils can be formed directly from the underlying bedrock (residual soils), weathered in place or from some type of deposit above the bedrock.

Almost all of New York state was covered with glacial deposits, left behind after the last ice age. It is estimated that the last ice sheet, called the Wisconsinan, reached its southernmost point on Staten Island and Long Island about 20,000 years ago and then began to recede northward. At this southernmost point the *terminal moraine*. A terminal moraine is a prominent ridge of rock debris dumped at the end of a glacier and formed of unsorted boulders, sand, gravel and clay. Ice-deposited parent materials (from the glacier) in New York include *glacial till*, an unsorted and unstratified mixture of materials left directly by the ice, and *glacial outwash*, the sorted and stratified material left behind by glacial meltwater. Outwash includes coarser grained sands and gravels in *outwash plains* and *deltas* and finer-grained silts and clays of *glaciolacustrine* (glacial lake) deposits.

Glacial till "deposits" include a variety of conditions:

- *Shallow till*: In some areas, particularly where the bedrock is more resistant, the ice did more scraping and abrading than depositing. Bedrock outcrops are common, along with shallow (<20" to bedrock) and moderately deep (20-40" to bedrock) soils.
- *Lodgement or basal till* refers to the material carried beneath the ice sheet, and left behind as the glacier receded. These soils are often characterized by a dense subsoil layer ("fragipan"), or a "dense basal till" substratum. These features are usually both root and water restrictive, firm in consistence and may have mottles or redoximorphic features present.
- *Ablation till* is material which was carried either within, or on the upper surface of the ice sheet, and dropped down as the ice melted and receded. Soils formed in ablation till generally have a friable subsoil and substratum.

Glacial till soils are characterized by a wide range in particle size (boulder to clay) and may have an abundance of coarse fragments.

Glacial outwash deposits can also be variable. Particle size distribution is related to energy of deposition. Glaciofluvial, or meltwater stream deposits are horizontal to gently dipping layers of sand and gravel; delta and lacustrine fan deposits are steeply to gently dipping layers of silt, sand, and gravel; and low energy lake bottom sediments are usually fine sand, silt and clay. Sorting, or separation of particle sizes, and stratification, or layering, are typical of glacial outwash deposits. In general, outwash deposits make better aquifers than till deposits as they are deeper and usually more porous.

Terminal moraine deposits may consist of till, or various proportions of till and stratified materials.

Geographically, till generally covers uplands and outwash is usually found in lowlands and valleys where meltwater ran. Most glacial material is locally derived, hence soil color and particle size distribution reflects the bedrock below. *Erratics* are rocks which are transported and deposited a great distance from their original location.

Other types of parent materials in New York state include *marine deposits,* which were left behind by an arm of the sea in the St. Lawrence and Champlain Valleys, and more recent stream deposits called ***alluvium***. In wetter areas and in some former glacial lake basins, soils have formed in organic materials**.**

Parent materials in New York City include:

- Deep glacial till: especially on Staten Island
- "shallow" glacial till over bedrock: especially in Manhattan and the Bronx, where the ice has scraped rather than deposited
- glacial outwash
- tidal marsh deposits
- "anthropogenic", or human-deposited materials: found almost anywhere in the urban environment

Soil boundaries often correspond to geologic boundaries.

For more information, visit the New York geological resources website:
http://www.albany.net/~go/newyorker/

Urban Soils

Webster's defines urban as: *of, relating to, characteristic of or constituting a city.*

Because of the high population density and resulting intense land use, soils in highly populated areas are usually disturbed. The soil horizons are no longer in place (intact) and the transport and accumulation of materials (local and foreign) has important impact. Generally urban soil disturbances include:

- mixing of soil horizons or removal of topsoil
- cutting and filling or grading of areas to level landscapes (to build homes, buildings, ballfields)
- filling of areas that are wet or low in elevation, or possess undesirable soil characteristics
- adding plant growth media

Fill is any material used to 'fill in' an area. It can be natural soil material (derived locally or not), waste materials (such as coal ash or dredged spoils) or a mixture of both. Soils in urban areas can contain cultural artifacts (like garbage or historic items), construction debris and various waste products. The addition of concrete and road salts to urban soils in the northeast tends to increase the their pH. The undisturbed soils in the area tend to be naturally acidic.

In mapping soils, a soil scientist will associate a particular soil with a particular landscape. Because of the high chance of disturbance, urban soils are less predictable and more difficult to map.

Other potential problems with urban soils include:

- Little/no organic matter addition
- Modified soil temperatures
- High potential for compaction from traffic or heavy use
- High possibility of contamination

Why should we know our urban soils?

Benefits of healthy soils in urban areas include:

- Vegetation for shade, recreation and aesthetics; community gardens
- Infiltration (water storage, groundwater recharge) versus runoff from compacted soils or impervious surfaces.
- Better water quality through interception & treatment of potential NPS pollutants
- Quality playing fields and stable structures

Soils in urban areas are more variable and more prone to degradation than soils in other areas. Because there are large areas of impervious surfaces and/or non-soil in urban areas, we need urban soils to function at their best.

Soil quality is defined as the capacity of a soil to function; to sustain plant and animal productivity; to maintain or enhance water and air quality; and to support human health and habitation. Soils perform the same important functions in urban areas, but since there is less soil, we must ensure that what is present is able to perform properly. Certain soil properties can change with use and management, resulting in a change in a soil's capacity to function. Soil bulk density, soil structure, organic matter content, pH, nutrient and chemical content are all "use-dependent" properties that affect the quality of a soil for one or more functions. Soil quality is affected by management. For more information on soil quality visit the NRCS Soil Quality Institute website:http://soils.usda.gov/sqi.

Soil degradation can be seen as a loss of soil quality. Because disturbance is common, urban soils are especially vulnerable to degradation.

Degradation of Soil and Soil Quality

It can take up to 1000 years to form an inch of soil, therefore soil is NOT a renewable resource in the time scale in which humans utilize soils. Soil can be degraded rather quickly by:

- Erosion
- Contamination
- Compaction

Erosion from construction sites, bare slopes, etc., is a problem in urban areas. Not only is valuable topsoil lost, but a potential water pollution problem with sediment, nutrients, pesticides, etc. is created.

Factors influencing *erosion* include:

- Rainfall intensity
- Soil erodibility
- Land cover
- Slope

Factors affecting soil *erodibility* include:

- Infiltration rate
- Type and stability of soil structure (aggregates are more difficult to erode)
- Organic matter content (helps promote aggregation)
- Particle size distribution (silt & very fine sand are most easily eroded)

Compaction is an increase in bulk density as a result of applied weight or pressure. This increase in bulk density generally increases with soil water content; wetter soils compact more. Upon compaction, pore space decreases, especially the large interconnected pores. Compaction has a negative effect on aeration, water permeability and root penetration.

Heavy traffic on urban soils tends to increase density and crush soil aggregates into smaller sizes until destroyed. In addition, the natural structure building processes (organic matter addition, wetting/drying cycles) tend to be weaker in compacted urban soils. Bare soils tend to form a crust. Soils high in silt and very fine sand, and low in organic matter are especially susceptible to compaction.

Compaction Remediation:

- Physically break up compacted zones
- Add organic matter if needed
- Keep traffic low
- Encourage plant growth

Contamination is an increase in the concentration of a natural or synthetic substance to a level that is detrimental to plants, microbes, animals or people. If often cannot be seen, smelled or otherwise identified. Common soil contaminants include heavy metals, pesticides, organic compounds (hydrocarbons, PCBs, PAHs) and salts. It is advantageous to know the land use history of a site. Soils can be managed (pH, organic matter content, etc.) to minimize the mobility or potential toxicity of contaminants.

Certain soil properties are not changed by use and management and enable a soil to carry out certain functions better than others. A tidal marsh soil consisting of organic soil materials may not be suited for a building site, but it does provides quality habitat for fiddler crabs and other species of the salt marsh.

Soil Organisms

Although at first glance soil may appear to be only dirt, soil contains a wealth of organisms, ranging from microscopic bacteria to large bugs and small burrowing mammals. The following is a description of the different general categories of soil organisms. Read onto the section entitled "The Soil Food Web" to further understand how these organisms interact.

Bacteria

Bacteria are single-celled organisms, which are densely populated in soil. A teaspoon of productive soil can contain anywhere from 100 million to 1 billion bacteria. Bacteria are generally the first organisms found in a developing ecosystem and there must be a healthy bacterial population before plants can even successfully root. Most soil bacteria are found near the *rhizosphere* , the soil zone immediately surrounding plant roots.

There are many varieties of bacteria, but the most important group is called the *decomposers*. These bacteria break down organic matter and their waste (nutrients such as nitrogen, phosphorus and sulfur) is used by other soil organisms and plants for growth. The *mutualists* are another group of bacteria. Mutualists attach themselves to the roots of plants, consuming carbon from the plant while "fixing" nitrogen from the air into a form which the plant can use.

Fungi

Like bacteria, fungi are also single-celled organisms, but tend to form into larger thread-like structures called *hyphae.* Fungi are decomposers, and they convert organic matter into usable nutrient compounds. Fungi hyphae help soil particles aggregate (stay together), making a more stable environment for larger organisms and increasing the water holding capacity of the soil. Fungi can also be categorized into the mutualists category and perform similar functions to bacteria. Most fungi, like bacteria, live near the rhizosphere.

Protozoa

Protozoa are single- celled creatures which live near bacteria and fungi populations in the soil and feed on these organisms. Protozoa to mineralize nutrients, which allows other organisms to use them. They require less nitrogen for survival than bacteria, so when protozoa consume bacteria, excess nitrogen is released into the soil.

Nematodes

Nematodes are critical for healthy soil, and as the most abundant cellular soil organism they provide a variety of functions. Nematodes, which are worm-like creatures, are usually grouped into four types: bacteria eating, fungi eating, plant eating and those that eat other nematodes and bugs. Some types of nematodes are very small (1 mm in length) and feed on algae and plant roots, while others are big enough to consume large bugs. Smaller nematodes serve as a food source for larger nematodes. Nematodes require less nitrogen than the smaller organisms they consume, releasing usable forms of the nutrient as they feed. They are also important in dispersing bacteria, fungi and protozoa throughout soil. Bacteria and fungi often *parasitize* nematodes by attaching themselves to the organisms and feeding on their nutrients. Nematodes can also act as parasites of plants, and often cause crop damage and disease in this way. They are a very useful indicator of soil quality because of their diversity and range of functions.

Arthropods

Soil contains a wealth and diversity of invertebrates, referred to as arthropods, which range in size from microscopic to several inches. Soil arthropods are categorized into fungal-feeders, shredders, predators and herbivores. Fungal feeders, such as springtails and mites, scrape fungi and bacteria off root surfaces increasing the mineralization of usable nutrients for plants and the decomposition of organic material. Shredders, such as millipedes, termites and cockroaches, eat other bugs and in the process break down plant material, making it easier for other organisms to further break down the nutrients. Predators, such as centipedes, spiders, and ants control the populations of other organisms, indirectly facilitating the breakdown of organic material. Herbivores, such as cicadas, eat plant roots. As soil passes through these arthropods, it is released in a more usable form that helps with soil cohesion, water-holding capacity thus diminishing erosion. Most arthropods live between the O and the A horizon, or the top three inches of soil.

Earthworms

Earthworms are the most prevalent type of soil *invertebrate* and eat bacteria, fungi, protozoa and small nematodes. They are crucial in dispersing their prey throughout the soil, which works to increase nutrient cycling throughout the soil. Earthworms burrow in the soil, creating channels which disperse organic matter through the soil, enhances the soil's water-holding capacity and provides space for plant roots to grow. Earthworms are necessary decomposers and generally begin the break-down process of organic material.

The Soil Food Web

A healthy and productive soil food web is an excellent indicator of overall soil health. The *soil food web* refers to the complex structure of interactions among plants as they decay and the organisms which breakdown this organic matter. Similar to the surface food web, the initial energy for the soil food web comes from the sun. Nutrients become available for use through the actions of the many decomposers that exist within soil. A healthy ecosystem supports diversity and abundance, which translates into higher nutrient retention. This nutrient retention occurs through a series of predator-prey relationships beginning with the smallest soil organisms. Bacteria and fungi decompose organic matter, releasing usable nutrients essential for plant growth. Bacteria and fungi are preyed upon by protozoa, nematodes and small arthropods, which in turn are preyed upon by larger bugs, millipedes, beetles, spiders and eventually small mammals.

Plant life comprises the first *trophic* level. They photosynthesize energy from the sun. Eventually, with death, these plants become organic "waste" and are decomposed by soil organisms. Nutrients are present as organic matter and are not functional unless soil decomposers break them down into usable forms.

Bacteria and fungi second trophic level of the soil food web. They attach to the roots of plants and mineralize nitrogen, phosphorus and sulfur. When bacteria and fungi populations in a soil ecosystem diminish, fewer nutrients are retained and more are carried away by surface and ground water.

The third trophic level consists of protozoa, small to medium size nematodes and microarthropods. These organisms eat bacteria, fungi, and small nematodes. Protozoa, exist in high proportion compared to nematodes and microarthropods; in about one teaspoon's worth of soil, there can be anywhere between 100 to 100,000 protozoa. These organisms require 5 to 10 times less nitrogen than their prey, creating a net release of nitrogen when they consume bacteria and fungi. Between 40 and 80 % of nitrogen in plants arise from this net release. Nematodes and microarthropods also require less nitrogen than bacteria, fungi and smaller nematodes, so their feeding releases nitrogen. Earthworms are larger arthropods but are considered part of the third trophic level.

Large arthropods and large nematodes comprise the fourth tropic level. They consume the organisms of the third trophic level. Nematodes deserve a special mention because they are such a diverse species; they can range in length from a few millimeters to more than two meters (this giant variety isn't found in soil), can be either beneficial or parasitic and exist at three "levels" of the soil trophic system. There also exists a wide array of arthropod species in soil including termites, centipedes, ants, cockroaches, spiders, scorpions and earthworms.

Sources and Additional Resources

There is a wealth of **Resources** available **online**:

The NRCS Soils page http://soils.usda.gov/ has links to Soil Surveys, and various educational materials.
Follow the Education link to Resources to K-12 to find "From the Surface Down**"
A good, full color introduction to soils and soil survey in pdf format.
Also available here is the "Soil Biology Primer,"
**A soil science glossary is also available from the above Resources link & Information on Soil Formation and Classification can be obtained through the Education to Soil Facts links.

**A good soils study guide designed for the NYC Envirothon http://www.houzi.org

The New York State Envirothon site has a good soils study guide with references and study questions: http://nysenvirothon.org/

Online References:

Edwards, Clide, Elaine Ingham and Andrew Moldenke. USDA online text book for Soil Biology http://soils.usda.gov/sqi/soil_quality/soil_biology/fw&soilhealth.html

Ingham, Dr. Elaine. "The Soil Foodweb: It's Importance in Ecosystem Health". www.rain.org/~sals/ingham.html

University of Saskatchewan College of Agriculture Website http://interactive.usask.ca/ski/agriculture/soils/soilliv/soilliv_web.htmln

Publication References:

Brady, N.C. 1990. The Nature and Properties of Soils. Macmillan Publishing Company, NY, NY.

Broderson, William D. "From the Soil Down: An Introduction to Soil Surveys for Agronomic Use", revised ed. Soil Conservation Service, for the United Department of Agriculture: 1994.

Buckman, N.G. 1990. The nature and properties of soils. Macmillan Publishing Company, NYC.

Cline, M.G. 1961. Soils and soil associations of New York. Cornell Extension Bulletin 930.

Flint, R.F. 1971. Glacial and Quaternary Geology. John Wiley and Sons.

Hillel, D. 1980. Fundamentals of soil physics. Academic Press Inc., Orlando, FL.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold, NYC.

Any soils related questions can be directed to the NYC Soil Survey team: richard.shaw@ny.usda.gov